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Utilization of unripe banana peel waste as feedstock for ethanol production

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Abstract: Banana is second largest produced fruit of total world's fruits. Cooking banana or plantains processing industry is generating enormous amount of waste in the form of unripe banana peel at one place, thus important to study waste management and utilization. Therefore, unripe banana peel was investigated for ethanol production. This study involved chemical characterization, optimization of acid hydrolysis, selection of yeast strain and optimization of fermentative production of ethanol from dried unripe banana peel powder (DUBPP). Ethanol concentration was determined using gas chromatography flame ionization detector (GC-FID). Characterization of DUBPP revealed notably amount of starch (41% w/w), cellulose (9.3% w/w) and protein (8.4% w/w). 49.2% w/w of reducing sugar was produced by acid hydrolysis of DUBPP at optimized conditions. Three yeast strains of *Saccharomyces cerevisiae* were screened for ethanol conversion efficiency, osmotolerance, ethanol tolerance, thermotolerance, fermentation ability at high temperature and sedimentation rate. Further, fermentation conditions were optimized for maximum ethanol production from acid hydrolysate of DUBPP. At optimized fermentation conditions, 35.5 g/l ethanol was produced using selected strain of *Saccharomyces cerevisiae* NCIM 3095. Hence, unripe banana peel waste can be good feedstock for ethanol production.

Keywords: Banana, Ethanol production, Banana peel, Waste management, Acid hydrolysis, Fermentation

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1 Introduction

Banana is important food crop for tropical and subtropical region and play important role in food security and economy. According to FAO 2014, global banana production was arround 118 million ton per year in the year 2012 and 2013. India was leading producer followed by China, Philippines and Brazil sequentially [1]. Of total banana produced mostly *Musa acuminata* genomes are sweet bananas or dessert bananas (68%) while hybrids of *M. acuminata* and *M. balbisiana* are mostly cooking bananas or plantains (32%). Unripe plantains contents high resistant starch and dietary fibres which have health benefits thus attracts food industry [2]. Most plantains varieties require cooking (boiling, roasting or frying) before they can be eaten [3]. Plantains processing industries are generating huge waste in the form of unripe banana peel waste at one place. Unripe plantain peels weighs up to 40% fresh weight of product [4]. Thus, It is indespensible to study the waste managment and utlization of unripe banana peel.

In today's world, the dependency on fossil fuels for various energy purposes is increasing day by day. Many countries have mandate on ethanol blend with gasoline to be used as fuel. As well as ethanol is very good organic solvent [5-7]. Hence, ethanol needs are rising to reduce fuel imports, boosting rural economies and improving air quality. Main feedstocks for ethanol production are sugarcane and corn grains, while many other agricultural raw materials are used worldwide [7]. Most of feedstock's used currently for ethanol productions are also used as food for human. Many attempts are being made to find new sources of feedstock, which are non-edible and easily available [7]. Currently sugar and starch containing feedstocks are most widely used. Lignocellulosic material can also be used however; it is difficult to convert them into sugar, which requires advance technology that may increase operating cost [6, 8 and 9]. Consistent effort has been made to design and improve a process, which would produce a sustainable transportation fuel using low cost feedstocks. Many agricultural raw materials

rich in fermentable carbohydrates tested worldwide for bioconversion from sugar to ethanol, but the cost of carbohydrate raw materials has become a limiting factor for large-scale production by the industries employing fermentation processes [9]. The price of feedstock contribute more than 55% to the production cost, inexpensive feedstock such a lignocellulosic biomass and agricultural food waste are being considered as alternative to expansive feedstock [10]. The production of ethanol from comparatively cheaper source of raw materials using efficient fermentative microorganisms is the only possible way to meet the demand of ethanol [11]. Agricultural and food processing industry creates huge amount of waste every year [12]. The failure or inability to salvage and reuse such materials economically results in the unnecessary waste and depletion of natural resources [12]. The solid wastes generated by fruit processing industries can serve as potential raw materials for the production of primary and secondary metabolites of industrial significance by use of microorganisms [13]. Theses fruit processing wastes can be used as potential feedstock for ethanol production and this could be an attractive alternative for disposal of the polluting residues [14, 15]. There are reports available on waste management from fruit industry waste such as; production of microbial enzymes for industrial use [12]; production of alcohol [17]; production of wine and vinegar; production of biogas [17].

The objective of present work was to study effective management and utilization of unripe banana peel waste of plantain processing waste. Dried unripe banana peel powder (DUBPP) was analyzed for chemical composition. Further, DUBPP was optimized for maximum sugar release by acid hydrolysis. Yeast strains were screened for various attributes to produce ethanol from acid hydrolysate of DUBPP. Fermentation conditions for ethanol production was optimized for acid hydrolysate of DUBPP by one factor at a time method.

2 Methods

2.1 Raw material preparation and chemical characterization of DUBPP

Unripe banana peels of hybrid variety of *Musa acuminata* and *Musa balbisiana* were collected from local banana chips manufacturer in bulk. This unripe banana peels were chopped into pieces and dried at 60°C for 24 h in tray drier then further ground to fine powder in electric grinder and sieved through mesh number 36 (0.45 mm). This raw material was stored in airtight container and kept in the desiccators until used for further experiments [18].

Moisture and ash content in DUBPP were determined as per the method of AOAC [19]. Total protein content was determined using Micro Kjeldahl procedure with a nitrogen-to-protein conversion factor of 6.25. Fat content was determined by Soxhlet method (using Instant Soxhlet apparatus-Socs Plus, Pelican equipments, Chennai, India) using petroleum ether (B. P. 60-80°C) as the solvent and carbohydrate by difference (Percentage carbohydrate content = 100 − (percentage moisture + percentage ash + percentage protein + percentage fat)). Aliquot of water soluble extract of powder sample was analysed for water soluble reduced sugar using dinitrosalicylic acid (DNS) method [20]. Starch was extracted using diluted perchloric acid and further analysed using anthrone reagent [21, 22]. Pectin content was determined using carbazole sulphuric acid method [23]. Cellulose content was determined using anthrone reagent as described in Sadasivam and Manikam [23]. Estimation of neutral detergent fibre (NDF), acid detergent fibre (ADF), hemicellulose and lignin were done by gravimetric method [23, 24]. All results reported as average of three determinations.

2.2 Optimization of acid hydrolysis by one factor at time (OFAT) approach

Acid hydrolysis was done using concentrated H_2SO_4. The parameter such as temperature, acid concentration (H_2SO_4), solid loading and reaction time for acid hydrolysis was optimized by OFAT approach and details of experimental conditions are given in Table 1. The first factor was then changed until an optimum value was reached. This optimum value for the first factor was then held constant while the second variable was varied and so on. All the experiments were conducted in triplicate and standard deviation was calculated.

2.3 Maintenance of yeast strains

Three strains of *S. cerevisiae* (NCIM 3095, NCIM 3570 and NCIM 3059) were procured from National Chemical Laboratory, Pune, Maharashtra, India. This culture was maintained in a MYGP medium composed of malt extract 3 g, yeast extract 3 g, glucose 10 g, peptone 5 g, agar 20 g in 1000 mL distilled water. Media was autoclaved at temperature of 120°C, pressure of 100 kPa for 20 min. Sub culturing was done every month. Master culture was stored at 4°C. For seed culture, a loop full of the yeast from the slant was transferred in 100 mL of MGYP broth in 250

Table 1. Various parmeter used for optimization of acid hydrolysis of DUBPP.

Variable parameter	Constant parameter			
	Temperatures (˚C)	Acid concentration (H_2SO_4) (% v/v)	Solid loading (% w/v)	Duration of reaction (min)
Temperature (˚C) (60, 80, 100, 120˚C (at 100 kPa))	-	1	5	10
Acid concentration (H_2SO_4) (% v/v) (0.5, 1, 1.5, 2)	120˚C (at 100 kPa)	-	5	10
Solid loading (% w/v) (5, 10, 15, 20, 25)	120˚C (at 100 kPa)	1.5	-	10
Duration of reaction (min) (10, 20, 30, 40, 50)	120˚C (at 100 kPa)	1.5	20	-

mL flask. It was incubated at 30˚C under shaking 150 rpm. Yeast culture of 8×10^9 CFU/ml was used for fermentation study.

2.4 Selection of yeast strain for ethanol production from DUBPP

Selection of yeast strain was done based on important parameters required for ethanol production at industrial scale such as reducing sugar to ethanol conversion efficiency of yeast strain, osmotolerance, ethanol tolerance, thermotolerance and sedimentation characteristics. For determination of conversion efficiency of different strains, 4% v/v of 12 h old seed of yeast strains (NCIM 3095, NCIM 3570, and NCIM 3059) inoculated in acid hydrolysate of DUBPP and incubated at room temperature (30 ± 2^0C) shaker at 150 rpm for 60 h. The samples were taken after each 6 h and analyzed for ethanol. The conversion efficiency of sugar to ethanol was calculated as practical yield divided by theoretical yield multiplied by 100 [25]. Osmotolerance of the yeast strains were tested in Sabouraud broth as described by Subashini et al. [26]. The yeast strains were inoculated in tubes containing modified TOL (Tolerance to ethanol) broth (Composition glucose 20 g, yeast extract 5 g, distilled water 1000 mL, pH 5) after media sterilization added with 4, 6, 8 and 10% w/v of ethanol. Cell growth in the form of turbidity was observed and compared with positive and negative control (Positive control: Ethanol absent, Negative control: Ethanol 20% w/v added) after 96h. Thermotolerance of yeast strains was tested as described by Subashini *et al.* by incubating at 35, 40, 45 and 50˚C [26]. Cell growth in the form of turbidity was observed and compared with positive and negative control (Positive control: incubated at 30˚C, Negative control: incubated at 60˚C) after 48h. Fermentation ability at high temperature was investigated by using inverted Durham tubes as described by Subashini *et al.* Sedimentation characteristics of yeast strains were studied as described by Brooks [25].

2.5 Optimization of fermentation by one factor at time (OFAT) approach

Fermentation study was performed in Erlenmeyer flasks closed with rubber cork and out rubber tube was used for release of CO_2. All the experiments were carried out in triplicate using acid hydrolysate of DUBPP. Seed culture was grown in MYGP medium and aseptically inoculated in acid hydrolysate. Those flask were incubated on rotary shaker at 150 rpm. Six experimental parameters were optimized such as seed age, seed volume, fermentation time, pH, temperature and nitrogen source by OFAT approach and detail conditions are mentioned in Table 2. OFAT was implemented by varying one factor at time and keeping other parameters constant. Ethanol concentration was determined as described below and expressed as g/l; ethanol productivity is expressed as g/l/h and calculated as gram of ethanol produced in liter of hydrolysate per hour of fermentation; Conversion efficiency is expressed as % w/w and calculated as practical yield divided by theoretical yield multiplied by 100. Theoretical yield was calculated by assuming that 1 g sugar yields 0.51 g ethanol [27].

2.6 Analytical methods

Quantitative determination of reducing sugar concentration was done by DNS method [20] and ethanol concentration was analysed using gas chromatography (GC) (Chemito 8610) equipped with flame ionization detector (FID) and a column poropak- Q (6ft, ¼ inch O.

D., stainless steel packed with 80-100 mesh). The column oven was operated isothermally at 140˚C; the injector and flame ionization detector were kept at 210˚C. Nitrogen was used as carrier gas and the combustion gas was a mixture of hydrogen and air. The samples were centrifuged at 8000 rpm for 20 min at 25˚C. The supernatant was then filtered through the filter disc (0.22 µm pore size). The filtered portion was then mixed with the internal standard (2-propanol) and run through the GC column. Peak area ratio was calculated by taking ratio of ethanol peak area to the *iso*-propanol peak area [28].

2.7 Statistical analysis

The significant difference of mean values was assessed with one-way analysis of variance (ANOVA). Tukey test was carried out using SPSS 16.0 software to determine whether there was any significant difference at level of ($p < 0.05$).

3 Results and discussion

3.1 Chemical characterization DUBPP

Chemical characterization of DUBPP is given in Table 3. DUBPP contents only 2.1% w/w of water soluble reducing sugar which was not practical to utilize for fermentative production of ethanol. But, DUBPP was found to be rich source of starch (41.2% w/w) and cellulose (9.3% w/w). This carbohydrates can be easily acid hydrolyzed to fermentable sugars. Fischer *et al.* stated that process production of ethanol from starch sources is highly efficient, but generally starchy feedstock is costly [29]. In present paper, first time reveling the chemical composition of DUBPP contianing notable high amount of starch, cellulose and also protein. Chemical composition of DUBPP is suitable for fermentative production of ethanol after hydrolysis. Hence this fruit waste has potential to be used as biomass for production of ethanol [30].

Table 2. Various parameter used for optimization of fermentation of acid hydrolysate of DUBPP.

Variable parameters	Constant parameters					
	Seed age (h)	Seed volume (% v/v)	Fermentation time (h)	pH	Temperature (˚C)	Nitrogen sources(w/v)
Seed age (h) (6, 12, 18, 24, 30)	-	4	48	6	30	NA
Seed volume (% v/v) (4, 8, 12, 16)	12	-	48	6	30	NA
Fermentation time (h) (6, 12, 18, 24, 30, 36, 42, 48)	12	12	-	6	30	NA
pH (4, 5, 6, 7)	12	12	36	-	30	NA
Temperature (˚C) (25, 30, 35, 40)	12	12	36	5	-	NA
Nitrogen sources (1% w/v) (malt extract, yeast extract, peptone, urea, ammonium sulphate)	12	12	36	5	30	_

NA: Not added

Table 3. Chemical characterization of dried unripe banana peel powder (DUBPP).

Parameters	% w/w on dry weight basis*
Moisture	10.0 ± 0.00
Total ash	7.6 ± 0.19
Protein	8.4 ± 0.10
Fat	4.7 ± 0.28
Carbohydrate	69.4 ± 0.14
Water soluble reducing sugar	2.1 ± 0.20
Starch	41.2 ± *2.1*
Pectin	7.4 ± 0.68
Cellulose	9.3 ± 0.29
Hemicellulose	3.2 ± 0.59
Lignin	2.3 ± 0.78
Acid Detergent Fibers (ADF)	17.5 ± 0.55
Neutral Detergent Fibers (NDF)	20.7 ± 0.63

*Results are mean ± SD of three determinations

3.2 Effect of acid hydrolysis parameters on reducing sugar release from DUBPP

Acid hydrolysis is widely utilized in the industry for chemical hydrolysis processes due to efficiency and low cost [31, 32]. Therefore in present study, acid hydrolysis of DUBPP was carried out using H_2SO_4. Effects of various parameters on reducing sugar release are shown in Figure 1-4. It was observed that reducing sugar release increased with temperature. Optimized temperature was 120˚C in autoclave at 100 kPa pressure given optimum sugar release. 1.5% v/v of H_2SO_4 was optimized for maximum sugar release further side of no increment was found. Application of high concentrations of H_2SO_4 resulted in browning or charring of hydrolysate occurred with increasing acid concentrations and also tend to formation of undesirable by-products along with sugar such as furfural and 5-dihydroxymethyl furfural, which are known to inhibit fermentation [32, 33]. These compounds are reported to be produced in very small concentration but they may be toxic to fermentation [34, 35]. In industrial scale solid loading is important parameter as it deciding factor of productivity. Then, aim was to take maximum amount of solid loading per batch. As the solid loading increased from 5 to 25% w/v sugar release decreases due to increase in viscosity which might lead to restrict the hydrolysis [36]. Solid loading (20% w/v) was taken as optimum for acid hydrolysis. Acid hydrolysis reaction time

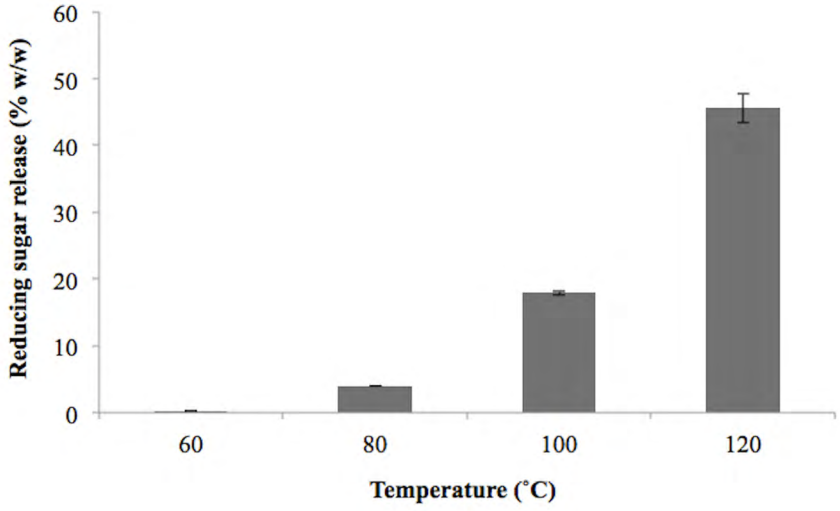

Figure 1. Effect of temperatures (60˚C, 80 ˚C, 100 ˚C in water bath and 120˚C in autoclave at 100 kPa) on reducing sugar release at constant conditions (Reaction time: 10 min; Solid load: 5% w/v; H_2SO_4:1% v/v).

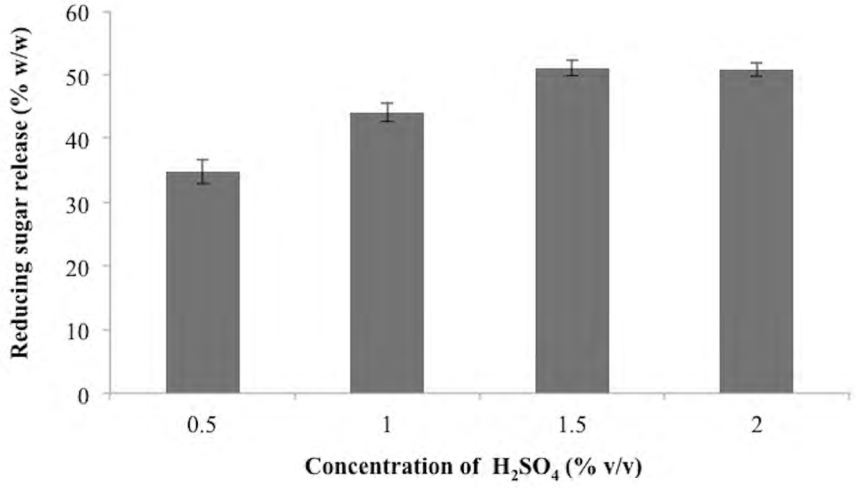

Figure 2. Effect of H_2SO_4 Concentrations (% v/v) on reducing sugar release at constant conditions (Reaction time: 10 min; Solid load: 5% w/v; Temperature: 120˚C (under 100 kPa pressure)).

is important as it responsible for speed of overall process. Duration of reaction (20 min) was found to be optimum at that time 49.2% of sugar release was obtained under optimized conditions.

3.3 Selection *S. Cerevisiae* on the basis of their important attributes for production of ethanol from DUBPP

There are different problems in the fermentative production of ethanol, the most important being yeast conversion efficiency, contamination, downstream process and inhibition by high substrate and product concentrations [37]. To overcome those challenges selection of yeast was done on the basis of important attributes for ethanol production [29]. Conversion efficiency is the most important attribute of screening of yeast strains. Conversion efficiency of the yeast strain during 60h fermentation cycle was carried and shown in Figure 5. *S. cerevisiae* NCIM 3095 was the most efficient ethanol producer giving maximum conversion efficiency of 42.8% w/w at 36h in acid hydrolysate of DUBPP. The osmotolerance, ethanol tolerance, thermal tolerance, fermentation ability at high temperature and sedimentation rate of three yeast strains were studied and summarized in Table 4. Osmotolerance has been studied as high substrate, product or salt concentrations that

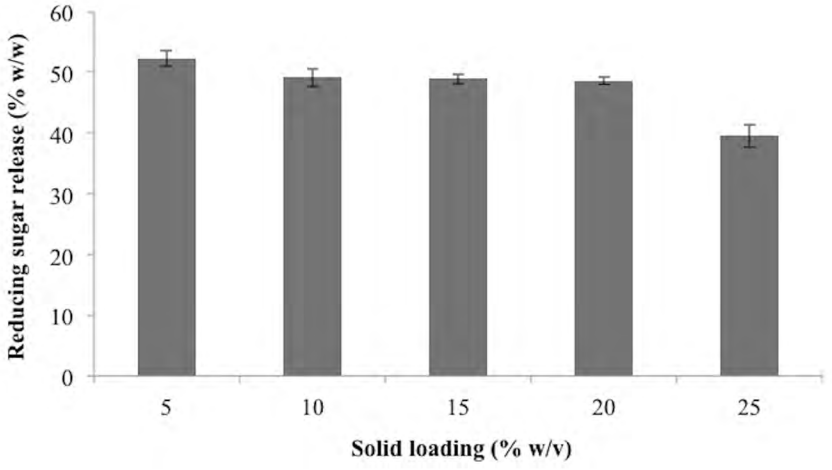

Figure 3. Effect of solid loading (% w/v) on reducing sugar release at constant conditions (Reaction time: 10 min; H_2SO_4:1.5% v/v; Temperature: 120˚C (under 100 kPa pressure)).

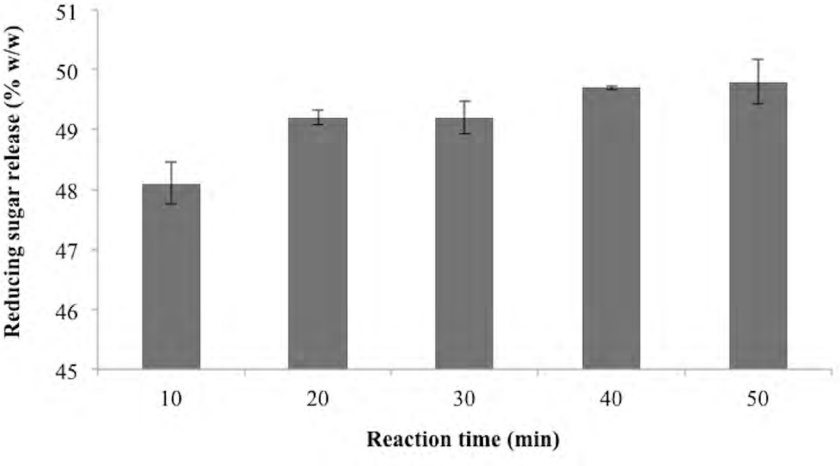

Figure 4. Effect of reaction time (min) on reducing sugar release at constant conditions (Solid load: 20% w/w; H_2SO_4:1.5% v/v; Temperature: 120˚C (under 100 kPa pressure)).

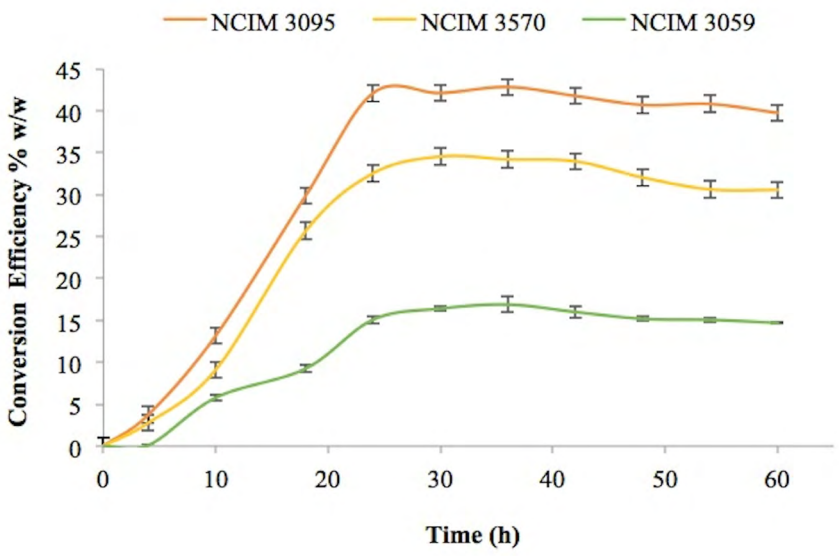

Figure 5. Conversion efficiency (% w/w) of *S. cerevisiae* (NCIM 3095, NCIM 3570 and NCIM 3059) strains from acid hydrolysate of unripe banana peel powder (UBPP) to ethanol in at pH (6), shaking 150 rpm in room temperature.

Table 4. Selection *S. cerevisiae* on the basis of their important attributes.

Strains	Osmotolerance Glucose conc. (% w/v)				Tolerance to ethanol Ethanol conc. (% v/v)				Thermotolerance Temperature (°C)				Fermentation ability Temperature (°C)				Sedimentation rate (%)
	15	20	25	30	4	6	8	10	35	40	45	50	30	35	40	45	
NCIM 3095	+++	+++	++	+	+++	++	+	+	+++	++	+	-	**	**	*	-	93.1
NCIM 3570	+++	++	+	-	+++	++	-	-	+++	+	-	-	*	*	*	-	3.5
NCIM 3059	+++	+	-	-	+++	+++	++	-	+++	+	-	-	**	**	*	-	3.1

Note: +++ Dense growth, ++ Medium growth, + Growth present, - Growth absent

** Vigorous fermentation, * Fermentation present, - Fermentation absent.

increase osmotic pressure are commonly encountered in industrial fermentations [29]. Osmotolerance was evaluated by varying sugar concentration from 15 to 30% w/v. *S. cerevisiae* NCIM 3095 strain was expressed highest osmotolerance up to 30% w/v. Ethanol tolerance is an important limiting factor for industrial exploitation of ethanol production. To investigate ethanol tolerance ability of strains, ethanol concentration was varied from 4 to 10% w/v in TOL broth. *S. cerevisiae* NCIM 3095 was tolerated 10% w/v ethanol concentration, whereas the other strains did not. In many warm countries, including India, summer temperatures frequently reach more than 35°C and in the typical ethanol fermentation processes carried out at 25 to 35°C with no cooling system. Due to exothermic metabolic reactions temperature rises to above 40°C leading to reduced ethanol productivities. Therefore it is very much essential to select thermo tolerant strain [38]. In present study, *S. cerevisiae* NCIM 3095 strain was found to be highest thermal tolerant strain which shown growth at 45°C. Not just thermal tolerance is important for ethanol production but also need to retain fermentation ability at high temperature. Fermentation ability of yeast strains at high temperature was inspected for presence of CO_2 in inverted Durham's tube in fermentation medium at various temperatures. All three yeast strain shown fermentation ability up to 40°C beyond that temperaure, fermentation ability was lost. High sedimentation rate of yeast helps in separation of biomass and supernatant. Sedimentation property of yeast strains provide effective, environment-friendly, simple and cost effective way of cell recycles by separating yeast cells from the culture broth after in-situ sedimentation of cells in the bioreactor [39, 40]. Sedimentating yeast strain suitable for developing efficient bioprocesses to produce [30]. *S. cerevisiae* NCIM 3095 strain was sediment faster than other strains (see Table 4).

3.4 Effect of fermentation parameters on ethanol production from acid hydrolysate of DUBPP

All fermentation experiments were carried out in triplicate and mean results are reported in Figure 6 and Table 5. Seed age is important parameter responsible for reduction of batch time as contributes in reduction of lag phase of production batch. The seed age 12h was found to be optimum seed age as it reaches maximum conversion efficiency (49.9% w/w) at 36h (see Figure 6). Effect of various seed volume, fermentation time, pH and temperature on ethanol concentration (g/l), ethanol productivity (g/l/h) and conversion efficiency (% w/w) of acid hydrolysate of DUBPP using *S. cerevisiae* NCIM 3095 is given in Table 5. As seed volume was increased from 4 to 16% v/v results increase in ethanol concentration was observed. Konar *et al.* suggested seed volume between 10% v/v was ideal for ethanol production [41]. So in present study, seed volume 12% v/v was selected for further optimization. Fermentation time is important parameter as it affects ethanol concentration as well as ethanol productivity. Fermentation time (36 h) was given optimum ethanol concentation as well as good ethanol productivity.

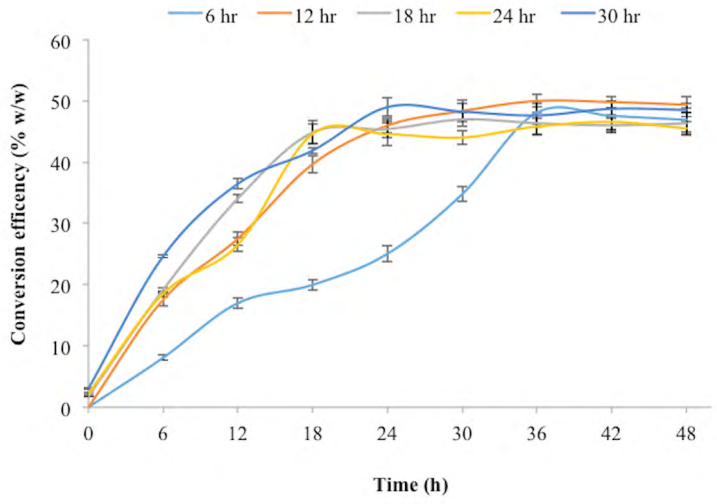

Figure 6. Effect of seed age (6 h, 12 h, 18 h, 24 h and 30 h) on conversion efficiency (% w/w) of acid hydrolysate of unripe banana peel powder (UBPP) to ethanol at pH (6), seed volume (4% v/v), and shaking 150 rpm in room temperature by *S. cerevisiae* NCIM 3095.

Table 5. Effect of various fermentation conditions on ethanol concentration, ethanol productivity and conversion efficiency of acid hydrolysate of DUBPP using *S. cerevisiae* NCIM 3095.

Parameters	Seed volume (%)				Fermentation time (h)				pH				Temperature (°C)			
	4	8	12	16	12	24	36	48	4	5	6	7	25	30	35	40
Ethanol concentration (g/l)	23.0^{a}	24.5^{a}	26.8^{b}	27.5^{c}	11.3^{a}	24.5^{b}	27.1^{c}	27.0^{c}	18.3^{a}	33.9^{b}	28.1^{c}	10.0^{d}	21.1^{a}	35.6^{b}	29.5^{c}	5.96^{d}
Ethanol productivity (g/l/h)	0.63^{a}	0.68^{a}	0.74^{b}	0.76^{c}	0.94^{a}	1.0^{b}	0.75^{c}	0.56^{d}	0.76^{a}	1.4^{b}	1.2^{c}	0.41^{d}	0.88^{a}	1.5^{b}	1.2^{c}	0.24^{d}
Conversion efficiency (% w/w)	45.9^{a}	48.8^{b}	53.5^{c}	54.8^{c}	42.5^{a}	52.9^{b}	54.1^{c}	53.9^{c}	36.5^{a}	67.5^{b}	55.9^{c}	19.9^{d}	42.0^{a}	71.0^{b}	58.9^{c}	11.9^{d}

*The values are means from three determinations.

The values with different superscripts in a row differ significantly ($p < 0.05$).

Hence, fermentation time (36h) was selected as optimized fermentation time. Initial pH of acid hydrolysate was varied form 4 to 7. At pH 5 maximum ethanol concentration was obtained, similar observation is reported by Fakruddin et al. [42]. Temperature shown remarkable influence on ethanol production as temperature incressed form 25 to 30˚C ethanol production was significantly increased but beyond that sudden drop in ethanol production. Therefore, temperature 30˚C was selected as optimized temperature. Additional nitrogen source was supplied for optimization of ethanol production. But there was not much effect was observes compared to control on ethanol production (see Figure 7). This might be due to already presence notable high protein in DUBPP. Similar finding was reported by Joshi in case of red potatoes for ethanol production [43].

4 Conclusions

The unripe banana peel is major waste of plantains processing industry. From chemical characterization revels DUBPP is abundant source of starch, other carbohydrates and protein. *S. cerevisiae* NCIM 3095 was found best strain for production of ethanol compared to other two strains. The maximum sugar release was obtained after acid hydrolysis i.e. 49.2% w/w from DUBPP at optimized condition. The optimum conditions for fermentative production of ethanol from acid hydrolysate of DUBPP were seed age (12h), seed volume (12% w/w), fermentation time (36h), pH (5) and temperature (30˚C), at this condition maximum ethanol concentration (35.6 g/l), productivity (1.5 g/l/h) and conversion efficiency (71.0% w/w) was achieved using *S. cerevisiae* NCIM 3095. The utilization of unripe banana peel waste generated from plantains processing can be done for ethanol production and this could be effective way of waste management and utilization.

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Conflict of interest: Authors declare nothing to disclose.

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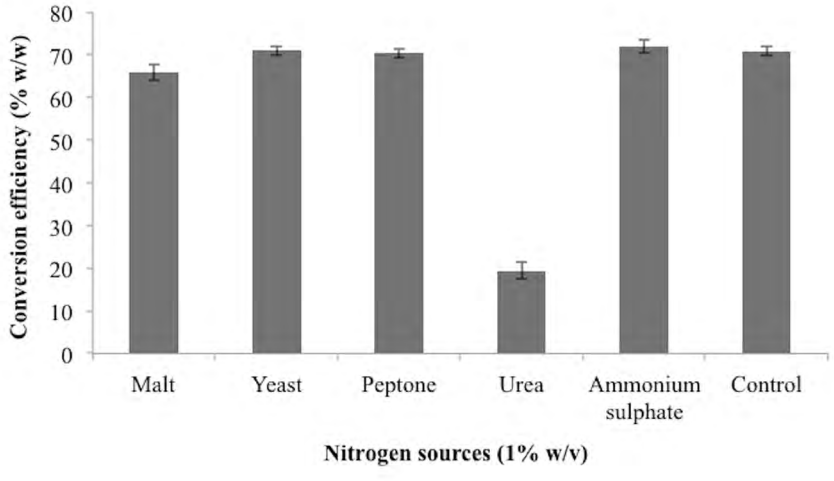

Figure 7. Effect of nitrogen sources (1% w/v) on conversion efficiency (% w/w) of acid hydrolysate of unripe banana peel powder (UBPP) to ethanol at pH (5), seed volume (12% v/v), shaking 150 rpm, fermentation time 36 h and temperature 30˚C by *S. cerevisiae* NCIM 3095.

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