International Journal of Advanced Chemistry Research
www.chemistryjournals.net
Online ISSN: 2664-679X, Print ISSN: 2664-6781
Received: 28-11-2021, Accepted: 13-12-2021, Published: 29-12-2021
Volume 3, Issue 2, 2021, Page No. 25-33

A production of bioethanol through the bioconversion of water hyacinth: A review

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Abstract
The demand for energy is increasing due to the rapid progress of industrial development while the amount of fossil fuels is decreasing day by day. Scientists are constantly looking for alternative sources of fossil fuels that will be sustainable but not harmful to the environment. Ethanol from biomass is an attractive, sustainable, and less toxic, less polluting fuel source in the modern era and the age of industrialization. The lignocellulose present in water hyacinth is a renewable source which is considered as a suitable alternative source of biomass for energy production. Cellulose aquatic plants are water hyacinth which have high carbohydrate, low lignin content and significantly lower reducing sugar infrastructure which is converted to fermentable sugar and later to ethanol. Ethanol production from water hyacinth involves two main types of conventional processes, firstly, lignin removal by pre-treatment of plant components, secondly, conversion of pre-treatment material to bioethanol through hydrolysis and fermentation process. This paper reviews all the conventional processes of making bioethanol from water hyacinth. The hydrolysis process mainly for acid and alkali and the fermentation process of yeast used for the production of bioethanol from water hyacinth have been discussed comparatively. Due to its low cost and easy availability, bioethanol from water hyacinth makes a strong promise in the 21st century.

Keywords: water hyacinth, cellulose, hydrolysis, fermentation, biofuel

Introduction

The present and potential world economy faces a significant problem in the global depletion of energy supplies due to ongoing over-use. The continuing decline in supplies of fossil fuel and consequent price rises have fostered interest in developing alternative technologies and substrates to meet global energy demand [1]. The environmental effect is a big reason why renewable energy sources are concerned. Ethanol has drawn worldwide attention because of its potential as an alternative automatically driven fuel [1]. Economic and environmental worries regarding fossil fuels depletion have led many countries to become involved in using biofuels to substitute fossil fuels as clean and cheap energy [2]. Bioethanol is considered to be an alternative to fossil fuels as a simple, healthy and sustainable resource [2]. This is derived mainly from either starch or sucrose crops, however, with the potential to increase soil competition between food production and the use of biomass energy and contribute to deforestation [3, 4]. Therefore, because of its low cost and easy availability, lignocellulose is progressively considered more attractive [5, 6].

Water hyacinth invades freshwater habitats, and is classified as one of the worst weeds for some reason, the water hyacinth is considered an invasive species [7]. Water hyacinth is often seen in the literature as one of the most dangerous weeds in the world because of the excessive and unregulated growth in pond, drainage and other water bodies [8]. Water hyacinth is well known as a free-flowing aquatic plant due to its productivity and water pollution. This means complete blackening of bodies of water can occur, which in turn can have negative effects on the climate, human health and financial growth. It can also increase rapidly to very high density (over 60 kg/m2) [1, 9, 10]. Water Hyacinth, among other forms of lignocellulosic compounds, is considered to be an desirable raw material for the processing and development of bioenergy including bioethanol, hydrogen and biochar.

Water hyacinth meets all requirements as a possible substrate for bioethanol production due to its ample abundance and high carbohydrate contents [1-2]. The dry biomass of water hyacinth consists primarily of low lignin (7–26%), cellulose-high (18–31%), and hemicellulose (18–43%), simple to hydrolyse for the reduction of sugar, then to ferments with successful yeasts into bioethanol [11]. Nevertheless, the successful enzyme hydrolysis has numerous problems. The lignin seal prevents the penetration by degrading enzymes is one of these issues [12]. Many researchers have found successful methods of pre-treatment to crack the lignin seal [13-16]. A further flash is the feedback inhibition of cellobiosis during bioethanol production following the hydrolysis fermentation cycle. Hydrolysis was more successful than alkali in acid. Researchers are studying and testing that cellulose, hemicellulose and lignin complicated shape are ideally broken by sulphuric acid. 1%, diluted sulfuric acid 2% helps to boost the cycle of hydrolysis and extracts full sugar from water hyacinth. Nitric acid was also used in hydrolyses, but the alkaline provided less sugar by hydrolysis. Sugar production will play an important role in ethanol production following the hydrolysis process. Yeast selection is more important when extracting ethanol from sugar by fermentation process. For the production of ethanol yeast must be cheaper and better done in the industrial sector. Maximum production of ethanol from sugar by fermentation process is shown to be P. Juliflora and L. Camera

and P. Stipites. In addition, this yeast is not used in the industrial sector because of certain yeast which is more expensive than S. cerevisiae. It is inexpensive, available and also have a better ethanol production.

For many countries, water jacinth harvests have been used in various useful uses. Methods have emerged to turn the plant material into useful items [17]. This review paper highlights water hyacinth function with the ultimate attention on its utilization for energy and engineering fields conducted in the last three decades. Based on these noteworthy research realizations it is desirable to recognize as an administration strategy to adjust in the commercial activities.

Composition of WH

Water Hyacinth (WH) biomass consists of monosaccharide and polysaccharide structures comprising different sugar and starch forms. The most common polymeric carbohydrates in WH are cellulose and hemicellulose. Interestingly, with the exception of WH, very little data is available on bioethanol production by aquatic plants [2]. As reported of [18], the smallest amount of cellulose in the stem has obtained according to WH, while the highest is located in the roots. WH is considered to be a good lignocellulosic material for the generation of bioenergy with high cellulose and hemicellulose content with low lignin, excellent growth rate and no competition on land use. Due to variations in carbon and lignin in different studies, the evaluation of the WH composition is significant. As reported by [19], WH has a large proportion of cellulose and hemicellulose (44 to 66.9% dry weight), and is poor in lignin from 3.5 to 9.5%, enough to remove fermentable sugars with specific pre-treats. Nonetheless, because of the compact structure between cellulose and hemicellulose lignin can be resistant to degradation. Due to a hard and costly hydrolyse operation, pre-treatment should be carried out to increase WH digestibility [20]. Many studies have reported on the composition of WH during the ethanol production process, as shown in (Table 1).

Table 1: Composition of Water Hyacinth

Reference	Cellulose	Hemicellulose	Lignin
(Ahn *et al*., 2012) [21]	34.19	17.66	12.22
(Xia *et al*., 2013) [22]	23.31	22.11	12.58
(Amit Ganguly *et al*., 2013) [23]	35	33	15.5
(Singh & Bishnoi, 2013) [24]	19.2	40.0	4.8
(J. Cheng *et al*., 2014) [25]	24.15	27.23	12.39
(Yan *et al*., 2015) [16]	31.81	25.64	3.55
(Lin *et al*., 2015) [26]	28.9	30.8	4.6
(Q. Zhang *et al*., 2016) [27]	18.07	28.21	7.03
(A. Das *et al*., 2016) [28]	24.7	32.2	3.2
(S. P. Das *et al*., 2016) [29]	31.44	44.68	19.99
(Q. Zhang *et al*., 2016) [27]	15.42±0.08	29.75±0.15	9.79±0.06

Method for ethanol production from WH

Several methods of processing are being used in biochar production, known as biomass conversion. Techniques for the conversion of bioenergy are usually divided into two categories: the biological catalyst and organism for biological and thermochemical transformation, whereas the latter is regulated by heat and chemical catalyst.

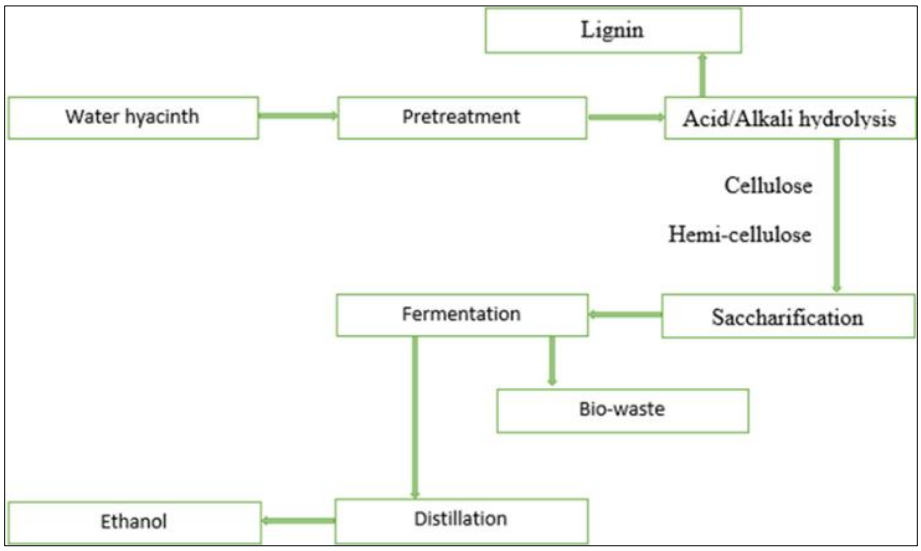

Fig 1: Step for ethanol production from WH

Water hyacinth is supplied from various sources such as ponds, shallow rivers, and canals. Water hyacinth is pasted into small pieces and then dried. After drying, pre-treatment should be done to separate lignin, cellulose, and hemicellulose. Separation of

lignin is most important because lignin compound interferes with sugar production. Acid or alkali is used for pre-treatment and hydrolysis. Many studies and analyses have shown that acid performs better for better hydrolysis. The hydrolyzed solution is then scarified to produce glucose. Glucose is produced through cellulose and hemicellulose scarification process. After completion of these processes, glucose and bio-waste are separated by filtration. Suitable yeast for fermentation process is used for maximum ethanol production. Then ethanol is separated by fermentation.

Pre-treatment method

Pre-treatment processes may also have a major effect on downstream system design, performance and expense [30-31]. Therefore, a fundamental understanding of various treatment technologies that help to suit a particular feedstock biomass' best pre-treatment method/combination [32]. According to [33], The best pre-treatment approach can be considered for biomass characteristics, quality of biomass, financial capital, and low impact on the environment. Alkali pre-treatment in conjunction with acid should be used as it is the right form for delignment [32]. As mentioned [34], twenty pre-treatments were used to increase WH enzyme hydrate performance. The results showed that alkaline/oxidative pre-treatment is the most powerful approach for enzymes to enhance hydrolysis. The pre-treatment cycle may also increase biomass and fermentable sugars' accessibility to the enzymes. Accessibility of enzymes in biomass and fermentable sugar yield can enhance the pre-treatment process [30]. In certain pre-treatment approaches, the yield of fermentable sugars can reach up to 90%, which is less than 20% without pre-treatment [35]. Pre-treatment with acid/alkali is normally done with WH. The efficacy of these pre-treatment methods is known as enzyme hydrolysis of glucose and of complete reducing sugars as well as fermentation of ethanol [36]. In a study by [37], acid pre-treatment provides two times higher concentration than alkali pre-treatment.

Hydrolysis method

Lignocellulosic biomass have used in several studies as a feedstock for the production of fermentable sugar, an important feature of bio-products such as bioethanol. The use of fermentable sugars to create organic outputs from starch crops is a common way to sustain bioethanol. The result has helped meet the huge demand for a low-cost, sustainable feed supply for the production of fermentable sugar [32]. First of all hydrolysis treatment is required for the conversion of sugar from water hyacinth. In hydrolysis treatment, cellulose and hemicellulose part of WH are converted to sugar and lignin is separated. Acid alkalis are required to convert cellulose and hemicellulose compounds into sugars. Acids and alkalis separate lignin by making sugar through chemical conversion with these compounds.

Acid Hydrolysis

Water jacinth needs to be hydrolyzed using various acids in a cleavagation of the β-1,4 linkages of glucose or xylose monomers, acetyl groups, to create xylose, arabinose, glucose and acetic acid. Acid hydrolysis will produce 90% of the theoretical value of sugar present in total fermentable sugar [38, 39]. sThe diluted acid method has to performed in the range of 30 min-2h by continuous processes at a temperature of 120-200°C and a pressure of 103 KPa (15 psi) to 517 KPa (75psi). The acid processes in concentrate may be succeed in generating high sugar outputs. Different acid forms of process hydrolyses like: 1% (v/v) (H_2SO_4), dilute sulfuric acid (2 %, v/v), HNO_3 (2%), HCl (2%), Peracetic Acid, $NaClO_2$, 3% HCOOH, etc. Acid of different kinds used for hydrolyses.

Alkali pretreatment

The alkaline effect depends on the material's lignin content. Those bases may be used for water hyacinth pretreatment. The saponification of intermolecular ester bonds linked to xylan hemicellulose is an alkaline hydrolysis mechanism. Once the connections have been broken, the porosity of the lignocellulosic material increases.

The dilution of NaOH (0.5 percent) induces swelling, leading to an increase of the internal surface region, a decrease in the degree of polymerization, a decrease in crystallinity, a separation of structural connections between lignin and carbohydrates and lignin structure disruption. In addition, ammonia was used for lignin removal pretreatment. The delignment efficiency for water hyacinth was 50-70%.

Various alkali forms used for alkalin pretreatment, such as NaOH (2%), 2.75% NaOH, 3% KOH, etc.

As mentioned [40] that after the wet storage and pre-treatment, the presence of carbohydrates in bio mass influences the enzyme saccharification and has led to decreases in sugar output. Different sugars are available in linkage with the use of different types of enzymes to deterioration the lignocellulosic structure [41]. Enzymatic hydrolysis is necessary for ethanol production to make carbohydrates available. WH produces more pentose sugars than hexose sugars in enzymatic hydrolysis. As reported by [42], The most important fermentable WH hydrolysate sugars are glucose and xylose. They have also established that in hydrolysing acid pre-treated WH the average reduced sugar yield was only 639.42 mg/g and in alkaline pre-treated WH it was only 136 mg / g. The average fermentable sugar yield after acid pre-treatment of WH by sulfuric acid was 0,54 g/g of WH (2% v/v) at 110°C for 90 min [43]. In a study by [22], enriched WH and 483 mg/g WH enzyme saccharity, microwave-acid pre-treatment reduced sugar yield by 94.6 percent. As mentioned [44], the reduction of WH sugar pre-treated with IL micro-emulsions at 70°C at 6 h at 563.7 mg/g was obtained, followed by an 86.1 percent hydrolyse yield. Thus in optimal conditions for a microwave WH pre-treated (T: 190°C, time = 10 min. and cellulose dosage = 5 wt.%), 0.296 g/g total volatile solids reducing sugar output are generated [26]. According to [34], the key source of WH sugar was discovered in the roots, excluding the leaves of Arabinose. As found by [45], The levels of 0.07 to 0.41 g/g WH of glucose, xylose and complete reduction in sugars. (Table 2) shows the characterization of different types of sugars in WH biomass**.**

Table 2: Hydrolysis of water hyacinth at different condition

Amount of acid/alkali	Amount of water hyacinth	Temperature	Time	Product	Reference
dilute sulfuric acid (2 %, v/v)	(10 %, w/v)	(121℃)	60 min.	sugar yield (149 mg/g)	(A. Das *et al*., 2016) [28]
HNO3 (2%)	(10 %, w/v)	(121℃)	60 min.	129 (mg/g)	(A. Das *et al*., 2016) [28]
HCl (2%)	(10 %, w/v)	(121℃)	60 min.	124 (mg/g)	(A. Das *et al*., 2016) [28]
NaOH (2%)	-	-	-	112 (mg/g)	(A. Das *et al*., 2016) [28]
Peracetic Acid	-	-	-	67.7%	(Abdel-Fattah & Abdel-Naby, 2012) [46]
NaClO2	-	-	-	64.0%	(Abdel-Fattah & Abdel-Naby, 2012) [46]
5% sulphuric acid	(10 %, w/v)	121 ± 3℃	60 min.	132.96 mg sugar/g dry matter	(Harun *et al*., 2011) [47]
1% (v/v) (H2SO4)	-	-	-	Glucose and total sugars yield of acid pretreatment were 445 and 714 mg/g of WH.	(Guragain *et al*., 2011) [36]
2.75% NaOH	-	-	1-hour	51, 65 and 82%	(Singh & Bishnoi, 2013) [24]
Microwave with 1% dilute H2SO4	-	-	-	Highest TRS was 0.482.8 g/g WH Highest	(J. Cheng *et al*., 2014) [25]
1.5% (v/v) H2 O2 and 3% (w/v) NaOH	-	-	-	Reducing sugars were (223.53 mg/g dry)	(Yan *et al*., 2015) [16]
Sodium hydroxide with a biomass loading of 10% (w/v), 5% (w/v) concentration of NAOH,	-	130°C.	soaked for 1h and treatment time of 10 min.	10.44 g/L	(S. P. Das *et al*., 2014) [48]
3% KOH	3g of the dried water hyacinth	121°C	15 min.	5.615 mg/g	(Awasthi *et al*., 2013) [40]
3% NaOH	3g of the dried water hyacinth	121°C	15 min.	5.723 mg/g	(Awasthi *et al*., 2013) [40]
3% HCOOH	3g of the dried water hyacinth	121°C	15 min.	4.78 mg/g	(Awasthi *et al*., 2013) [40]
0.25% H2SO4	-	100°C	60 min.	(322.3-366) mg/g	(Ma *et al*., 2010) [14]

Fermentation and ethanol production

This section examined several types of microorganisms and enzymes which also contribute to the production of ethanol from WH. There are two kinds of enzyme and fermentation approaches, apart from various pretreatment methodologies, including Simultaneous Saccharification and Fermentation (SSF) and Separate Hydrolysis and Fermentation (SHF). Depending on the characteristics of the fermenting microorganism, the correct fermentation process. Saccharomyces cerevisiae, Escherichia coli, Zymomonas mobilis, Pachysolen tannophilus, C. shehatae, Pichia stipitis, Candida brassicae, and Mucor indicus are some natural or wild-type microorganisms that have been used in the processing of ethanol. For the meantime, the best known yeast and bacteria are S. cerevisiae and Z. mobilis.

As mentioned that Candida shehatae and Pichia stipitis yeasts have a strong potential at low pH, although for various components like ethanol, they have a poor tolerance. In the development of industrial bioethanol, yeast S. Cerevisiae is the most popular and typical microorganism. Significant attempts are being made to develop the xylose metabolization microorganism. S. Cerevisiae are only able to ferment hexoses, which are likely to contain low levels of ethanol.

In terms of bioethanol development the advantages of Zymomonas mobilis over cerevisiae are (1) increased sugar absorption and the yield of ethanol; (2) decreased production of biomass; (3) greater tolerance of ethanol; (4) genetic engineering adaptability Z. mobilis showed better efficiency in SHF, as microorganisms do not function well at low glucose levels usually seen during SSF. Several studies have analyzed and evaluated the potential of ethanol production from WH [1, 2]. (Table 3) shows recent studies regarding ethanol production from WH biomass.

Table 3: Ethanol production using yeast by fermentation process

Yeast	Amount of solid solution	Temperature ˚C	Time	PH	Product of ethanol	Reference
mixed fermentation by Saccharomyces cerevisiae (MTCC 173) and Zymomonas mobilis (MTCC 2428)	5% v/v	(50℃)	24h	5.5	ethanol production of 13.6 mg/ml	(A. Das *et al*., 2016) [28]
Candida Intermedia	-	35℃	67.60h	4.18	33.04g/L	(Manivannan *et al*., 2012) [51]
Pichia stipites	5% v/v	30 ± 0.2℃	20h	5.0 ± 0.2	0.425 gp/gs	(Kumar *et al*., 2009) [19]
Sachharomyces cerevisiae (Sc-SR4, Sc-MR8)	-	30℃	-	5	0.32 g/g	(Hossain *et al*., 1970) [52]
S. cerevisiae	-	38.87°C	81.87h	-	1.291g/L	(Q. Zhang *et al*., 2016) [27]

Kluyveromyces marxianu K213	-	-	-	-	7.34 g/L	(Yan *et al*., 2015) [16]
Pichia stipites and Pachysolen tannophilus	-	-	24h	4.5	0.22 g/g	(Bhattacharya & Kumar, 2010) [53]
Candida shehatae	-	30°C	3 wks.	5.6	0.19 g g-1	(Isarankura-na-ayudhya & Tantimongcolwt, 2007) [54]
Pichia stipitis NRRL Y-7124	-	-	84h	-	0.32 g/g	(Silva *et al*., 2011) [55]

Result and discussion

Alfalfa enzyme hydrolyse fermentation with cerevisiae resulted in 98% sugar consumption, with a fermentation efficiency of 85% and an ethanol productivity of 1.3 g/l/h [56]. S. cerevisiae provided 20.0 and 8.2 g/l ethanol and an ethanol production of 3.33 and 2.7 g/l/h, respectively, for the fermentation of acid and alkali treated apple bagasse with S. cerevisiae [57]. In another report, 45.7 g/l ethanol with an ethanol yield of 94 percent provided enzymatic hydrolysate containing 110 g/l sugar fermented with S. cerevisiae [58]. On fermentation of enzymatic hydrolysates of P. juliflora and camera containing 36.5 and 37.5 g/l sugars, an ethanol yield of 0.48 g/g was obtained, respectively. Candida, Pichia and Dekkera, isolated from sugarcane molasses, developed low ethanol and acetic acid concentrations as inhibitors of fermentative yeast in a study on the isolation of possible fermentation strains [59]. The genetic moderation of K. marxianus has also been used to demonstrate cellulolytic T. reesei and Aspergillus aculeatus behaviour, which allows lignocellulose to be converted into ethanol during CBP processes at 48°C to produce 0.47g/g ethanol. Seperate hydrolysis and fermentation (SHF), developed using a cellulase mixture, xylanase and pectinase on water hyacinth leaves pretreated with dilute acid, was carried out using three separate yeast strains Saccharomyces cerevisiae TISTR 5048, Saccharomyces cerevisiae KM 1195 and Saccharomyces cerevisiae KM 7253, respectively. elluclast and Viscozyme L. were enzymatic saccharification. The maximum ethanol yield of 0.35g/g biomass was obtained with the batch fermentation [21]. A crude fermentation analysis using the popular Saccharomyces cerevisiae baker's yeast resulted in an ethanol content of 4.4 g/L for the enzyme hydrolysenation (cellulase and β-glucosidase) of alkali-treated water-hyacinth biomass [42]. Set separate water hydrolysis and water hyacinth-biomass fermentation pretreated from taxodia (10 days) and Saccharomyces cerevisiae 0.25% of H2SO4 was caused by 0.192 g/g of the dry matter, the yield was 1.34 times higher as acid-treated water hyacinth [14].

The industrial baker's yeast (Saccharomyces cerevisiae), which is 95 percent theoretical yield (0.51 g/g glucose), has developed an ethanol yield of 0.484 g/g of sugar reduction. Saccharomyces cerevisiae, Scheffersomyces stipitis and co-culture of both Saccharomyces and ethanol levels of 4.3, 6.2 and 9.8 g/L were concentreted and fermentated, enzymatic hydrolysate has been treat with [24]. As a result of the ability to ferment of Pentose Sugars, the maximum ethanol yield of 0.411 grams g−1 was obtained from T. reesei and P. stipite co-culture. Enzyme hydrolyse has been performed using the Trichoderma reesei NRRL-3652, enzyme complex (cellulase 18.33 IU/mL and xylanase 31.43 IU/mL). With P. tannophilus reaching 0.043 g/g maximal ethanol concentration 0.021, 0.037 g/g and 0.015 g/g intermediates, P. stipites and S. cerevisiae has been produced the highest ethanol production [45].

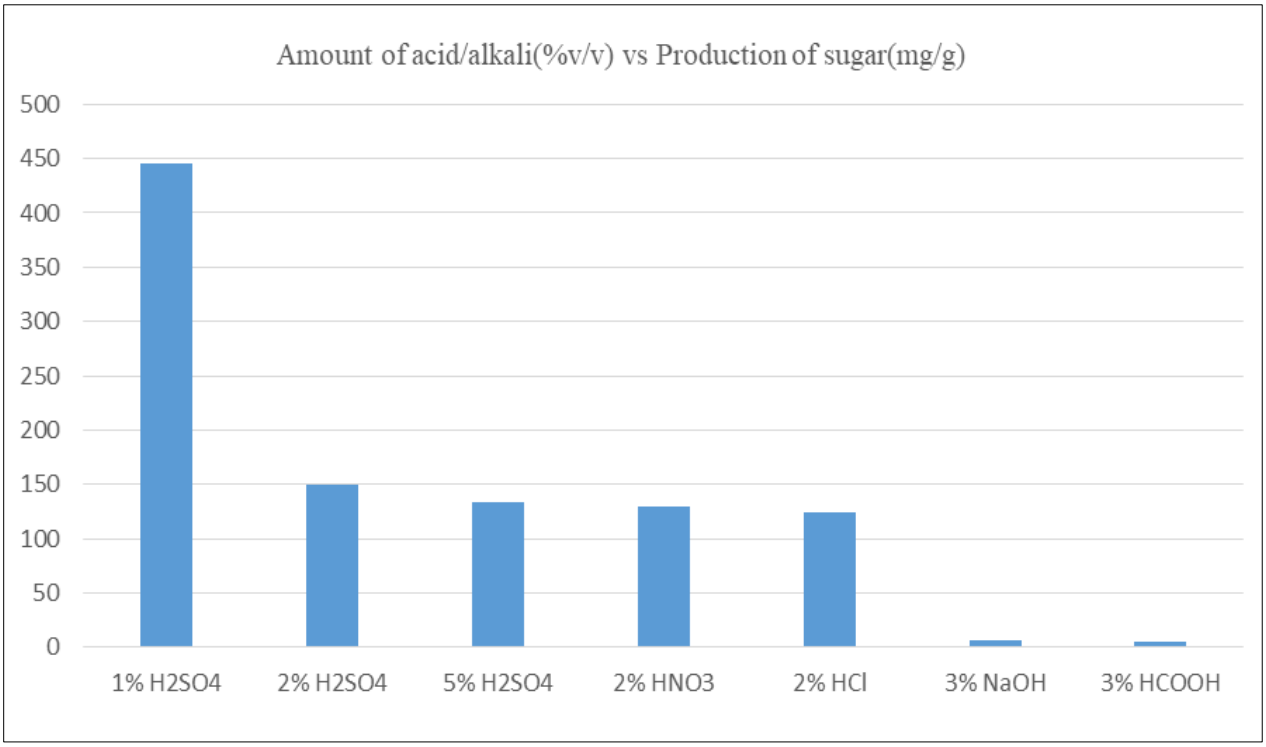

Fig 2: The performance of sugar production depends on the concentration of different acids used for sugar production.

Hydrolysis of water hyacinth using different types and different concentrations of acids for ethanol production produces different amounts of sugar. Sugar production in this hydrolysis process depends on the concentration of the acid used. (Figure 2) shows that hydrolysis with 1% sulfuric acid produces the most 445 (mg/g) of sugar. 2% sulfuric acid, much denser than 1% sulfuric acid, produces 149 (mg/g) of sugar much less and hydrolysis of water hyacinth with 5% sulfuric acid produces less sugar than 2% sulfuric acid. Thus, from the bar chart of (Figure 2), it can be said that reducing the concentration of acid increases the amount of sugar produced at a very disproportionate rate. 2% nitric acid and 2% hydrochloric acid have lower sugar production efficiency than 2% sulfuric acid. 3% sodium hydroxide and 3% formic acid can produce sugar by hydrolysis with very small amount of water hyacinth. From the above discussion and bar chart, it can be concluded that hydrolysis of water hyacinth with dilute sulfuric acid produces more sugar.

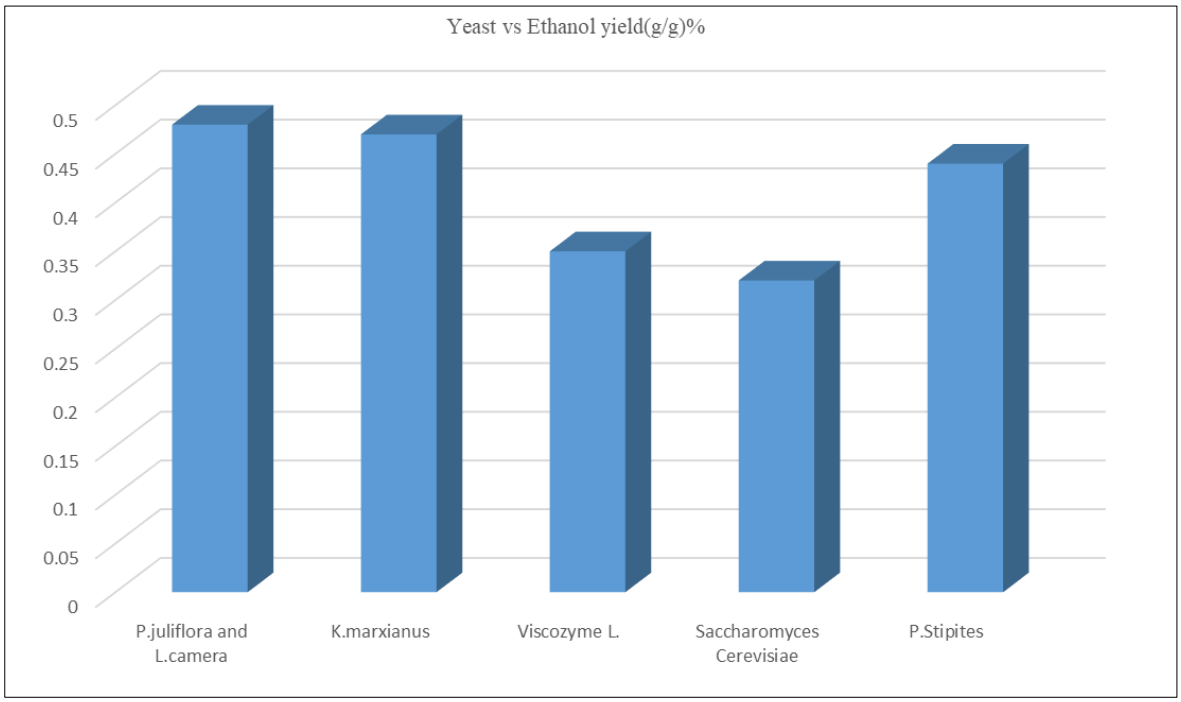

Fig 3: The performance of the variety yeast used for ethanol production

Different types of yeast use for fermentation process and showed several amount of ethanol production. Among the different types of yeast used from (Figure 3), the highest yield percentage of P. Juliflora and L. camera is 0.48. K. Marxianus east progress is good but less efficient 0.47 is found than P. Juliflora and L. Camera. The Saccharomyces Cerevisiae yeast industry is used to produce ethanol from water hyacinth with a yield percentage of 0.32 in (Figure 3). (Figure 3) further shows that for ethanol production P. Stipites yeast is good but it costs more than Saccharomyces Cerevisiae. Viscozyme L. yeast is also used for ethanol production with a yield percentage of 0.35.

Future prospects and outlook

The technology to produce bioethanol from water hyacinth is fully functional, efficient and the use of environmentally friendly technology is still in the early stages of development. Although the full valuable utilization of water hyacinth is increasing day by day, it is improving technologically and better results may come in the long run. The production of bio-ethanol from water hyacinth through bioconversion is a positive factor, as the water hyacinth is disrupted and uncontrolled economically and ecologically while in water. It can be said that the proper use of water hyacinth means positive management of waste water. Bio-ethanol is much less expensive than water hyacinth in terms of cost. In the future more phytotechnologies for water hyacinth will be developed for wastewater treatment. It is hoped that the use of lignocellulose for future ethanol production will increase further and reduce costs. As a result, it will be possible to effectively use water hyacinth through research and metabolic and process engineering for more ethanol production. Therefore, the overall bio-ethanol production industry will improve in the future.

Conclusion

Notable biomass of high carbohydrate and low lignin content is water hyacinth. For this reason, water hyacinth is a very good alternative fuel for the second generation. The hydrolysis process plays a role as the main economic barrier to the production of bioethanol. Researchers consider the economic aspects of the compounds used for maximum production. It is better to use acid compound than alkali compound for hydrolysis process as it produces more sugar. Comparative studies have shown that 1% H_2SO_4 performs well for the hydrolysis process. Furthermore, the usage of cost effective raw materials such as lignocellulosic residuals in effective fermentation methods (e.g. SSF), the economic aspects of ethanol production can be improved. Yeast is required for ethanol production from sugar, yeast selection is very important for maximum ethanol production. Saccharomyces cerevisiae is used in the yeast industry for ethanol production

from water hyacinth because it gives cheap and good production. On the other hand for P. Stipites and good ethanol production but P. Stipites cost more than saccharomyces cerevisiae. Scientist think that the reduction cost of pre-treatment and saccharification with proper reactor design can improved the cost of ethanol production from water hyacinth.

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