



Comparative Studies on Production of Bioethanol from Rice Straw Using *Bacillus subtilis* and *Trichoderma viride* as Hydrolyzing Agents

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Authors' contributions

This work was carried out in collaboration between both authors. Author OOC designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author AAF managed the analyses of the study and managed the literature searches. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/MRJI/2019/v28i330134

Editor(s):

(1) Dr. Sabina Fijan, University of Maribor, Slovenia, Fakulteta za Zdravstvene Vede, Faculty of Health Sciences, Žitna Ulica 15, 2000, Maribor, Slovenia.

Reviewers:

(1) Rasheed Owolabi, University of Lagos, Nigeria.

(2) Muhammad Irfan, University of Sargodha, Pakistan.

Complete Peer review History: <http://www.sdiarticle3.com/review-history/46826>

Original Research Article

Received 25 October 2018

Accepted 30 January 2019

Published 26 July 2019

ABSTRACT

Ethanol production by *S. cerevisiae* was carried out using rice straw as substrate and *B. subtilis* and *T. viride* as hydrolyzing agents. The aim of this research is to compare the potential of rice straw (non-edible waste material) for bioethanol production using *Bacillus subtilis* and *Trichoderma viride* as cellulose hydrolyzing agents. The sample was dried and ground; and was subjected to chemical pretreatment and microbial hydrolysis to maximize sugar production. Standard methods were used to carry out isolation, identification and analysis of sample which includes proximate, mineral and physicochemical analysis. The sample was fermented for seven days during which ethanol yield was determined. Cellulose hydrolysis screening carried out on each of the two organisms revealed *T. viride* having the higher clearance zone of 1.8 cm, while *B. subtilis* had 1.5 cm. Proximate analysis obtained from the samples showed that the pretreatment method was relatively effective giving an increase in the cellulose and decrease in the hemicellulose and lignin contents of the samples. This showed rice straw having a cellulose content of $51.33 \pm 0.17\%$ after pretreatment. Potassium content was relatively high (17.96 mg/g), Hydrolysis using *T. viride* gave higher reducing

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sugar yield than that obtained using *B. subtilis* with 26.6 g and 12.21 g respectively. The pH was observed to decrease during fermentation while total titratable acidity observed showed an increase. Highest ethanol yield of 16.21 g/100 g was obtained using *T. viride* as hydrolyzing agent.

Keywords: Bioethanol; rice straw; *Bacillus subtilis*; *Trichoderma viride*; *Saccharomyces cerevisiae*.

1. INTRODUCTION

Ethanol, also called ethyl alcohol, pure alcohol, grain alcohol, or drinking alcohol, is a volatile, flammable, colorless liquid [1].

The environmental crisis and the shortage of fossil fuels have turned public attention to the utilization of other forms of energy, which are environmentally friendly and renewable, such as bio-ethanol. Recent years research has focused on the second-generation biofuels, where wastes or by-products are utilized as raw material, compared to the first-generation biofuels where sugars and starch were utilized, and the utilization of either sugars or corn for the production of biofuels have contributed to the increase of their price worldwide, resulting in severe problems for the poorer countries [2]. Lignocellulosic biomass represents great potential to be utilized as raw material due to the high amounts produced every year, and their wide availability.

Rice straw is one of the abundant lignocellulosic waste materials in the world. It is annually produced in large quantity reaching about 731 million tons distributed in Africa (20.9 million tons), Asia (667.6 million tons), Europe (3.9 million tons) and America (37.2 million tons). This amount of rice straw can potentially produce 205 billion liters of bioethanol per year, which is the largest amount from a single biomass feedstock [2].

2. MATERIALS AND METHOD

2.1 Source for Samples

One thousand (1,000) grams of fresh rice straws were collected from Ekiti state (Igbimo). The sample was washed thoroughly; sun dried and powdered using Tiger ES250 Engine food processor. The sample was divided into two portions; the first portion was used for analysis while the second was used for fermentation.

2.2 Pretreatment of Samples

A two-stage process which combines the Dilute Acid Pre-hydrolysis (DAPH-100-121) and alkaline delignification using NaOH as described

by [3,4] was used. Dry sample was treated with dilute sulfuric acid which involved the use of 1.25% (w/v) H₂SO₄ solution in a 1:8 g: g solid: liquid ratio. The One step Dilute Acid Pre-hydrolysis (DAPH-121) was performed in an autoclave at 121°C for 17 min, after which the solids were collected and drained. The solids were then treated with 2% (w/v) sodium hydroxide solution in a solid: liquid ratio of 1:20 g: g, at 120°C for 90 min. After that, the residual solid material (cellulose pulp) separated by filtration was washed with water to remove the residual alkali and was dried at 50 ± 5°C for 24 h.

2.3 Microorganisms for Fermentation

Saccharomyces cerevisiae was obtained from the stock culture of Microbiology Laboratory Federal University of Technology, Akure, while *Bacillus subtilis* and *Trichoderma viride* was isolated from rice straw.

2.4 Cellulose Hydrolysis Test on Isolated Strains of *Bacillus subtilis* and *Trichoderma viride*

A modified method of [5] was used. Cellulase activity was examined relatively by measurement of the diameter of clearance on agar plates containing substrate (carboxy methyl cellulose). Bacterial and fungi isolates were grown in appropriate liquid medium containing 0.5% (w/v) CMC for 48 and 96 hours respectively.

After incubation, centrifugation was carried out, after which 0.5 ml of each culture supernatant was dropped into wells made on appropriate agar plates containing 0.5% (w/v) CMC and incubated for 24 hours at 4°C to diffuse enzyme. After that, the agar plates were incubated for further 24 hours at 37°C, after which the plates were stained with 1% (w/v) lugol iodine, the diameter of clearance of each plate was then measured.

2.5 Determination of Proximate Composition

Proximate composition which include; moisture, crude protein, total fat, ash and crude fiber, was determined by standard method of [6].

Moisture content of the samples was determined by oven drying method and expressed as dry basis. Crude protein was also be determined by an automated Kjeldahl method, using Kjeldahl 2006 digester. The crude fat was determined by extracting a known weight of samples with petroleum ether, using a Soxhlet apparatus while ash content was be determined by incineration method.

2.6 Determination of Cellulose Hemicellulose and Lignin

The method of [7] was used. The substrates were analyzed for cellulose, hemi-cellulose and acid insoluble lignin which were done before and after pretreatment. Cellulose was determined using a colorimetric method with the anthrone reagent. Ground samples were treated and boiled at 100°C with a mixture of nitric/acetic acid (1:8, v/v) for 1 hour to remove lignin, hemicelluloses and xylosans after successive centrifugations, and diluted with 67% H₂SO₄ (v/v). Cellulose was then determined at 620 nm using cold anthrone reagent.

Hemicellulose and lignin contents of the substrates were determined as follows: the residue from above containing Hemicellulose and lignin was then were boiled with 5 mL of 72% (w/w) H₂SO₄ solution for 4.5 hours in order to hydrolyze the hemicellulose. The suspension remaining after the above treatment was filtered through a crucible and the solid residue dried at 105°C for 24 hours and weighed (W1). The residue was then transferred to a pre-weighed dry porcelain crucible and heated at 600°C for 5 hours. After cooling down, it was weighed (W2). Acid insoluble lignin was then calculated by the difference (W1 - W2) [8].

The filtrate from the H₂SO₄ treatment that contained the sugars released from hemicellulose was thoroughly stirred and homogenized. Glucose (C1) and reducing sugar (C2) concentrations in the filtrate were determined. Following these measurements, the hemicellulose content was then calculated from the following equation:

$$\% \text{ (w/w) hemicelluloses} = \frac{(W/S) \times (C2 - C1)}{V/M} \times 100$$

Where; W = molecular weight ratio of the polymer and monomer pentose, S = scarification yield, C2 = determined reducing sugars concentration (g/L), C1 = glucose concentration

(g/L), V = total volume of sugar solution (L), M = dry weight of the sample (g).

2.7 Determination of Mineral Elements

The mineral composition (Potassium, Sodium, Calcium, Magnesium, Zinc, Iron, and Copper) will be determined by wet ashing method followed by spectrophotometric reading of the level of mineral.

Triplicate samples (1 g) of each sample will be ashed in muffle furnace at 450°C for 5-6 hours. The ashed samples and silica dishes will then be removed and transferred into the desiccators to cool after which the samples will be dissolved with 1 ml of 0.5% HNO₃. Little distilled water will be added and filtered into a clean small plastic bottle using number 43 Whatman filter. Distilled water will then be used to dilute the solution up to 50 ml. Atomic absorption spectrophotometer (Buck 201, VGP) will be used in determining the mineral content [6]. The mineral content will then be calculated using the formula below:

$$\text{Mineral (mg/100 g)} = \frac{R \times V \times D}{Wt}$$

When R = Solution concentration, V = Volume of sample digested, D = Dilution factor, and Wt = Weight of sample

2.8 Preparation of Inoculum

Trichoderma viride, *Bacillus subtilis* and *Saccharomyces cereviceae* inocula were prepared by introducing slant cultures to 150 ml of sterile growth media contained in 500 ml conical flasks. The flasks were incubated on a rotary shaker at 30°C for 96 hours [9].

2.9 Ethanol Fermentation Medium

Rice straw was used as the base medium supplemented with all of the other ingredients of growth medium as described by [10].

2.10 Microbial Hydrolysis

One hundred (100) grams of the pretreated substrate was weighed in duplicates into 1000 ml conical flasks and made up to mark with distilled water, corked and sterilized at 121°C for 15 min. Sterile distilled water was added to the flasks to a final volume of 1 liter and the flasks plugged with sterile cotton wool. After cooling, the medium was inoculated with 50 ml of 36 hours culture of *Trichoderma viride* and *Bacillus*

subtilis separately; the pH of the medium was then adjusted to 5.5. Hydrolysis was carried out at ambient temperature for five days on a rotary shaker. A second un-inoculated flask served as control. Samples were taken at the end of Five days for reducing sugar determination [11].

2.11 Fermentation

Fermentation was carried out as described by [12]. Each of the medium from the above was inoculated with 50 ml culture of *Saccharomyces cerevisiae* to carryout fermentation for seven (7) days. The fermentation was then monitored from day 1, the pH of the hydrolysate containing *Saccharomyces cerevisiae* was adjusted to 5.5 and fermentation carried out at ambient temperature on a rotary shaker. The ethanol yield was determined at 48 hours interval during fermentation. The fermentate was separated by centrifugation at 9000 rpm to separate the waste from the supernatant [11]. All procedures were carried out in triplicates.

2.12 Centrifugation and Distillation

After fermentation, the broth was centrifuged at 6000 rpm for 10 minutes. The supernatant was collected and fed into a simple distillation column. The boiling temperature of ethanol is 78°C hence distillation was carried out around that temperature to facilitate the evaporation of ethanol. The vapour was collected and got condensed by means of the circulation of cold water around the column. The distillate having ethanol was recovered in a conical flask at the other end of the column.

2.13 Determination of Reducing Sugar Produced

The reducing sugar was determined by titrimetric methods. 30 ml of hydrolysis broth was weighed into the burette. 10 ml of mixed Fehlings solution was pipetted into a conical flask and 4 drops of 1% methylene blue indicator was added. The solution was heated and while boiling the broth on the burette was titrated against the solution on the conical flask until the colour disappears [13]. The reducing sugar was calculated as follows:

$$\% \text{Reducing Sugar} = \frac{47.5 \times 300}{T \times W} \quad [13]$$

T represents the titre value

W represents the weight of the peel sample

2.14 Determination of Ethanol Yield

The distillate collected was weighed and its mass obtained, ethanol yield was the expressed as weight of ethanol in grams/weight of sample in grams [11].

2.15 Determination of Ethanol Concentration

Ethanol concentration was determined by comparing the density of the ethanol produced with the standard ethanol density curve. Standard ethanol curve would be obtained by taking series of percentage (v/v) ethanol (10%, 20%, 30%, 40% and 50%) solution which was prepared in a 100 ml volumetric flask and the weights was measured as described by [14]. The density of each of the prepared ethanol solution was calculated and a standard curve of density against percentage ethanol (w/v) was plotted.

2.16 Determination of pH

The pH of each fermenting substrate was measured at 24 hours interval for seven days using a digital pH meter, standardized with buffer of 7.0. The pH was then determined by inserting the electrode bulb into a sample from each fermenting substrate.

2.17 Total Titratable Acid

This was determined using the method of [15] 10ml of the fermenting medium was transferred into a beaker, followed by the addition of 3 drops of phenolphthalein indicator. The sample was then titrated against 0.1M NaOH to an end point of a definite pink color. The volume of NaOH used was noted and the titratable acid percentage was calculated using the following formula:

$$TTA(\%) = V \times 0.15 \quad [15]$$

Were; V = Volume of NaOH used

2.18 Comparative Analysis of the Properties of Bioethanol Produced from Rice Straw and Commercial Ethanol

Comparative analysis of properties (such as appearance, relative density, melting point, boiling point, viscosity, refractive index, burning

characteristics and flash point) of bioethanol produced from cocoyam and sweet potato peels and conventional ethanol was determined using standard methods [6].

2.19 Statistical Analysis

The data obtained from various treatments was expressed as the mean \pm standard error. Computer software SPSS 16 was used to determine the differences between each parameter using one-way analysis of variance (ANOVA). Duncan multiple range tests was used to compared the means at probability level of 0.05%

3. RESULTS

The cellulose hydrolyzing ability of each of the isolated organism is shown on Table 1. The two isolated organisms tested positive for cellulose

activity. *Trichoderma viride* showed the higher cellulose hydrolyzing ability with clearance diameter of 1.8cm. *Bacillus subtilis* on the other hand showed a clearance diameter of 1.5 cm.

The proximate composition of Rice straw is giving in Fig. 1. Rice straw had a moisture content of 7.86%, protein content of 3.10%, fiber content of 20.83% and lipid content of 1.43%. Rice straw was however observed to contain high cellulose content of 33.50.

The mineral composition Rice straw is shown in Table 2. Rice straw showed high Potassium content of 17.96 mg/g, likewise the same was observed for Calcium (3.00 mg/g). It was also shown that rice straw was relatively low in sodium content. Nitrogen content gave 0.80 mg/g. It can however be observed that rice straw had high mineral composition.

Table 1. Diameter of clearance for cellulose hydrolysis (cm) by the microbial isolates

Microorganisms	Cell diameter	Diameter of clearance
<i>Bacillus subtilis</i>	0.80 \pm 0.00 ^a	1.50 \pm 0.00 ^e
<i>Trichoderma viride</i>	0.90 \pm 0.17 ^a	1.80 \pm 0.10 ^e

Data are represented as mean \pm standard deviation, n=3 with the same superscript down the row are not significantly different ($p < 0.05$)

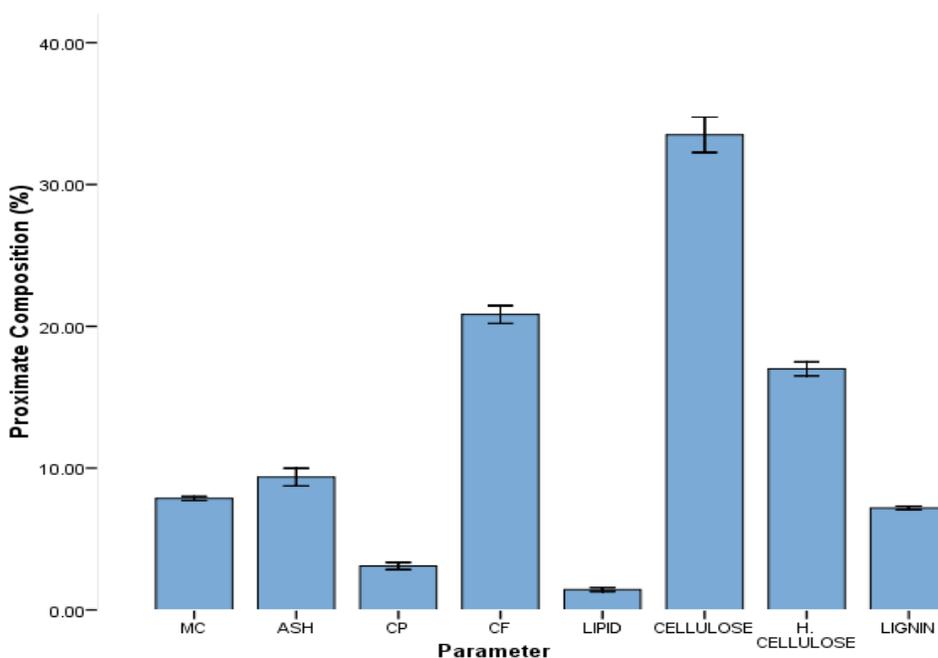


Fig. 1. Proximate composition of rice straw before pretreatment (%)
Key; MC=Moisture content, CP=Crude protein, CF= Crude fibre

Table 2. Mineral composition rice straw

Parameter	Rice straw
Na	2.30 ± 0.40 ^b
K	17.96 ± 0.15 ^c
P	0.90 ± 0.03 ^c
Ca	3.02 ± 0.07 ^c
C	48.90 ± 0.05 ^d
Mg	1.87 ± 0.03 ^b
N	0.80 ± 0.01 ^a
C:N Ratio	61.12 ± 0.11 ^e

Key: Na=sodium, K= potassium, P=phosphorous, Ca=calcium, C=carbon Mg=magnesium, N=nitrogen
Data are represented as mean ± standard deviation, n=3 with the same superscript across the column are not significantly different (p<0.05)

Table 3 shows the effect of pretreatment on the cellulose, hemicellulose and lignin components of rice straw. There was a relatively high increase in cellulose from 33.50% to 51.30%. It was also observed that hemi-cellulose decreased from 17.00% to 10.67%. Similar decrease is shown for lignin content as well, with a decrease from 7.19% to 5.68%.

The reducing sugar produced after five days of hydrolysis using *T. viride* and *B. subtilis* is giving in Fig. 2. *T. viride* showed the higher reducing sugar yield of 26.60 g/100 g. *B. subtilis* on the other hand gave relatively lower yield of 12.21 g/100 g.

The changes in pH during fermentation rice straw using *T. viride* and *S. cerevisiae* and *B. subtilis*

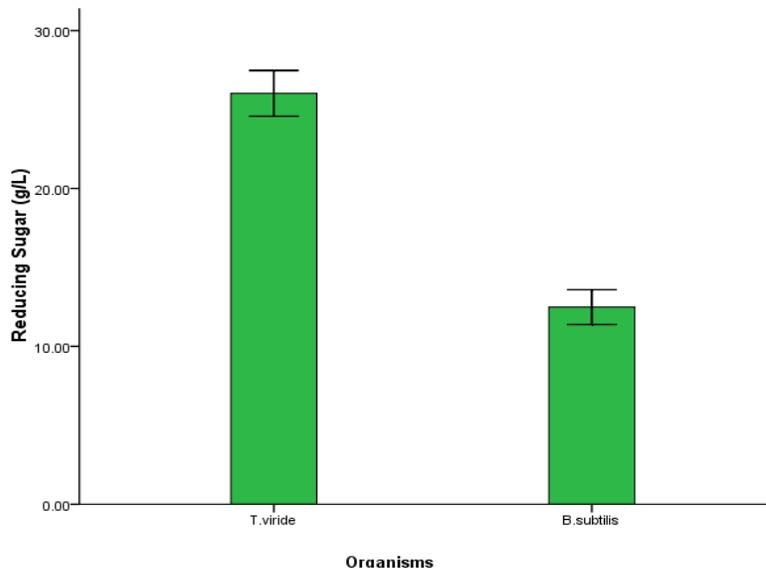
and *S. cerevisiae* is shown in Fig. 3. A general decrease in the pH was observed from the initial standardized pH of 5.5 as fermentation proceeded. Fermentation showed a decrease, with a final pH of 3.8 after 7 days when using *T. viride* and *S. cerevisiae*, while a final pH of 4.5 after 7 days was observed using *B. subtilis* and *S. cerevisiae*.

The total titratable acidity during fermentation of rice straw using *T. viride* and *S. cerevisiae* and *B. subtilis* and *S. cerevisiae* is shown in Fig. 4. An increase in the TTA was observed from the initial TTA as fermentation proceeded. Result showed an increase in TTA, from an initial TTA of 0.06% to 0.15% after 7 days when using *T. viride* and *S. cerevisiae*, while a relatively high increase in TTA, from an initial TTA of 0.09% to 1.66% after 7 days was observed while using *B. subtilis* and *S. cerevisiae*.

Table 3. Effect of acid pretreatment on the cellulose, hemi-cellulose and lignin components of rice straw

Parameter	Before pretreatment	After pretreatment
Cellulose	33.50 ± 0.17 ^a	51.33 ± 0.17 ^a
Hemi-cellulose	17.00 ± 0.17 ^a	10.67 ± 0.17 ^a
Lignin	7.19 ± 0.17 ^a	5.68 ± 0.17 ^a

Data are represented as mean ± standard deviation, n=3 with the same superscript down the row are not significantly different (p<0.05)

**Fig. 2. Reducing sugar produced by rice straw after 5 days hydrolysis using *Trichoderma viride* and *Bacillus subtilis* as hydrolyzing agents**

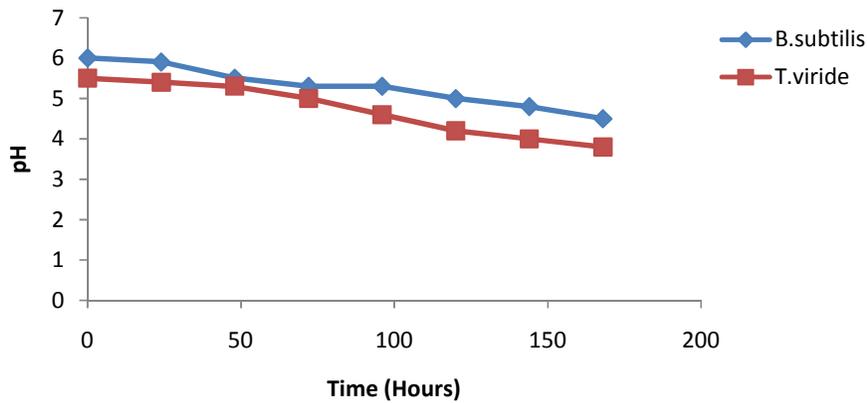


Fig. 3. pH of rice straw during fermentation using *T. viride* and *S. cerevisiae* and *B. subtilis* and *S. cerevisiae*

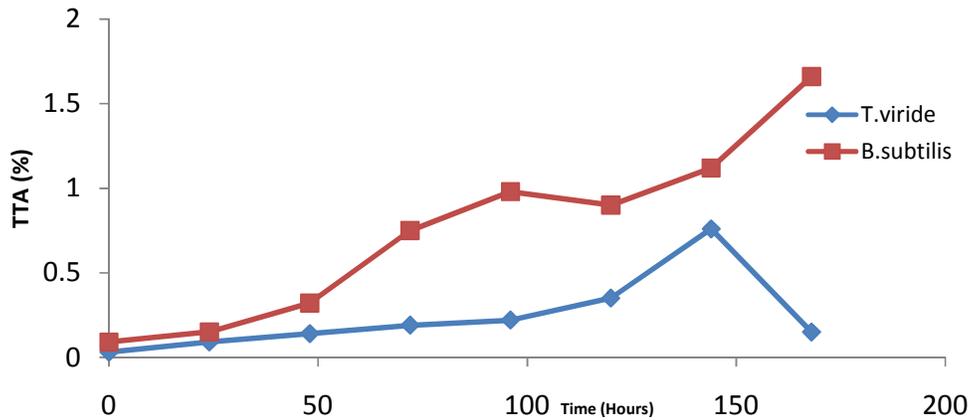


Fig. 4. Total titratable acidity (%) of rice straw during fermentation using *T. viride* and *S. cerevisiae* and *B. subtilis* and *S. cerevisiae*

Fig. 5 shows the ethanol yield of the rice straw during seven days fermentation using *T. viride* and *S. cerevisiae* and *B. subtilis* and *S. cerevisiae*. The ethanol yield was observed to increase as the fermentation proceeded. The combination of *T. viride* and *S. cerevisiae* had an initial yield of 1.92 g/100 g while *B. subtilis* and *S. cerevisiae* had an initial yield of 1.90 g/100 g after 24 hours. However after 7 days of fermentation, *T. viride* and *S. cerevisiae* showed a final yield of 16.21 g/100 g while *B. subtilis* and *S. cerevisiae* showed a final yield of 7.59 g/100 g.

The percentage (v/v) of final ethanol produced by rice straw using *T. viride* and *S. cerevisiae* and *B. subtilis* and *S. cerevisiae* is given in Fig. 6. The highest percentage of 2.08% was given by the combination of *T. viride* and *S. cerevisiae*,

while *B. subtilis* and *S. cerevisiae* gave a final volume of 0.96%.

Table 4 reveals the result of comparative analysis of the bioethanol produce from rice straw and the conventional ethanol commercially available. Both the ethanol produced and commercial ethanol appeared colourless, burns with blue flame and have refractive index of 1.36. Other properties of the bioethanol produced from rice straw and commercial ethanol such as relative density (0.77g/cm³, 0.75 g/cm³ and 0.789 g/cm³ respectively), boiling point (-112°C, -113°C and -114°C respectively), melting point(78.5°C, 78.5°C and 78.37°C respectively), viscosity (0.0119, 0.0122 and 0.0012 respectively) and flash point(11°C, 12°C, and 13-14°C respectively) showed little discrepancies.

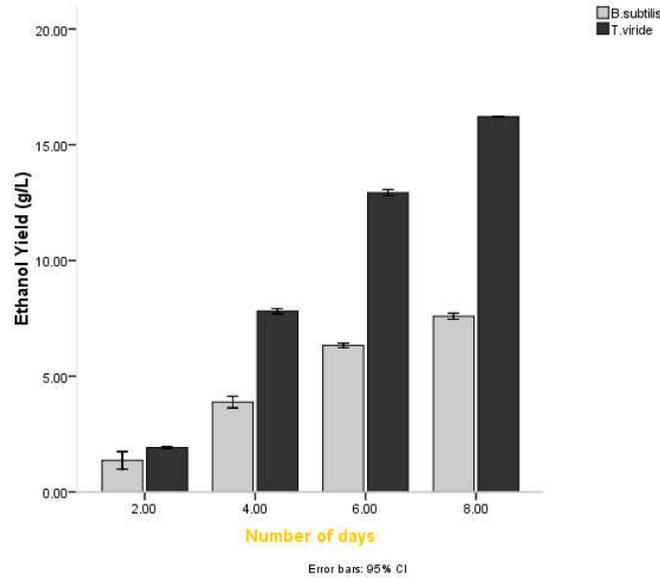


Fig. 5. Ethanol yield from rice straw using *T. viride* and *S. cerevisiae* and *B. subtilis* and *S. cerevisiae*

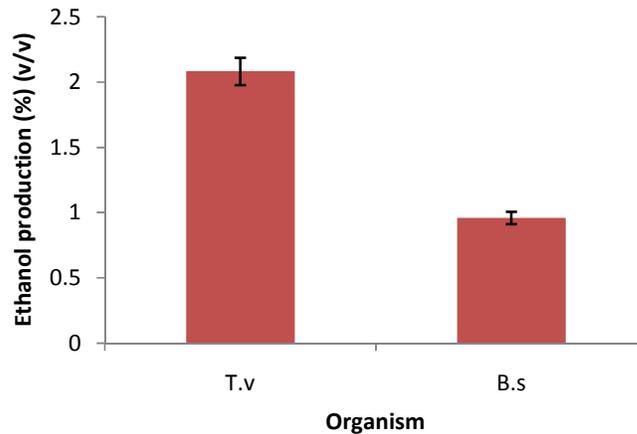


Fig. 6. Percentage (v/v) ethanol produced rice straw using *T. viride* and *S. cerevisiae* and *B. subtilis* and *S. cerevisiae*

Key: T.v= *Trichoderma viride*, B.s= *Bacillus subtilis*

Table 4. Comparative analysis of commercial ethanol and bioethanol produced from rice straw

Ethanol properties	Bioethanol from Rice straw using <i>T. viride</i> and <i>S. cerevisiae</i>	Bioethanol from Rice straw using <i>B. subtilis</i> and <i>S. cerevisiae</i>	Commercial Ethanol
Appearance	Colourless	Colourless	Colourless
Relative density	0.77g/cm ³	0.75g/cm ³	0.789g/cm ³
Melting point	-112°C	-113°C	-114°C
Boiling point	78.5°C	78.5°C	78.37°C
Viscosity	0.0119	0.0122	0.0012 pa s at 20°C
Burning characteristics	Burns with blue flame	Burns with blue flame	Burns with blue flame
Refractive index	1.36	1.36	1.36
Flash point	11°C	12°C	13-14°C

4. DISCUSSION

The screening for the production of cellulase (Table 1) showed that the two organisms screened, tested positive for cellulase activity with zones of inhibition ranging from 0.5cm to 1.8 cm. Zones of clearance ranging from 0.4 cm to 2.9 cm by *Aspergillus sp.*, using same method had earlier been reported, indicating that the zone of clearance was a direct result of the amount of cellulase enzyme produced by the organism. Both *Bacillus subtilis*, and *Trichoderma viride* showed high cellulase activity of 1.5 cm and 1.8 cm respectively. This was supported by the work of [16,17], which demonstrated cellulase activity in similar organisms. [18] also reported *T. viride* isolated from rice straw having a relatively high cellulase activity.

The proximate analysis of Rice straw (Fig 1), Showed the cellulose and lignin content of rice straw was 33.5% and 7.18% respectively which was relatively high, this was somewhat lower than 40.8% and 7.8% obtained by [19], and this is probable the result of varying environmental, soil and growth conditions in which the plant were obtained. Moisture content of 7.86% was recorded, [20] reported a range of moisture content of 8.5 – 9.1% (dm) as well as [21]. The results from the proximate analysis shows that the digestibility of rice straw is hindered by many physicochemical, structural, and compositional factors which require a suitable pretreatment in order to enhance the susceptibility of biomass for hydrolysis.

The mineral analysis (Table 2) showed a relative variation in composition. Rice straw had a relatively high level of Potassium (17.96 mg/g) which was considerably higher than 16.79 reported by [22]. Nitrogen content was found to be relatively low.

The result for the acid pretreatment of Rice Straw was highly effective especially after the application of NaOH (Table 3). The result showed a drastic increase in the cellulose composition of rice straw and a subsequent decrease in the hemicellulose and lignin content. This is due to the fact that the first treatment with sulfuric acid solubilized the hemi cellulosic fraction and increased the diffusion of sodium hydroxide into the lignocellulosic structure, thus enhancing soda pulping and liberating the cellulose fibers from lignin thereby causing the washing away of hemicellulose and lignin during

filtration hence obtaining a solid residue with high cellulose content [23,24]. The results obtained are in agreement with the finding of [25], who reported similar increase and decrease in the cellulose, hemi-cellulose and lignin contents of acid pretreated BSG, and in contrast to that of [26] who reported a decrease in all three components, probably due to simultaneous pretreatment and hydrolysis. The high cellulose content and decreased hemicellulose and lignin contents would allow for the enhancement of microbial saccharification [27].

The reducing sugar yield obtained after three days hydrolysis of pretreated substrate with *T. viride* and *B. subtilis* (Fig.2) showed that of *T. viride* relatively higher than *B. subtilis*. This was in agreement with [18], who showed a great difference between the cellulase activity of *Trichoderma sp.* and *Bacillus sp.* this can be attributed to the ability of *Trichoderma sp.* to produce all components of cellulase complex, endocellulase, exocellulase, and β -glucosidase in good proportions as well as production of other enzymes such as xylanases or laccases in comparison to other enzyme producers [28]. Rice straw had high reducing sugar yield of 26.6 g using *T. viride* and 13.21 g using *B. subtilis*.

There was significant decrease in the pH of the fermenting medium (Fig. 3), this is due to the release of various organic acids from the utilization of the substrates [29]. The medium gave a final pH of 3.8 using *T. viride*, 4.5 using *B. subtilis* and this could be the result of high nutrient composition of rice straw which favoured the growth of the organisms and hence the production of metabolites. The result of the total titratable acidity (Fig 4) showed a general increase in the TTA, this can however be attributed to the utilization of free sugars by yeast and lactobacillus [30].

The fermentation of the substrate using *Saccharomyces cerevisiae* (Fig. 5) showed that the yield of ethanol is proportional to fermentation time where the yield increases with increase in time, this was due to the continuous utilization of the sugar by yeast, and this is in agreement with [31]. It was also revealed that the combination of *T. viride* and *S. cerevisiae* gave considerably higher ethanol yield, 100g of rice straw for instance gave an ethanol yield of 16.21g using *T. viride* and *S. cerevisiae* and 7.59g using *B. subtilis* and *S. cereviceae*. This was due to the efficiency of the organism during the hydrolysis stage, this was however lower

than 17.31 reported by [32], and higher than 15 g/l by [31] and 11g/l by [18], who stated that the ethanol yield of the substrate is directly proportional to its cellulose content.

The percentage yield which was in direct relation to the initial yield observed (Fig. 6), Rice straw having a percentage of 2.96 with *T. viride* and 0.08 with *B. subtilis*. Ethanol generated from acid pretreated rice straw compared favorably to commercially available ethanol and was found to poses similar properties. From the findings it can be said that Rice straw is a relatively efficient substrate for ethanol production and acid being an effective pretreatment method.

5. CONCLUSION

This study established the efficacy of Rice straw for bioethanol production, as well as the efficiency of selected microorganisms in the production process. The results therefore confirmed the use of acid as an important means of pre-treating lignocellulosic biomers, giving a high increase in cellulose generated for fermentation.

The proximate analysis showed rice straw to have high cellulose content, mineral content equally showed rice straw to be rich in mineral content, hence making it nutritious for microorganisms. However, *Trichodema viride* was found to be more effective in cellulose hydrolysis than *Bacillus subtilis*, thereby generated higher reducing sugar yield. Furthermore Rice straw was found to be an efficient substrate for bioethanol production with a maximum ethanol yield of 16.21 g and a percentage yield of 2.08.

6. RECOMMENDATION

This research has successfully shown Rice straw to be an effective substrate for bioethanol production via the cellulose utilization pathway and can thus be employed as an alternative source for biofuel production, which would pose no environmental and food security problem. There is therefore the need for further research to improve the productivity and quality of ethanol generated from this substrate. Furthermore, more research should be carried out to improve the cellulose hydrolyzing ability of promising microorganisms in a bid to enhance the bioethanol yield from cellulolytic biomers. Finally more attention should equally be given to the pretreatment method of Rice straw in other to

improve its efficiency as well as produce alternative chemical-free methods in other to rid the environments of these toxic chemicals currently employed.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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