

TITLE: PRODUCTION OF BIOETHANOL USING COMMON AND RARE YAM SPECIES

V.C. Onwujiogu*; E. Dinneya-Onuoha

Department of Pure and Industrial Chemistry, University of Nigeria, Nsukka, Enugu State, Nigeria.

ABSTRACT

This study investigates the production of bioethanol from three different yam species: *Dioscorea Cayenensis*, *Dioscorea Bulbifera*, and *Dioscorea Rotundata*, using hydrolysis, fermentation, and distillation processes. Yams are chosen due to their high starch content, making them a viable substrate for bioethanol production. The process involved preparing phosphate buffers, enzymatic hydrolysis to break down starch into fermentable sugars, followed by fermentation using *Saccharomyces cerevisiae*, and distillation to extract ethanol. The ethanol yields were found to be 13.06% for *Dioscorea Rotundata*, 15.92% for *Dioscorea Cayenensis*, and 15.51% for *Dioscorea Bulbifera*. Recent research corroborates the potential of using yam and other tubers for bioethanol production, pointing out their efficiency and sustainability as alternative energy sources. This research study contributes to the growing body of knowledge on bioethanol production from non-traditional sources, emphasizing the role of local varieties in enhancing biofuel yields. The findings indicate that underutilized yam species can provide significant ethanol yields, offering a sustainable solution to energy needs and reducing dependence on fossil fuels.

KEYWORDS: Bioethanol, yam species, distillation, hydrolysis, fermentation, sustainable energy.

INTRODUCTION

Bioethanol is a form of renewable energy derived from biological sources [1]. The demand for sustainable energy solutions and the depletion of fossil fuel sources have drawn attention to bioethanol as an alternative energy source on a worldwide scale [2]. A popular process for producing bioethanol is the conversion of carbon-based feedstock [3]. As long as all of the minerals needed for growth—like phosphorus and nitrogen—are returned to the soil, agricultural feedstocks are regarded as renewables as they employ photosynthesis to obtain energy from the sun [4]. Sugar cane, cassava, bagasse, miscanthus, sugar beet, sorghum, barley, switch grass, hemp,

kenaf, potatoes, molasses, corn, wheat, cotton, artichoke, and other biomass, as well as various cellulose wastes, can all be used to make ethanol (C_2H_5OH) [5]. Bioethanol has a significant history in Nigeria, marked by a number of policy initiatives and economic investments [6]. Recent studies show that in the next forty (40) years or less, Nigeria's crude oil will be exhausted. With this, there is the need to cushion the effect of the coming development and cut down her over dependence on crude oil for energy [7]. In 2007, the Nigerian government recognized the potential of bioethanol as a sustainable energy source and introduced the Nigerian Biofuel Policy [8]. This

policy aimed to promote the local production of bioethanol to meet the national demand of 5.14 billion liters per annum. The policy was a significant step towards reducing Nigeria's dependence on imported fossil fuels and addressing concerns about energy security [8].

In response to the biofuel policy, investors have put in over \$3.86 billion for the construction of nineteen (19) ethanol bio-refineries, feedstock plantations, and 10,000 units of mini-refineries. These investments are expected to produce over 2.66 billion liters of fuel-grade ethanol annually. The potential benefits of emerging bioethanol projects include economic investment, energy security, improved rural infrastructure and employment opportunity [9].

Nigeria is the world's largest producer of yams, producing 61,171 kilotonnes (kt) in 2022, which accounts for 69.3% of the world's yam production [10].

According to Ajiboye et al. [11], there are about half a dozen species of yams being cultivated in Nigeria which includes: White Yam (*Dioscorea rotundata*): This is the most widely cultivated species in Nigeria, Yellow Yam (*Dioscorea cayenensis*) known for its distinctive yellow flesh, Aerial Yam (*Dioscorea bulbifera*) which is a less common variety, Water Yam (*Dioscorea alata*), etc. Yams, particularly local varieties, offer a promising feedstock for bioethanol production due to their high starch content [12]. The percentage ethanol yield from local yams from West Africa Nigeria is high compared to the

yield of batch production of other feedstock [13]. Malaysia's percentage yield of bioethanol was estimated to be approximately 14% for batch production [14].

In a recent study conducted by Villadiego-del Villar et al. [15], the use of Simultaneous Saccharification and Fermentation (SSF) for bioethanol production from *Dioscorea rotundata* (white yam) using the yeast *Saccharomyces bayanus* was assessed.

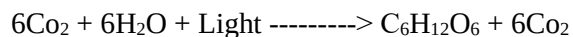
Based on the theoretical amount of starch present in the tuber, the hydrolysis yield was computed, and samples with yam concentrations of 10% and 15% w/w had a yield of 90%. The sample with the highest ethanol productivity, 0.19 g/Lh, had a 10% w/w yam concentration. The chemical characteristics and ethanol fermentation of several *Dioscorea* species, such as *Dioscorea alata*, *Dioscorea esculenta*, and *Dioscorea hispida*, were the main topics of a related study by Papraneecharoen and Singphan [16].

The study reported obtaining 65.95 g/L, 64.17 g/L, and 59.19 g/L of TRS from *Dioscorea alata*, *Dioscorea esculenta*, and *Dioscorea hispida*, respectively, after enzymatic starch digestion using 0.1% w/w of α -amylase. Another study also examined the generation of bioethanol from the non-cultivated, non-food waste material *Dioscorea bulbifera*. According to the study, *Dioscorea bulbifera* peels produced 251 L/ton of ethanol while *Dioscorea bulbifera* starch produced 425 L/ton. Significant ethanol yields are shown by the results, especially from

Dioscorea bulbifera, which starch gives a high yield of 425 [17]. This research explores the potential of converting yam starch into ethanol using optimized methodologies. Ethanol fuel is commonly used to power automobiles, and is most helpful in producing environmentally friendly engines [18]. Ethanol is capable of supporting the engine of farm tractors but it is most feasible to use in car engines only. In addition to improving engine efficiency, ethanol fuel is inexpensive. Only ethanol-friendly engines are capable of achieving this efficiency [19]. Ethanol (E100) uses 51% more fuel than gasoline in a typical engine. Additionally, ethanol can be used as rocket fuel [20]. An engine's compression ratio can be raised for greater thermal efficiency due to ethanol's higher octane rating [21]. In a study by Wooldridge et al. [22], a compression ratio of 19.5 with fuels ranging from plain ethanol to E50 was made possible by sophisticated engine management and enhanced exhaust gas recirculation. Thermal efficiency was attained up to about diesel levels. As a result, a clean ethanol vehicle would have roughly the same fuel efficiency as one that runs on gasoline.

Chemistry Of Ethanol

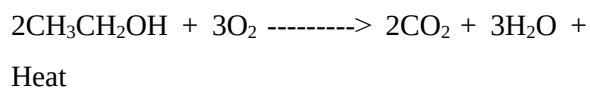
Glucose is created in the plant by photosynthesis.



During ethanol fermentation, glucose is decomposed into ethanol and carbon dioxide.

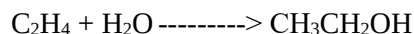


During combustion, ethanol reacts with oxygen to produce carbon dioxide, water and heat.



After doubling the combustion reaction and adding all three reactions together, there are equal numbers of each glucose molecule, and when all three reactions are added together, there are equal numbers of each type of atom on each side of the equation, and the net reaction for the overall production and consumption of ethanol is simply: Light $\longrightarrow$ Heat. By expanding hot air, the engine's piston is propelled by the heat generated during the combustion of ethanol. Since sunlight is the only source of energy that the planet receives, it can be claimed that sunlight powers the engine [23, 24]. This is also true of renewable energy sources.

Ethanol can also be produced in the laboratory from ethane. The addition of water to the double bond converts ethane to ethanol. This is carried out in the presence of an acid which catalyzes the reaction, but is not consumed in the reaction [25].



Dioscorea Bulbifera, Rotundata, And Cayenensis.

Dioscorea Bulbifera also known as air potato is native to Africa and Asia. The perennial vine *Dioscorea bulbifera* has two different kinds of storage organs and large leaves. The plant produces tubers below ground and bulbils in the leaf axis of the twining stems. These tubers resemble tiny oblong potatoes [26]. *Dioscorea*

Rotundata, also known as a group of cultivated Dioscorea yams of African origin belonging to the botanical section Enantiophyllum Uline, has a short annual vegetative cycle of 6-8 months, a tuber with a long dormancy period of 3-5 months, and a slightly or non-pigmented creamy or white flesh [27]. Dioscorea cayenensis, commonly known as Yellow Yam or Yellow Guinea Yam, is a significant species of yam cultivated primarily in West Africa. It is a spiny vine that can grow between 10 to 12 meters long. The leaves are pale green and heart-shaped, contributing to the plant's unique appearance. The roots have a rough outer layer and pale yellow flesh. A single root can weigh up to 3 kilograms. The plant can grow in soils with a pH range of 5.3 to 8, with an optimal range of 6 to 6.7 [28].

Advantages Of Bioethanol

Ethanol is a source of renewable energy and has the capacity to be available in the future. Ethanol and other renewable energy sources are highly sought after in the current environment. Ethanol output rises in tandem with demand [29]. When compared to fossil fuels, ethanol is more affordable [30]. The primary benefit of using bioethanol fuel is that it doesn't contribute to air

pollution. According to life cycle analysis, the process of producing bioethanol is the primary factor in reducing greenhouse gas emissions outside of agriculture. Since the globe is on the verge of catastrophe, the ozone layer's depletion has been a worldwide concern [31].

Criticism

The development and use of biofuel raise a number of social, economic, environmental, and technical concerns. Moderating oil prices, the "food vs. fuel" argument, poverty alleviation possibilities, carbon emission levels, sustainable biofuel production, biodiversity loss, soil erosion and deforestation, water resource impacts, energy balance and efficiency, and more are some of these [32].

While second generation biofuels are made from lignocellulosic biomass, woody crops, agricultural residues, or waste that makes it difficult to extract the necessary fuel, first generation biofuels are made from sugars and vegetable oils found in arable crops that are easily extracted using traditional methods or technology [33, 34]. This research is a first-generation biofuel.



i) Dioscorea Cayenensis (Live sample picture)

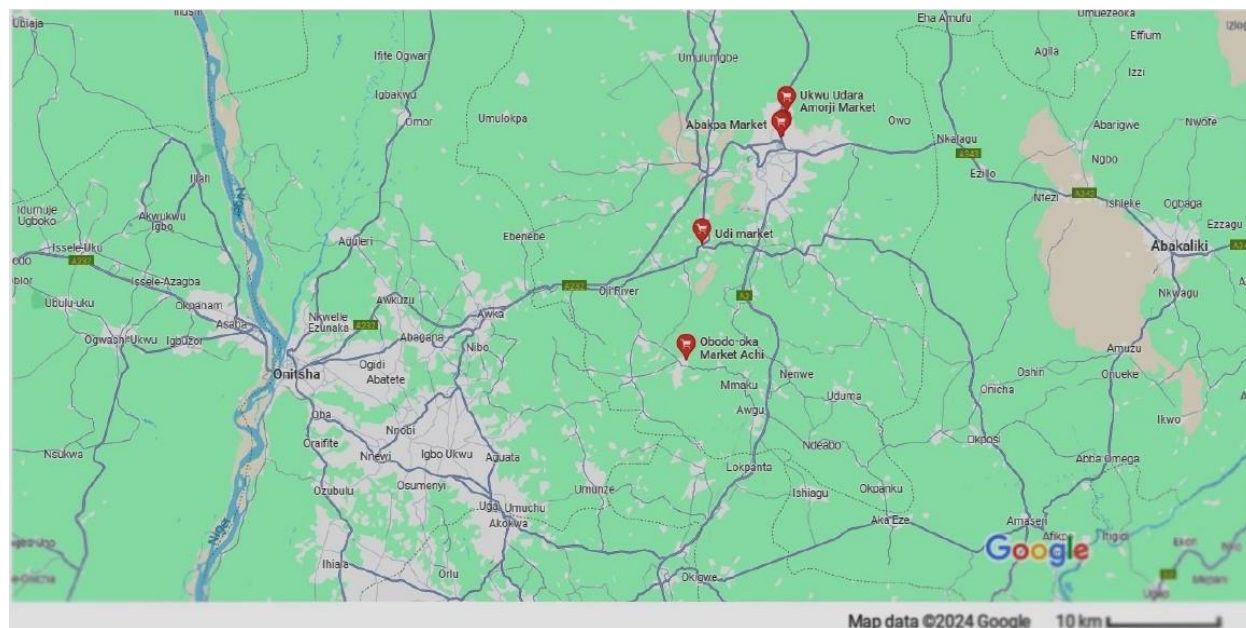


ii) Dioscorea Rotundata (Live sample picture)



iii) Dioscorea Bulbifera (Live sample picture)

MAP OF ENUGU STATE SHOWING SAMPLING AREA



MATERIALS AND METHODS

Three yam species were sourced from different locations in Enugu State, Nigeria: *Dioscorea Bulbifera* from Achi in Oji River Local Government, *Dioscorea Rotundata* from Abakpa Market in Enugu East Local Government, and *Dioscorea Cayenensis* from Udi in Udi Local Government. The yam samples were peeled, washed, grated, sun-dried, and milled into powder. The experimental procedure was conducted in four stages:

Preparation of Phosphate Buffer:

Sodium hydrogen tetraoxophosphate (Na_2HPO_4) solution (1.77 g in 250 ml distilled water) and sodium dihydrogen tetraoxophosphate (Na_2HPO_4) solution (1.50 g in 250 ml water) were prepared and adjusted to 0.05 M at pH 6.5. The

solutions were stored in the refrigerator at 4°C. Phosphate buffer (0.05 M, pH 6.5) was prepared by mixing 30.45 ml of NaH_2PO_4 and 69.55 ml of Na_2HPO_4 .

Hydrolysis - Optimum Condition of Hydrolysis:

10 g of enzyme powder (alpha and beta amylase) was dissolved in 200 ml phosphate buffer and centrifuged at 4250 rpm for 3 minutes. The supernatant was collected to obtain a 10 g/100 ml enzyme solution. 40 g of yam powder was dissolved in 800 ml phosphate buffer. 100 ml of enzyme solution was mixed with 400 ml yam solution in a 500 ml volumetric flask and incubated at 60°C for 30 minutes, followed by 30°C for 60 minutes.

Fermentation Process - Preparation of Inoculum:

50 g of glucose powder was dissolved in 500 ml distilled water, and 4.001 g of urea was added and boiled. After cooling to ambient temperature, 10 g of yeast (*Saccharomyces cerevisiae*) and 5 g of cellulose were added. The inoculum was incubated for 24 hours with an aerator.

The inoculum was added to the hydrolyzed yam solution and fermented at 37°C for 5-6 days.

Distillation:

The fermented solution was distilled at 78°C for one hour using an alcohol distillation apparatus. The distillate was subjected to ethanol testing.

Tests:

The distillate was subjected to ethanol test. Ethanol reacts to form a yellow solid, triiodomethane when treated with iodine solution and sodium hydroxide solution. 10 drops of the distillate was measured in a test tube and 25 drops of iodine solution was added to it using a pipette. 10 drops of sodium hydroxide solution was equally added. When the test tube was gently swirled, the dark color of the iodine started to fade. The mixture in the test tube became cloudy with a yellow precipitate of triiodomethane (iodoform) and a distinct antiseptic smell. The specific gravity of ethanol was also calculated using a 50 ml specific gravity bottle and an electronic weighing balance. The formula is given as $\frac{W_3 - W_1}{W_2 - W_1}$ where w_1 is the weight of empty

specific gravity bottle, W_2 is the weight of empty specific gravity bottle and water and W_3 is the weight of specific gravity bottle plus distillate.

RESULTS AND DISCUSSION

The percentage volume of ethanol yield was determined using the AOAC's official method of analysis (1990), in relation to apparent specific gravity at various temperatures [35]. The yam species *Dioscorea Rotundata*, *Dioscorea Cayenensis*, and *Dioscorea Bulbifera* yielded 113 mls, 135 mls and 147 mls respectively as the volume of distillate after one hour of distillation. This goes to show that *Dioscorea Bulbifera* gave the highest yield volume of distillate at a temperature of 30 °C, followed closely by *Dioscorea Cayenensis* at temperature 30 °C and lastly *Dioscorea Rotundata* at 32 °C. The higher the quantity of ethanol in the distillate, the lower the temperature of the solution as ethanol is a colder liquid when compared to water [36]. The specific gravity of the species *Dioscorea Rotundata*, *Dioscorea Cayenensis* and *Dioscorea Bulbifera* were 0.9820, 0.9786 and 0.9791 respectively. This shows that *Dioscorea Rotundata* is more hydrous than the other two species. This variation in specific gravity contributed greatly to the variation in the volume of ethanol yield. The hydration of ethanol is due to high miscibility of water and ethanol as both are polar solvents. Their miscibility results in an

azotrope solution, which cannot be separated by distillation.

SAMPLE	DISTILLATE (MLS)	SPECIFIC GRAVITY	TEMPERATURE (°C)	% OF ETHANOL
D. Rotundata (40 g)	113	0.9820	32	13.06%
D. Cayenensis (40 g)	135	0.9786	30	15.92%
D. Bulbifera (40 g)	147	0.9791	30	15.51%

ETHANOL YIELD FROM SOME STARCHY CROPS IN LITERATURE

Species	% Ethanol Yield	Method Used	Reference
<i>Dioscorea alata</i>	50.42%	Enzymatic hydrolysis & fermentation	[37]
<i>Cassava peel</i>	17.38%	Acid hydrolysis & fermentation	[38]
<i>Sweet Potato</i>	3.35%	Acid hydrolysis & yeast fermentation	[39]
<i>D. Rotundata</i>	13.06%	Enzyme + yeast	Present Study
<i>D. Cayenensis</i>	15.92%	Enzyme + yeast	Present Study
<i>D. Bulbifera</i>	15.51%	Enzyme + yeast	Present Study

CONCLUSION

This research study highlights the potential of yam species, specifically *Dioscorea Cayenensis*, *Dioscorea Bulbifera*, and *Dioscorea Rotundata*, as viable substrates for bioethanol production. The findings reveal significant ethanol yields from these underutilized crops, with *Dioscorea Cayenensis* achieving the highest yield at 15.92%, followed by *Dioscorea Bulbifera* at 15.51%, and *Dioscorea Rotundata* at 13.06%. These results underline the efficiency and sustainability of using high-starch-content yams for bioethanol production, which contributes to the diversification of biofuel feedstock sources.

The study's methodology involving enzymatic hydrolysis, fermentation with *Saccharomyces cerevisiae*, and subsequent distillation, proves effective in converting yam starch into fermentable sugars and extracting ethanol.

In the context of Nigeria's energy sector, where reliance on fossil fuels is prevalent, the successful utilization of yam species for bioethanol production presents a promising alternative. This matches the Nigerian Biofuel Policy's objectives, aiming to enhance energy security, reduce environmental impact, and foster economic growth through sustainable practices.

REFERENCES

- Kupczyk, A., Mączyńska-Sęczek, J., Golisz, E., & Borowski, P. F. (2020). Renewable energy sources in transport on the example of methyl esters and bioethanol. *Processes*, 8(12), 1610.
- Sivakumar, G., Vail, D. R., Xu, J., Burner, D. M., Lay, J. O., Ge, X., & Weathers, P. J. (2010). Bioethanol and biodiesel: Alternative liquid fuels for future generations. *Engineering in Life Sciences*, 10(1), 8-18.

3. Toor, M., Kumar, S. S., Malyan, S. K., Bishnoi, N. R., Mathimani, T., Rajendran, K., & Pugazhendhi, A. (2020). An overview on bioethanol production from lignocellulosic feedstocks. *Chemosphere*, 242, 125080.
4. Leger, D., Matassa, S., Noor, E., Shepon, A., Milo, R., & Bar-Even, A. (2021). Photovoltaic-driven microbial protein production can use land and sunlight more efficiently than conventional crops. *Proceedings of the National Academy of Sciences*, 118(26), e2015025118.
5. Aasim, M., Baloch, F. S., Nadeem, M. A., Habyarimana, E., Ahmed, S., & Chung, G. (Eds.). (2023). *Biotechnology and Omics Approaches for Bioenergy Crops*. Springer Nature.
6. Adewuyi, A. (2020). Challenges and prospects of renewable energy in Nigeria: A case of bioethanol and biodiesel production. *Energy Reports*, 6, 77-88.
7. Ishaka, D. (2017). Over-Dependence on Oil and its Implication for Development in Nigeria. 2. 25-33.
8. Nwozor, A., Owofe, G., Olowojolu, O., Ake, M., Adedire, S., & Ogundele, O. (2021, February). Nigeria's quest for alternative clean energy through biofuels: an assessment. In *IOP Conference Series: Earth and Environmental Science* (Vol. 655, No. 1, p. 012054). IOP Publishing.
9. Kulyal, L., & Jalal, P. (2022). Bioenergy, a finer alternative for India: Scope, barriers, socio-economic benefits and identified solution. *Bioresource Technology Reports*, 17, 100947.
10. Faostat, (2023). Which Country Produces the Most Yam? HelgiLibrary. <https://www.helgilibrary.com/charts/which-country-produces-the-most-yam/>
11. Ajiboye, T. O., Edagbo, D. E., Alowonle, A., Michael, C., Oyewole, F., Adegboye, S., ... & Olaniyan, A. O. (2021). Current Status of Yam (*Dioscorea* Sp) Genetic Resources-Case Study of Selected Locations in South-West Nigeria. *Sumerianz Journal of Agriculture and Veterinary*, 4(1), 7-12.
12. Jagatee, S.B., Shuvashish D, Preeti, S., Santi & M.R. (2015). Bioprospecting Starchy Feedstocks for Bioethanol Production: A Future Perspective. *Journal of Microbiology Research and Reviews*. 3. 24-42.
13. Awoyale, A. A., & Lokhat, D. (2019). Harnessing the potential of bio-ethanol production from lignocellulosic biomass in Nigeria—a review. *Biofuels, Bioproducts and Biorefining*, 13(1), 192-207.
14. Chin, K. L., & H'ng, P. S. (2013). A real story of bioethanol from biomass: Malaysia perspective. *Biomass now-sustainable growth and use*, 329-346.
15. Villadiego-del Villar, A. E., Sarmiento-Zea, N., León-Pulido, J., & Rojas-Pérez, L. C. (2021). Bioethanol production from yam (*Dioscorea Rotundata*) Using simultaneous saccharification and fermentation (SSF). *Tecnológicas*, 24(50), 116-125.
16. Papraneecharoen, S., & Singphan, N. (2019). Chemical properties and ethanol fermentation from *Dioscorea* sp. *PRRJ*, 14(1), 105-116.
17. Agu, R. C., Walker, J. W., Okolo, B. N., Moneke, A. N., Amadi, O. C., & Eze, C. N. (2014). Bio-ethanol production from *Dioscorea Bulbifera* tuber (local name: "Adugebe")-A renewable non-cultivated, non-food, waste material in Nigeria. *The Journal of Solid Waste Technology and Management*, 40(2), 152-159.
18. Sakthivel, P., Subramanian, K. A., & Mathai, R. (2018). Indian scenario of ethanol fuel and its utilization in automotive transportation sector. *Resources, Conservation and Recycling*, 132, 102-120.
19. Deshpande, Poonawala, N., & Nagarkar, M. (2021). AN OVERVIEW ON ETHANOL USE IN IC ENGINE AS ALTERNATIVE FUEL.
20. Iodice, P., Senatore, A., Langella, G., & Amoresano, A. (2017). Advantages of ethanol-gasoline blends as fuel substitute for last generation Si engines. *Environmental Progress & Sustainable Energy*. 36. 10.1002/ep.12545.
21. Leone, T. G., Anderson, J. E., Davis, R. S., Iqbal, A., Reese, R. A., Shelby, M. H., &

- Studzinski, W. M. (2015). The effect of compression ratio, fuel octane rating, and ethanol content on spark-ignition engine efficiency. *Environmental science & technology*, 49(18), 10778-10789.
22. Wooldridge, M., Boehman, A., Lavoie, G., Middleton, R., & Fatouraie, M. (2017). *Utilizing Alternative Fuel Ignition Properties to Improve SI and CI Engine Efficiency* (No. DOE-UMICH-6831). Univ. of Michigan, Ann Arbor, MI (United States).
23. Chierogato, A., Velasquez Ochoa, J., Bandinelli, C., Fornasari, G., Cavani, F., & Mella, M. (2015). On the chemistry of ethanol on basic oxides: revising mechanisms and intermediates in the Lebedev and Guerbet reactions. *ChemSusChem*, 8(2), 377-388.
24. Zhang, Y., El-Merhubi, H., Lefort, B., Le Moyne, L., Curran, H. J., & Kéromnès, A. (2018). Probing the low-temperature chemistry of ethanol via the addition of dimethyl ether. *Combustion and Flame*, 190, 74-86.
25. Sun, J., & Wang, Y. (2014). Recent advances in catalytic conversion of ethanol to chemicals. *ACS catalysis*, 4(4), 1078-1090.
26. Sam, S. M., & Wahua, C. (2022). Phytochemical and micro anatomical studies on leaf, stem and petiole of two species of Dioscorea (*Dioscorea alata* L. And *Dioscorea bulbifera* L.). *Journal of Applied Sciences and Environmental Management*, 26(3), 467-474.
27. Paterne, E., Affokpon, A., Loko, L., Agbangla, C., & Dansi, A. (2019). Yam (*Dioscorea rotundata* Poir and *D. cayenensis* Lam complex) in the Traditional Agriculture of Benin: Present-Day Cultivar Diversity and Farmers' Perception on their Tolerance to Tuber Dry Rot caused by the Nematode *Scutellonema bradys*. *International Journal of Current Microbiology and Applied Sciences*. 8. 1119-1138. 10.20546/ijcmas.2019.802.131.
28. Chaudhary, S., Singh, S., & Kumar, M.D., Yadav, S., Sinha, N., & Kumar, M. (2022). RECENT TRENDS OF YAM (*DIOSCOREA*) PRODUCTION -A REVIEW. Vol. 9. 935-942.
29. Dalena, F., Senatore, A., Iulianelli, A., Di Paola, L., Basile, M., & Basile, A. (2019). Ethanol from biomass: future and perspectives. In *Ethanol* (pp. 25-59). Elsevier.
30. Manochio, C., Andrade, B. R., Rodriguez, R. P., & Moraes, B. S. (2017). Ethanol from biomass: A comparative overview. *Renewable and Sustainable Energy Reviews*, 80, 743-755.
31. Kularathne, I. W., Gunathilake, C. A., Rathneweera, A. C., Kalpage, C. S., & Rajapakse, S. (2019). The effect of use of biofuels on environmental pollution—A review. *International Journal of Renewable Energy Research*, 9(3), 1355-1367.
32. Joshi, G., Pandey, J., Rana, S., & Rawat, D. (2017). Challenges and opportunities for the application of biofuel. *Renewable and Sustainable Energy Reviews*. 79. 850-866. 10.1016/j.rser.2017.05.185.
33. Teklit, G.A, Mentore, V., Adrián, Bonilla-Petriciolet, Shiv, P., Eric D. van H., Sami R. (2021). Emerging technologies for biofuel production: A critical review on recent progress, challenges and perspectives, *Journal of Environmental Management*, Volume 290, 112627, ISSN 0301-4797. <https://doi.org/10.1016/j.jenvman.2021.112627>.
34. Nanda, S., Rana, R., Sarangi, P., Dalai, A., & Kozinski, J. (2018). A Broad Introduction to First-, Second-, and Third-Generation Biofuels. 10.1007/978-981-13-1307-3_1.
35. Ibeto, C. N., Okoye, C. O. B., & Ofoefule, A. U. (2014). Bio-ethanol Production from Thermally Pre-treated Corn Chaff and Cassava Waste Water. *International Research Journal of Pure and Applied Chemistry*, 4(2), 227-233.
36. Gil, I. D., Uyazán, A. M., Aguilar, J. L., Rodríguez, G., & Caicedo, L. A. (2008). Separation of ethanol and water by extractive distillation with salt and solvent as entrainer: process simulation. *Brazilian Journal of Chemical Engineering*, 25, 207-215.
37. Hashimi A.M. (2021). UTILIZATION OF WATER YAM (*Dioscorea alata*) AS A SOURCE OF ETHANOL. J. Chem. Soc. Nigeria, Vol. 46, No.1, pp 0079–0082[2021]

38. Sokan-Adeaga, A. A., Ana, G. R., Olorunnisola, A. O., Sokan-Adeaga, M. A., Roy, H., Reza, M. S., & Islam, M. S. (2023). Ethanol production from cassava.

39. Okoro, T. C., Onwumelu, D. C., Igbinidu-Uwuigbe, E. P., Ofoegbu, D. C., Onwuka, M. K., & Nnebeana, S. E. (2022). Determination of optimum conditions for maximum bioethanol yield from the Nigerian sweet potato (*Ipomoea Batatas* (L.) Lam). *World Journal of Advanced Engineering Technology and Sciences*, 7(1), 075-085.