Sustainable Ethanol: Identifying and Assessing Sorghum and Jerusalem Artichoke as Alternatives to Corn as a Source of Ethanol

Emma Carson, Peter Choi, Rohan Sama, & Supraj Velaga

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Abstract

This research explores sorghum and Jerusalem artichoke as sustainable alternatives to corn for ethanol production in the United States. With nearly 30% of the U.S. corn supply dedicated to specifically ethanol production, concerns over corn use distribution and environmental impact have been raised. Sorghum and Jerusalem artichoke offer promising solutions due to their resilience and efficiency in varied environmental conditions. This study evaluates sorghum's suitability through its high biomass yield, drought resistance, and adaptability across different climates. Research highlights its potential for sustainable ethanol production, emphasizing its low carbon emission rates and biomass production per acre annually. Integrating sorghum into existing agricultural systems will push toward biofuel production efficiency without unnecessary funding for infrastructure changes. Similarly, Jerusalem artichoke is a robust alternative, thriving on marginal lands without consistent irrigation or fertilization. Its perennial trait to pests and diseases makes it a strong alternative for ethanol production. One of the most advantageous benefits of this crop is that it offers twice the ethanol yield that corn can produce per acre. The crop's inulin-rich tubers allow for efficient conversion into ethanol. Overall, Jerusalem artichoke is more sustainable and produces higher yields of ethanol. Findings indicate that both sorghum and Jerusalem artichoke align with sustainability goals by efficiently creating clean energy and reducing greenhouse gas emissions when ethanol is being produced. Challenges such as harvesting infrastructure and technological adaptation for widespread adoption are assessed, alongside the potential economic and environmental implications of transitioning to these alternative crops. Ultimately, this research contributes to understanding the feasibility and benefits of finding biofuel sources beyond corn, aiming to support global clean energy initiatives and achieve USDA-NIFA sustainability goals by 2030. Adopting sorghum and Jerusalem artichoke as primary biofuel sources holds substantial promise in promoting responsible land use, reducing dependency on finite resources, and ensuring energy security in the face of climate change challenges.

Introduction

Since the beginning of the 21st century, the biggest question has been whether there are any alternatives to fossil fuels. Ethanol has been identified as one major alternative. Ethanol has been used in the U.S. since the turn of the century (Cleveland, 2024). Today, using ethanol has

been seen to have a positive impact on rural America. However, the majority of U.S. ethanol is produced from corn. Forty percent of the 2016 U.S. corn crop was used to produce ethanol (USDA, 2024). Now, imagine living in a world where all the corn goes towards biofuel production. What about a world in which there is no corn for animal feed, industry, or human consumption? Corn is an essential resource in many products that are used by consumers daily (Farm Progress, n.d.). Due to the versatility of corn, it is important to ensure that not all of it goes towards producing ethanol. If a large portion of the U.S. corn crop goes toward ethanol production, there would not be enough corn for human consumption, livestock, industrial uses, etc. (Serna-Saldivar, 2018).

Problem Statement

In today's world, ethanol is one of the most important biofuels. However, due to ethanol's massive use in the fuel economy, corn is being used in unprecedented amounts to produce large amounts of ethanol in the U.S. Due to this, alternative crops are being sought out to replace corn. The following is an analysis of two crops that can serve as better alternatives to corn and their benefits and limitations. These two crops have been identified as superior alternatives over corn to effectively produce ethanol.

The United States Department of Agriculture has created multiple goals to achieve greater sustainability in agriculture. Identifying alternative crops to corn for ethanol production is vital to achieving these goals as more sustainable crops can greatly help reach these goals. The United States Department of Agriculture's sustainability goal "affordable and clean energy" is an urgent and important goal to achieve because of the constant need for clean energy throughout the world without harming the Earth. Not only would it contribute towards meeting the 2030 Sustainable Development Goals but would also help in the progression of ethanol production and efficiency.

The search for sustainable and environmentally friendly biofuels is critical in addressing global climate change. The United States Department of Agriculture's National Institute of Food and Agriculture (USDA-NIFA) emphasizes the importance of developing renewable energy sources to reduce greenhouse gas emissions and enhance energy security. In alignment with the UN Sustainable Development goal of "climate action", exploring alternative biofuel crops is essential for mitigating climate change while promoting sustainable agricultural practices (United Nations, 2023).

Also, in alignment with the United Nations Sustainable Development goal of "Responsible Consumption and Production", the use of alternative biofuels instead of fossil fuels is important to prevent the overuse and dependency on fossil fuels, to lower greenhouse gas emissions, and to enhance global energy security.

Methods

To address the ongoing problem of finding two alternative crops to corn for bioethanol production, it was necessary to break the question into smaller pieces. Before research was done to find solutions, it was imperative to understand what ethanol is. Research was conducted to discover how ethanol was created. Through the help of local librarians, many scholarly articles

were found and analyzed, using search engines like Google Scholar and the Virginia Tech library database. Using keywords such as “ethanol production,” “ethanol,” “ethanol producing crops,” “high starch inducing crops,” and “corn ethanol production,” results were narrowed down. Corn, especially, is a frequent crop within the U.S. that is utilized to make ethanol due to its high starch content. However, due to corn’s low energy return on investment (EROI), other crops with high ethanol-producing capabilities were delved into, eventually narrowing it down to Jerusalem artichoke and sorghum (Mathewson & Bosch, 2023). Then, the benefits and limitations of both Jerusalem artichoke and sorghum were researched to compare and contrast corn.

Background

What is Ethanol?

Ethanol is a natural alcohol. Being derived from ethane, it is part of the alkane family (National Center for Biotechnology Information, 2024; Wyman, 2004). Ethanol’s unique structure makes it useful in many different chemical compounds such as drinkable alcohol, fuel sources, disinfectants, and solvents. Some chemical properties of ethanol are flammability, hygroscopy, and the ability to create homogeneous mixtures (Australian Government Department of Climate Change, Energy, the Environment and Water, 2022; UCLA, 2016). Some physical properties of ethanol include being colorless, producing odor, and having a density of 789.3 g/L (National Center for Biotechnology Information, 2024). One of the most important aspects of ethanol may be its utility in fuel, being incorporated in over 98% of U.S. gasoline (US Department of Energy, 2024).

History of Ethanol

The history of ethanol being a fuel source is lengthy, however, as the 1800s began, ethanol was used as an alternative to oil lamps. Due to ethanol’s properties of being odorless after being burnt and easy to make, ethanol was preferred over whale oil. Additionally, the first engine was created in 1826, where ethanol was combined with fuel. This led to the rise of ethanol production for not only engines but also liquid fuel for lamps. Over 90 million gallons of grain alcohol were produced during 1850 (Abebe, 2008). As the Civil War started on April 12, 1861, the Union taxed the purchase of ethanol to pay for the Union's efforts in defeating the Confederates (U.S. Energy Information Administration, 2008).

In 1876, Nicholaus Otto created the four-internal combustion engine, using ethanol as its main fuel source (Gustafson, 2010). During the beginning of the 20th century, ethanol production majorly increased before and during World War 1 and 2. For example, ethanol production in Germany rose to 250 million gallons before World War 1 (Kovarik, 2001).

By the time the 1970s came around, Archer Daniels Midland (ADM) found its manufacturers were able to create ethanol as a byproduct when creating corn syrup. ADM sparked the ethanol market and made ethanol into an expensive fuel source for both gasohol and as octane fuel . Gasohol is a solution of gasoline and ethanol where ethanol does not exceed 10% of the total volume. In 1988, when the U.S. was removing lead from gasoline, they replaced it with ethanol as the “octane booster.” (Keeney, 2011)

During the years 1980 to 1984, the U.S. government enacted a series of acts in favor of ethanol producers: For example, The Energy Security Act of 1980, Gasohol Competition Act, Crude Windfall Tax Act, etc. In 2003, ethanol was changed to only 52 cents per gallon within the U.S. The U.S. was able to create over 15.4 billion gallons of ethanol in the year 2022 (U.S. Energy Information Administration, 2008).

Process of Making Ethanol

The majority of ethanol produced is made through a process called dry milling. The crop received first will be grinded into a mush called a "meal." Then water and enzymes will be added to the mixture so the starch can be converted into sugar. After this is done, it will be left for fermentation, which will create alcohol/ethanol. After the fermentation process, the mixture will undergo distillation through a molecular sieve so all water molecules will be filtered out. Next, by adding 2% denaturant, the ethanol will be made undrinkable so people would not abuse the alcohol produced (Renewable Fuels Association, n.d.). Then the ethanol is stored and shipped to markets.

In addition to dry milling, there is a process called wet milling. Wet milling starts when the grain is separated through "steeping." Steeping is when the grain is submerged in a liquid under its boiling point to soften it. This allows for starch, protein, and fiber to be extracted. Then the starch is further separated and fermented, using the same methods as dry milling (Renewable Fuels Association, n.d.).

For crops that have a higher amount of cellulosic feedstock, biochemical processes are utilized. First, in the biochemical process, the crops are treated so they would make hemicellulose sugars. Then those crops would go through hydrolysis to break down the cellulose into sugar. Next, the fermentation of those sugars is completed to produce ethanol (U.S. Department of Energy, n.d.).

What is Bioenergy?

Bioenergy is a renewable source of energy made from organic materials such as food, wood waste, crops, and microalgae. The first known use of bioenergy was 200,000 years ago when humans discovered fire. Today, ethanol is a form of bioenergy. Since ethanol is a renewable fuel source created from plant mass and has a 66% energy capacity of gasoline, it is frequently included in a solution of 90% gasoline and 10% of ethanol (U.S. Department of Energy, n.d.).

Advantages of Bioenergy

Bioenergy is important because it contributes to the decrease of carbon emissions, replaces fossil fuels, creates jobs, and increases the local economy. Additionally, in the U.S. alone, bioenergy gave 1.1 million jobs, 85 billion kilowatt-hours of electricity, and saved over 260 billion dollars (U.S. Department of Energy, n.d.). Across the world, over 40% of the world's household energy comes from bioenergy, and over 2.5 billion people worldwide depend on biofuel. Within just over 30 years, between 1971 to 2004, the amount of bioenergy used increased by 80% (Sagar & Kartha, 2007).

Disadvantages of Bioenergy

Due to bioenergy becoming a major market in future years, tripling its market value to over 900 billion by 2032 (Fortune Business Insights, 2024), bioenergy production can affect the water quality, soil conditions, greenhouse gas emissions, air quality, and biodiversity.

Ecosystems are already fragile. By changing the landscape to a bioenergy-efficient crop, it will greatly change the structure of the soil and its composition. By only having a 19% increase in corn production in the U.S. from 2006 to 2007, it reduced crop diversity and weakened local pest control services as much as 24%, costing $58 million. Through this change, it can greatly affect the biodiversity in the surrounding environment. Biofuel companies produced numerous water changes and issues have affected the ecosystem. Agriculture uses between 65% and 85% of water withdrawal in the west of the United States. Crops, such as corn, can drain water supplies, taking four gallons of water for each gallon of ethanol produced from corn, while petroleum takes one and a half gallons of water per gallon. By the time the year 2050 comes, the average use of agricultural water will increase from 18% to 46% just for bioenergy production (Dale et al., 2010). Additionally, having bioenergy crops can cause socio-economic issues like competition for land use, immense requirements to process biomass, and depreciation of rural areas like farmland and forests.

Processes of Making Bioenergy

There are three main ways to create bioenergy: burning, bacterial decomposition, and the conversion of biomass to gas or liquid fuel. The burning process uses biomass materials that can easily be burned, such as wood. As the materials are set ablaze after being desiccated, the heat being released will seethe the water. This mechanical energy will push turbines connected to generators, creating electrical energy (U.S. Department of Energy, n.d.).

Bacterial decomposition standardly uses organic waste from animals and crops. First, the waste is broken down into simpler compounds. Then, the following three stages are completed so methane can be produced and captured: acidogenesis, acetogenesis, and methanogenesis. The acidogenic bacteria converts the compounds into “simple organic compounds” the acetogenesis bacteria can use. Next, the acetogenesis bacteria convert these materials into acetic acid, hydrogen, and carbon dioxide. In methanogenesis, methanogenic archaea convert those products into methane, which is collected to form biogas (Kinyua et al., 2016; U.S. Department of Energy, n.d.).

Biomass is converted into gas or liquid fuel by gasification and pyrolysis. Gasification occurs when biomass is heated to high temperatures with little oxygen where it does not burst into flames (U.S. Department of Energy, n.d.). This creates gas biofuel. Pyrolysis is similar to gasification, however, oxygen is not present when heated. This allows gas to be emitted from the biomass and compacted into pyrolysis oil, also known as bio-oil (USDA, 2021).

History of Corn

For a person to understand the reason behind finding different crops for ethanol production, they need to know the history. Corn was first traced back to Mesoamerica, which is located in present-day Mexico and Central America. During this period, corn was called

Teosinte. Corn was considered a wild crop during that time and was later domesticated by indigenous people. Corn has become the crop it is today due to the genetic modifications that were made. Through many generations of farmers, corn was selectively bred for desirable qualities such as kernel size and sweetness. Farmers did this to attempt to make corn bigger, sweeter, and more efficient. For the farmers to be able to modify corn they had to go through a long and complicated process. In the process of modifying Teosinte into corn farmers had to select plants that had benefits that would later help to improve corn. They then had to crossbreed the two plants and reinforce the traits that would benefit the future. The process that past farmers had to go through to modify the ancestors of corn versus the modern processes farmers do to modify corn have become more efficient (Mirza, 2023).

The Role Of Corn In Ethanol

To create ethanol, there has to be starch, and corn has been one of the staple sources of starch. Therefore, corn has been the most influential and used crop when creating ethanol. It has been proven that corn has one of the highest starch contents compared to other plants.

Researchers have learned that a single kernel of corn consists of 74% starch. This is an extremely large amount of starch for just one tiny piece of corn. However, not only can the kernels be used in ethanol production, but so can the stover. The stover consists of the stalk, leaves, and the husk (Serna-Saldivar, 2018). This means every piece of corn can be used in ethanol production.

However, a lot of corn has been used for just ethanol production. For example, in 2020, more than 40% of all the corn produced in the U.S. went towards ethanol production (Ramsey, 2023). This is to be considered an extreme amount of corn going towards the production of ethanol. In order for companies to make a profitable amount of ethanol they must use a large amount of corn (Bothast, 2004). This just goes to show that the majority of the U.S. corn is going towards the production of ethanol.

Benefits Of Using Corn

Using corn for ethanol production has many benefits. Scientists have found that using corn to create ethanol produces less greenhouse gas emissions. This is a very positive impact due to the amount of greenhouse gasses other industries produce. Another upside to using corn in ethanol production is its high return on investment. Every piece of corn can be used to produce ethanol, meaning that none of the corn is going to waste (Mosier, 2006). Another benefit to using corn is its hardiness. Corn does not require a lot of water for it to grow and thrive. This can be very helpful for farmers growing this crop as they would not have to dedicate their time towards consistent irrigation and watering. Not only is corn drought-resistant, but also does not require any fertilizer. Corn can survive long periods of drought and extreme heat (Mossier, 2004). Based on these reasons alone, corn is one of the top crops in the production of ethanol.

Disadvantages Of Using Corn

While corn has its upsides, it also has its downsides. Corn is not only used in the production of ethanol but also in many other industries. One of the biggest industries that use

corn is the livestock industry (Ruan, 2019). The livestock industry uses corn in the majority of their feed. More than 50% of corn in the U.S. goes towards animal feed (Serna-Salvador, 2018). However, using corn to produce ethanol makes it harder for farmers to get enough corn to supply animal livestock. Furthermore, this same issue can be seen for a daily consumer as it would mean there could be shortages of corn for human consumption. Corn is not limited to just being used for ethanol but it is also used for human and animal consumption. Since ethanol companies rely on corn to produce ethanol, human consumers and animal feed production companies have to work harder to find a source of corn (Ruan, 2019). With corn becoming less abundant in production, producers and consumers are struggling. This is something American people should no longer have to struggle with, since there are other solutions that can be used in the production of ethanol.

What is Sorghum?

Sorghum is an ancient grain with a rich history. It is known for its resilience and adaptability to various climates. Since it is a grain, it is edible and can even be popped like popcorn for consumption (Emanuelli, 2023). This shows the versatility of sorghum and on the other hand it serves as a strong source of ethanol. Sorghum is classified into four main types: grain, forage, sweet, and biomass. Each of these serves different purposes. Grain sorghum is used for food products and animal feed. Forage sorghum primarily serves as silage or hay for animal livestock. Sweet sorghum is primarily grown for its syrup used in sweeteners and most importantly biofuels. This type of sorghum is most known for creating the ethanol present in most products that contain ethanol. Biomass sorghum is cultivated for renewable energy production, especially bioethanol (Kansas Farm Food Connection, 2018).

History of Sorghum

Sorghum's journey from Africa to other parts of the world highlights its significance as a versatile crop. It is believed to have originated in northeastern Africa, with the earliest records dating back to 8000 B.C. from an archaeological site near the Egyptian-Sudanese border (Kansas Farm Food Connection, 2018). Due to its ability to thrive in hot and dry conditions, sorghum spread across Africa and subsequently to India, China, and Australia. In the United States, the first known mention of sorghum was by Benjamin Franklin in 1757, who noted its use for making brooms. In the 1960s, sorghum production in the United States faced challenges due to diseases, such as downy mildew, and pests like the green bug. However, scientists and growers developed hybrids that ensure the crop stays alive and well (Kansas Farm Food Connection, 2018).

Today, sorghum is cultivated widely across the "Sorghum Belt" from Texas to South Dakota, with Kansas being the largest producer of grain sorghum in the country (Kansas Farm Food Connection, 2018).

How Sorghum Produces Ethanol

Sweet sorghum is a valuable crop for ethanol production due to its high sugar content. The stalks of sweet sorghum contain sugars that yield 400 to 800 gallons of ethanol per acre (Biofuels Academy, 2024). This process involves pressing the juice from the sorghum stalks,

fermenting the sugars, and distilling the alcohol. Bagasse, the leftover material after pressing, can be used as fuel for the distillation process. In return, this makes the production cycle more sustainable (Biofuels Academy, 2024).

There are two primary methods for converting sweet sorghum into biofuel: gasification and fermentation. Gasification involves burning sorghum biomass to produce synthetic gas, bio-oil, and charcoal. Synthetic gas and bio-oil are considered transportation fuels. On the other hand, charcoal is used to enhance soil structure (Farm Energy, 2023). Fermentation uses yeast to convert the sugars in sweet sorghum into ethanol. This juicing process requires proper equipment, like diffusers, to ensure the best ethanol yield. Additionally, the leftovers of fermentation can be utilized for livestock feed or fertilizer (Farm Energy, 2023).

Benefits and Limitations of Sorghum

One of the advantages of sweet sorghum is its ability to adapt to different climates. According to the Biofuels Academy, it has a relatively short growing season, "ranging from 92 to 180 days, compared to sugarcane's 12 to 24 months in tropical climates" (Biofuels Academy, 2024). Sweet sorghum's efficient nitrogen use only requires 37% of the nitrogen used by corn, and 17% less irrigation water (University of California, Davis, 2024). However, there are challenges with sweet sorghum cultivation and ethanol production.

Sorghum is less cold-tolerant than corn. It requires soil temperatures above 65°F for actual growth development (Farm Energy, 2023). Another problem is how sorghum is prone to high plant population densities. This kind of issue can lead to lodging where the stalks are blown down by strong winds.

Additionally, the sugars in sorghum stalks degrade quickly. This means that after the juicing process finishes, the manufacturer needs to extract the juice immediately to maximize ethanol yield. This logistical challenge increases transportation costs and reduces flexibility in the harvesting process.

Furthermore, the lack of funding and recognition for sorghum production has led to poor-quality harvesting equipment. This, in a way, restricts the possibility of mass production of sorghum. While several equipment companies are beginning to research prototypes, funding and publicity remain a big challenge in this industry (Farm Energy, 2023).

What is Jerusalem Artichoke?

Jerusalem artichoke (*Helianthus tuberosus*) is a plant in the Compositae family. The most popular member of this family is the sunflower. The Jerusalem artichoke is native to the U.S.A. and is a perennial plant that grows one to three meters tall. The plant produces yellow flowers, which resembles sunflowers. Jerusalem artichoke is also characterized by its hairy oval-shaped leaves. The most carbohydrate-rich part of the plant, its tubers, are used as food. Native Americans have grown Jerusalem artichoke for centuries before the arrival of Europeans (Yang, 2015).

History of Jerusalem Artichoke

The Jerusalem artichoke is thought to be native to North America and Canada (Thompson, 2021). Native Amercians have been using Jerusalem artichoke as a food source for years until French explorer Samuel de Champlain came into contact with the crop and the Native Americans who had cultivated it. Before the name "Jerusalem Artichoke" was coined, the Native Amercians called it the "Sunroot". Champlain claimed that it tasted similar to an artichoke and with French colonialism, the crop made it back to France. Later, when the crop arrived in Italy, it became known as the "girasole", or sunflower in Italian. With the mispronunciation of English speakers, "girasole" turned into "Jerusalem", hence the current name now being Jerusalem artichoke (VanZandt, 2020).

Benefits and Limitations of Jerusalem Artichoke

As it is a native crop, it has many advantageous traits compared to other crops. These traits include fast growth, tolerance to cold weather and frost, drought tolerance, adaptability to poor soils, pest and disease tolerance, and little to no fertilizer needs. At the time of writing, the primary feedstock for ethanol production in the U.S. is corn. However, the use of corn for ethanol production restricts its use elsewhere, which brings up the argument of whether farmland should be used for the production of food or fuel. Due to its lack of need for fertilizer and tolerance to poor soil, Jerusalem artichoke can be grown on marginal lands, which makes it more advantageous, as it does not take up space for important food crops. The tubers of the Jerusalem artichoke are very inulin-rich. Inulin is easily hydrolyzed and turned into ethanol with biocatalyst cultures. The ethanol production from Jerusalem artichoke tubers is equivalent to the production of ethanol from sugarcane and, more importantly for the U.S., double that produced from corn. These factors make Jerusalem artichoke a much more advantageous feedstock for ethanol production than corn (Yang, 2015).

A study was conducted in the Castelo Branco region of Portugal. A small amount of Jerusalem artichoke was planted on land with forest soil, which is not suitable for agricultural production. The plants were not provided with water, apart from rainfall. They were also not given fertilizers or pesticides. After 214 days, 48 kilograms of tubers were yielded by this land, which corresponds to 40,000 kilograms of tubers per hectare. However, this is only half the largest tuber yield recorded, about 90,000 kilograms per hectare. Those conducting the study stated the reduced yields were caused by non-optimal growing conditions. Despite these conditions, the Jerusalem artichoke in this study was projected to yield about four to nine times the projected yield of corn in a hectare (which was 11,130 kilograms per hectare in 2023) (Paixao, 2018; USDA/NASS QuickStats Ad-Hoc Query Tool, n.d.).

How Jerusalem Artichoke Produces Ethanol

There are two methods by which ethanol can be extracted from Jerusalem artichoke tubers. One method is separating hydrolysis and fermentation. Using this method, the inulin hydrolysis and fermentation of the sugars of the tubers are done in different reactors. The tubers are usually mashed into a pulp and through hydrolysis, they are turned into fermentable sugars through the use of an inulinase enzyme or dilute mineral acids. The fermentable sugar is then separated from the remaining solid residue of the tubers and moved to a fermenter where the sugar is fermented into ethanol through yeast (Yang, 2015).

Another method is the simultaneous saccharification and fermentation method. This method is less costly and more efficient, as it reduces the amount of fermentable sugar since the material is not transferred and separated between reactors. However, for the production of ethanol from Jerusalem artichoke tubers, there is difficulty in identifying the most efficient enzymes, which can conduct both hydrolysis and fermentation. In this method, a mixture of inulinase and yeast is used to turn the tubers into ethanol (Yang, 2015).

Due to its hardiness, its productivity, and its richness in inulin, Jerusalem artichoke is a superior feedstock when compared to corn for the production of ethanol.

Solutions

The future of the U.S. corn supply is at massive risk. Almost 30% of the U.S. corn supply is going toward ethanol production (Ruan, 2019). This is why the U.S. needs to transition into a better alternative crop. Sorghum is an effective and sustainable alternative to corn for ethanol production. Gunther, a Californian researcher, has identified new brands of sorghum seeds that can be good for energy production. These varieties are highly drought-resistant. Also, they can grow on different types of land and reach up to 20 feet in height within four months (Gunther, 2014). Sorghum only requires a few carbon inputs and produces more biomass per acre annually.

Furthermore, sorghum's sustainability profile includes its potential to produce easily accessible fermentable sugars for biofuels and low-moisture feedstock for cellulosic biofuels and biomass boilers (Gunther, 2014). This shows the advantages of sorghum over corn, mainly due to its ability to thrive in less favorable conditions. These qualities make sorghum a strong alternative for large-scale ethanol production.

Sorghum's versatility and efficiency make it a promising crop for biofuel production in diverse climates. The “SWEETFUEL” project has demonstrated that sorghum can be adapted for temperate and tropical climates (Cordis, 2015). Inhabitable zones and breeding programs have developed biomass sorghum varieties for second-generation ethanol production. These varieties give off a high biomass yield and are better adapted to low temperatures. In tropical climates, sweet sorghum varieties can produce sugar in their stalks, while also yielding grain, making them suitable for first-generation ethanol production without compromising food security (Cordis, 2015). The project also identified sorghum's high water and nutrient use efficiency, short growth cycle, and potential for significant genetic improvement. Overall, this project showed how sorghum can thrive in completely different environments and prove to be a better alternative for ethanol production than corn.

Sorghum's integration into existing agricultural systems can enhance biofuel production efficiency and sustainability. In Brazil, sweet sorghum is being integrated into the sugarcane industry to complement sugarcane production during the off-season (Cordis, 2015). This same method can be applied to any area with enough land to cultivate each season. Thus, growing sorghum in states like Texas and Montana would have a positive turn in investment, as growing them would be cost-efficient and lead to mass production of sorghum. This integration also allows for more frequent operation times of ethanol plants without additional investments in new equipment or expansion of land use. The compatibility of sorghum with existing sugarcane

infrastructure demonstrates its potential to increase ethanol output efficiently (Cordis, 2015).

By leveraging sorghum's compatibility with current agricultural practices and infrastructure, the biofuel industry can achieve higher efficiency and sustainability. This approach minimizes the need for new investments and land use changes, thereby reducing the environmental footprint of biofuel production. The multifaceted utility of sorghum, from ethanol production to providing valuable by-products, strengthens its case as a superior alternative to traditional biofuel crops like corn. Though sorghum appears to be a promising solution, another solution has been identified.

Jerusalem artichoke (*Helianthus tuberosus)* has immense potential as a superior alternative to corn to produce ethanol. As discussed, Jerusalem artichoke is a native perennial with drought and frost tolerance. Corn, however, is not native and lacks frost tolerance. Corn is also not a perennial and must therefore be seeded each year. The most important characteristic of Jerusalem artichoke is its ability to grow on marginal land, as it does not require the nutrition of farmland. This opens up farmland to grow important food crops. Corn, however, requires much nutrition and takes up precious farmland. This raises the debate of whether farmland should be used for food or fuel. Another important characteristic of the Jerusalem artichoke is its ability to thrive without irrigation, fertilization, or pesticides (Yang, 2015).

Corn however is susceptible to certain pests and disease. Corn also requires large amounts of nitrogen to grow. Despite using fewer resources, Jerusalem artichoke is projected to be four to nine times more productive than corn by weight of tubers per hectare. This is based on the weight of the tubers alone and the biomass without the stalk of the plants considered (Paixao, 2018). As the plants can grow one to three meters tall, there is a significant amount of biomass produced by the stalks (Yang, 2015). The above highlights areas in which Jerusalem artichoke is superior to corn, the most important of which, is the ability of Jerusalem artichoke to thrive in marginal lands with little fertility, its hardiness, lack of need for fertilization or irrigation, and its productivity. These characteristics, combined with others, make Jerusalem artichoke an excellent candidate for the commercial production of ethanol. This crop would perform especially well in its native range, however, it has also been grown to produce ethanol in Europe and Asia (Paixao, 2018).

The hardiness and efficiency of Jerusalem artichoke make it a promising crop for biofuel production. The tubers of the Jerusalem artichoke are rich in inulin, which is easily converted to ethanol through hydrolysis and fermentation. As it can be grown on marginal land with little to no other inputs, it is an extremely sustainable crop. Also, as it is a native crop, there are environmental benefits to growing Jerusalem artichoke compared to a crop like corn. These benefits include how Jerusalem artichoke is perennial, frost tolerance, pest and disease resistance (Yang, 2015). Corn lacks most of these characteristics, namely frost tolerance, and being a perennial. As an annual, corn needs to be reseeded each year, and seeds must be purchased from a seed company (Ruan, 2019). This, combined with the other characteristics of Jerusalem artichoke makes it a much more superior ethanol crop than corn.

While two crops that could be alternatives to corn have been identified, one has more potential for ethanol production than the other. Both crops can create more ethanol than corn, however, Jerusalem artichoke is ultimately more efficient than sorghum and corn. Both

sorghum and Jerusalem artichoke are very hardy crops, being able to grow on marginal lands, thrive with no fertilizer, and are drought tolerant. Jerusalem artichoke, however, as a native crop, has the added advantage over sorghum of being frost-tolerant and perennial.

Conclusion

In conclusion, corn has been found to not be the most efficient crop for the production of ethanol. The overreliance on corn for ethanol production has many challenges such as nutrient depletion in soil and the fight for balancing corn supply for food, industrial, and livestock needs. This research has explored and assessed sorghum and Jerusalem artichoke as viable alternatives to corn for ethanol production. By using Jerusalem artichoke and sorghum for the production of ethanol, important farmland can be preserved for food production. Sorghum offers high ethanol yield potential, adaptability to different climates, and has efficient land usage. However, based on logistics in its funding in equipment and challenges in harvesting infrastructure, it has its limitations.

On the other hand, Jerusalem artichoke thrives in marginal lands, is a native perennial, and is rich in inulin, easily converted into ethanol. However, as it is a perennial, Jerusalem artichoke has the potential to become an invasive weed. Another possible challenge that can arise from Jerusalem artichoke cultivation may be its height as it can reach heights of one to three meters (Yang, 2015).

Both of these crops align with the ultimate goal of reaching sustainability on Earth by promoting responsible land use, reducing greenhouse gas emissions, and ensuring energy security. All of these components are factors if improved upon, that can help reach the 17 USDA-NIFA goals by 2030. Implementing sorghum and Jerusalem artichoke as primary biofuel sources has strong potential, backed up by research, to contribute to global clean energy initiatives.

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