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Unveiling The Multifaceted Exploration From Genomic Insights To Functional Applications Of The Agave Genus: A Comprehensive Review

Sanjoy Kumar Dhar[1], Jaspreet Kaur[2], Gaurav Mudgal[3]*

[1,2,3*]University Institute of Biotechnology, Chandigarh University, Mohali, Punjab, India
[1]ORCID ID: 0000-0001-7783-6525, Email: sanjoy.r21@cumail.in
[2]ORCID ID: 0000-0001-5384-2496, Email: jaspreet.r47@cumail.in

***Corresponding author:** Gaurav Mudgal
*University Institute of Biotechnology, Chandigarh University, Mohali, Punjab, India
ORCID ID: 0000-0003-4303-4983, Email: Gaurav.mudgal@cumail.in

Abstract
The Agave genus within the angiosperms presents a rich tapestry of potential and versatility, encompassing molecular characteristics, chemical composition, functional properties, and applications in biofuel, rendering it a compelling and multifaceted subject for exploration. This study delves into the genomic mysteries, evolutionary narratives, and genetic robustness of agaves, coupled with a thorough examination of the chemical profile of its by-products. Additionally, it unravels the functional capacities of agave, showcasing its prowess in antioxidant, anti-inflammatory, antibacterial, and antifungal realms, along with its suitability as a food ingredient. Furthermore, the paper underscores the biofuel potential inherent in agave, emphasizing its role in bioethanol production, hydrogen, and methane generation, as well as its applications in nanocomposites and nanocrystals. These findings contribute not only to theoretical frameworks but also inform policy formulations and practical applications. In essence, this work offers a holistic comprehension of the agave genus, elucidating its multifaceted attributes, and potential applications, and paving the way for future research and innovation.

Keywords: Genomic, bioenergy, metabolites, biofuel, evolution, transcriptome, diversity.

1. Introduction:

The agave genus, consisting of over 275 plant species and remarkable adaptability, has emerged as a captivating subject of extensive scientific exploration and interest across various disciplines.. The versatility and capability of the agave genus focus on its molecular characteristics, chemical composition, useful residences, biofuel capability, future potentialities, and implications for various industries. Through synthesizing current studies and exploring key aspects, we are seeking to provide a holistic understanding of the unique attributes and applications of Agave plants (Saxena, Pappu, Haque, Sharma, & technology, 2011). Researchers have been captivated by the agave genus for a significant period, as each possesses distinct expertise and insights. Pioneering scholars have laid the groundwork for comprehending the genetic composition, evolutionary history, and genetic durability of agave (King, 2000). Constructing upon this understanding, cutting-edge scholars have continued to contribute valuable insights into agave's secrets, unraveling its genomic enigma, expertise in its role as an evolutionary masterpiece, and exploring the genetic resilience that permits its survival in numerous environments. These findings have multiplied our understanding of the intricate mechanisms that govern agave's development, model, and capability programs. Further to the genetic aspects, researchers have also focused on the chemical composition of agave using products. Investigations have shed light on the rich form of compounds determined in agave flora, which include carbohydrates, phenolics, terpenes, and flavonoids. These compounds exhibit diverse properties houses that have implications for diverse industries. Furthermore, researchers have explored the useful capability of agave, uncovering its antioxidant and anti-inflammatory abilities, antibacterial and antifungal properties, in addition to its capacity as an ingredient in meal substances. The recognition of agave as a potential biofuel feedstock has also gained traction. Research explores its potential in bioethanol production, hydrogen, and methane technology, and the improvement of nanocomposites and nanocrystals (Balleza, Alessandrini, & Beltrán García, 2019). Individual research contributes valuable insights, and a comprehensive synthesis is necessary to evaluate agave's versatility and potential applications. Moreover, the urgency to discover sustainable and renewable alternatives in diverse industries has increased the importance of studying agave and its ability as a bioresource. By elucidating the untapped potential of agave, we aim to inspire similar research and innovation in utilizing this notable genus. This is to address urgent demands on the international front. Literature evaluation encompassing research from numerous disciplines, including genomics, biochemistry, and bioengineering, was performed. Our research strategy involved formulating precise study questions to manage our goal. This allowed us to systematically compare and synthesize the existing agave information body. We deeply analyzed agave's genomic traits, chemical composition, practical habitats, and biofuel applications, employing a complete technique to capture the multidimensional nature of this fascinating genus (Nagarajan, 2017). The agave genus represents a reservoir of versatility and potential. This is due to its particular molecular characteristics, various chemical compositions, and practical properties that provide promising applications in diverse industries (Espinosa-Andrews & Urias-Silvas, 2012). Through our comprehensive evaluation of current studies, we intend to offer a complete knowledge of the agave genus and its implications across extraordinary domains. Unraveling agave's mysteries, we will explore its genomic enigma, uncover its evolutionary masterpiece, and delve into its genetic resilience. Building upon this foundation, one can delve into the chemical makeup of agave by products, discussing the diverse array of compounds and their potential applications, inclusive of the purposeful ability of agave in antioxidant and anti-inflammatory properties, antibacterial and antifungal attributes, in addition to its relevance as a source of food elements (López-Romero et al., 2018). Moreover, we can explore agave's potential as a biofuel feedstock. We can specialize in its role in bioethanol manufacturing, hydrogen, and methane generation, and its utilization in nanocomposites and nanocrystals. By embarking on this study, the versatility and potential of the agave genus, pave the way for similar exploration, innovation, and the sustainable applications of agave in diverse industries. Through our collective efforts, we are hoping to make a contribution to the developing body of understanding surrounding agave, inspire additional research, and promote responsible utilization of this awesome plant genus.

2. Decoding Agave's Secrets:

2.1 Unveiling the Genomic Enigma:

The realm of genetic alchemy opens up new possibilities for understanding the enigmatic agave plant through genomic sequencing and analysis. By delving into agave's DNA, we can uncover its genetic secrets and unravel the genomic enigma within. Agave species exhibit distinct patterns in their microbial communities. The impact of plant compartments on prokaryotic communities and the influence of host species' biogeography on fungal communities are evident in these patterns. Cultivated *A. tequilana* shows reduced prokaryotic variability than indigenous agaves, but no disparities were found in microbial variation within the internal microbiome. Interestingly, agave species share core prokaryotic and fungal taxa that play essential roles in promoting plant development and conferring resistance to abiotic stress, suggesting frequent underlying principles in agave-microbe interactions (Martínez-Rodríguez et al., 2014). In a specific study on agave hybrid H11648, Illumina paired-end sequencing generated approximately 49.25 million clean reads, resulting in the identification of 148,046 genes. The investigation also involved characterizing CAM-related gene families and identifying 12 genes responsible for cellulose synthesis (CesA) from the *Asparagus* genome, as well as 38 CesA sequences from four agave species. This analysis points towards the importance of transcriptional regulation in agave fiber development, as conserved evolutionary patterns were observed in both phylogenetic and expression analyses (Huang et al., 2019).

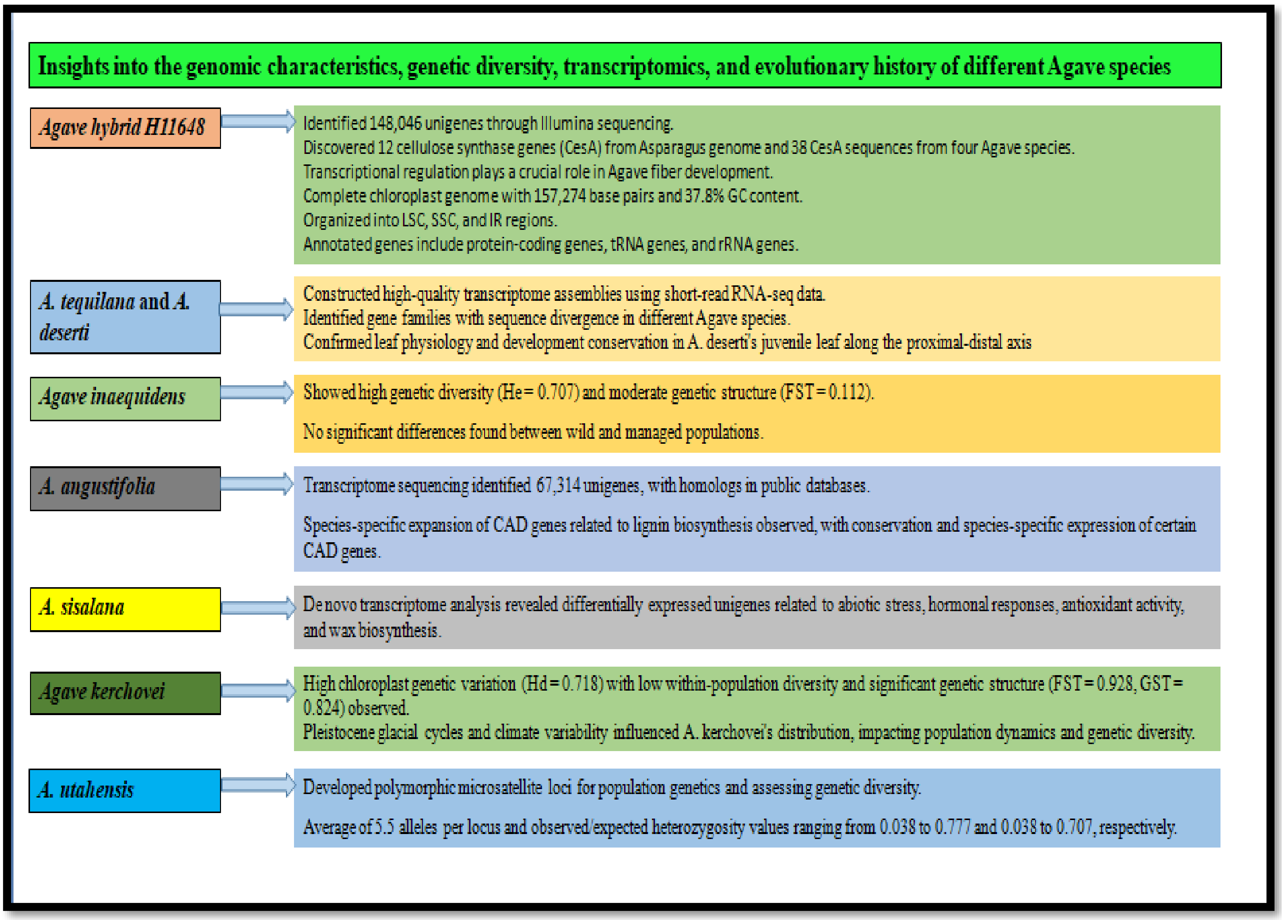

Figure: 1 Comparison among Agave's genomic enigma.

Moreover, comprehensive and top-notch de novo transcriptome analyses of *A. tequilana* and *A. deserti* were successfully constructed using short-read RNA-seq data. This enabled the identification of genetic clusters that exhibit genetic variation in different agave species. Specifically, the analysis of the *A. deserti* young leaf validated the consistent preservation of monocotyledonous leaf morphology and growth characteristics. (Gross et al., 2013). Research on *Agave inaequidens* has revealed substantial genetic variability (He = 0.707) and a moderate level of genetic organization (FST = 0.112), with no notable distinctions between populations in the wild and under management. This genetic diversity, coupled with their ability to grow with minimal inputs and produce substantial biomass, highlights the economic potential of agave species, which are currently utilized for various applications such that alcoholic beverages, sweeteners, fibers, and specialty chemicals (Figueredo et al., 2015). The analysis of agave hybrid 11648's entire chloroplast DNA uncovered its features, such as a length of 157,274 base pairs, GC content of 37.8%, and its structure consisting of a large single copy region (LSC), a small single copy region (SSC), and a pair of inverted repeat regions (IR). Agave chloroplast genomes also feature identified genes comprising coding for proteins, transfer RNA (tRNA) genes, and ribosomal RNA (rRNA) genes (G. Jin et al., 2020). Transcriptome sequencing of *A. angustifolia* resulted in the identification of 67,314 unique genes, 50% of which had analogous sequences in public databases. Distinct amplification of CAD genes in particular species (related to lignin biosynthesis) was observed in *Arabidopsis*, rice, and agave, with expression assessment indicating the conservation of certain CAD genes (CAD1/2/4/6) and expression unique to certain species (CAD3/5/7) . Under drought conditions, the transcriptome of *A. sisalana* was analyzed using a de novo approach, revealing differentially expressed unigenes and significant genes involved in abiotic stress responses, hormonal responses, antioxidant activity, and wax biosynthesis (Sarwar et al., 2019). Transcriptome data from four agave species were used to identify complementary DNA (cDNAs) and amino

acid sequences corresponding to genes encoding invertases, fucosyltransferase, and fructan exohydrolases (FEH), unveiling distinct isoforms and tissue-specific expression patterns (Avila de Dios, Gomez Vargas, Damian Santos, & Simpson, 2015).
Patterns of SAUR gene expression in agave species exhibit distinctive characteristics and differential expression during the CAM cycle of the plant. The agave genus is relatively young, with an estimated age of 7.8 to 10.1 million years, speciation rates surged around 8 to 6 and 3 to 2.5 million years ago (Deng et al., 2019). *Agave kerchovei*, a specific species, demonstrates significant amounts of chloroplast genetic diversity (Hd = 0.718), with low diversity within communities and significant genetic composition (FST = 0.928, GST = 0.824). Pleistocene glacial cycles have likely influenced the dispersion of *A. kerchovei*, with climatic variability and complex topography affecting genetic variability and demographic changes. The species' potential dispersion has remained constant since the core Holocene (6,000 years ago), with a central group of populations concentrated in the Tehuacán Valley and independent evolution of peripheral populations (Aguirre-Planter et al., 2020). The fundamental metabolic elements needed for CAM (Crassulacean Acid Metabolism) in agave originate from ancient genomes in non-vascular plants responsible, while controlling proteins responsible for metabolic reprogramming underwent more recent development common to C3, C4, and CAM species. The development of structural regions in proteins involved in basic metabolism and communication,
in addition to the modification of gene transcription, has undergone accelerated changes to facilitate CAM evolution in agave. Potential candidate genes contributing to CAM adaptation have been identified (Lim, Lee, Choi, Yim, & Cushman, 2019).

Furthermore, polymorphic microsatellite loci were developed for *A. utahensis.* These loci had a mean of 5.5 genetic variants per locus and observed-to- anticipate heterozygosity levels ranging from 0.038 to 0.777 and 0.038 to 0.707, correspondingly. These genetic markers provide valuable tools for studying population genetics and assessing genetic diversity within *A. utahensis* populations (Byers, Maughan, Clouse, & Stewart, 2014). The studies conducted on agave species have shed light on various aspects of their biology, including microbial communities, genomic characteristics, transcriptomics, genetic diversity, and evolutionary history. These findings facilitate to enhanced comprehension of agave-microbe interactions, the biological basis of critical traits such as fiber development and CAM, and the potential economic value of agave species as bioenergy crops and for various industrial applications.

2.2 Evolution's Masterpiece:

Agaves have extensive adaptations to gas exchange, water relations, temperature tolerance, photosynthesis, and nutrient uptake to thrive in harsh environments. Their survival in extreme conditions can be attributed to these remarkable adaptations, and they play vital ecological roles by providing food and shelter for other organisms (Verhoek, 1989). The composition of prokaryotic communities in agave species is influenced by the plant compartment. In contrast, fungal communities are more affected by the geographical distribution of the plant species. Planted *Agave tequilana* exhibits Diminished prokaryotic variation than indigenous agaves, but microbial diversity within the plant remains consistent. Agaves share prominent prokaryotic and fungal species that contribute to plant development and enhance adaptability to abiotic hardship, suggesting frequent underlying fundamentals in agave-microorganism relationships (Coleman-Derr et al., 2016). *Stenocereus spp.,* including *Stenocereus queretaroensis,* produce attractive edible fruits and adapt to water-limited environments by separating vegetative and reproductive growth. *Stenocereus queretaroensis's* sluggish development is influenced by insufficient nitrogen levels, chlorophyll deficiency, and specific micronutrient scarcities. The Agave genus is relatively young, estimated to be approximately 7,800 to 10,100 centuries old, with significant speciation rates occurring around (8-6) and (3-2.5) million years ago (Pimienta, Hernandez, Domingues, & Nobel, 1998). Cultivated variants of Henequen exhibit reduced genetic diversity compared to wild populations, indicating genetic erosion, with the Kitam Ki variant showing the closest resemblance to wild populations (Figueredo et al., 2015). *Agave potatorum*, benefits from associations with shrub species, especially in early life stages, promoting germination, seedling survival, and growth rates (Rangel-Landa, Casas, Dávila, & Management, 2015). Agave species are mostly discovered in Mexico and well-suited to hot, arid environments. Agaves store carbohydrates as fructan polymers, which serve multiple functional roles due to their unique properties. Certain anatomical characteristics, such as root and leaf traits, are significant for taxonomic studies and exhibit relationships with morphological features (!!! INVALID CITATION !!! {}).

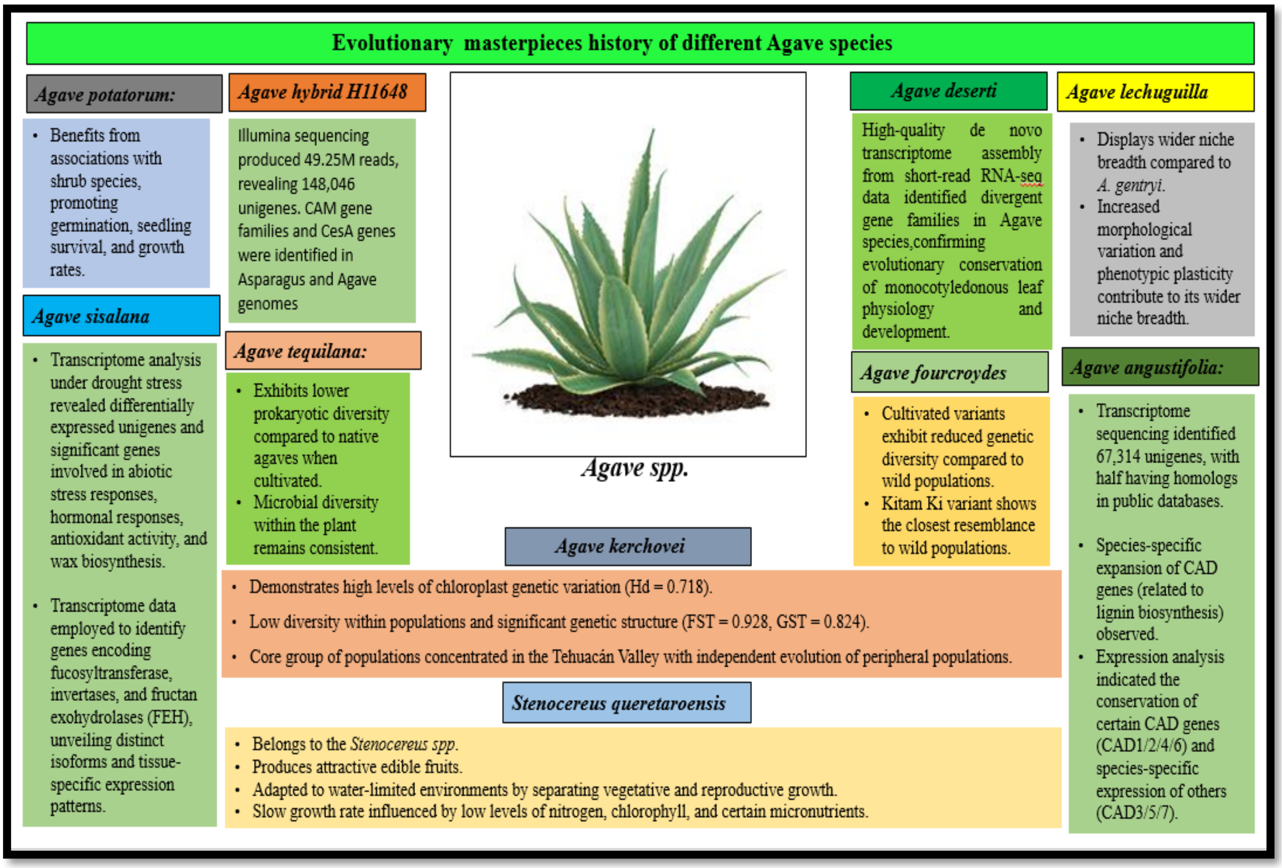

Figure: 2 Ecological adaptations beyond imagination

Limited water availability of agaves affects biomass accumulation, biomass allocation, and specific physiological responses, such as proline accumulation and leaf thickness (Rangel-Landa et al., 2015). Desertification in North America played an essential role in the proliferation of agaves. The generalist pollination structure agave has led to increased speciation than *Yucca's* specialized pollination. *Agave lechuguilla* displays a wider niche breadth than *A.gentryi* due to increased morphological variation and phenotypic plasticity. Different agave species exhibit specific timings of nectar and pollen production, suggesting distinct pollination strategies (Rocha et al., 2006). Agaves utilize Crassulacean Acid Metabolism (CAM) for efficient water use, with CO_2 uptake occurring at night. The Environmental Productivity Index (EPI) enables the quantification of CO_2 uptake by agaves based on rainfall, temperature, and photosynthetically active radiation, providing predictive productivity estimates. Tillage practices reduce soil carbon levels, and associated nutrients, while distillery effluent increases soil cation levels and livestock grazing has minimal impact on soil nutrient levels. Effective soil fertility management is crucial for maintaining long-term soil health in agave-growing regions (Nobel, 1990).

2.3 Genetic Resilience:

Amplified fragment length polymorphism (AFLP) evaluation verified significant genetic variations among individuals, although these variations did not show a direct correlation with the observed variations in resistance phenotypes (Blears, De Grandis, Lee, Trevors, & Biotechnology, 1998).

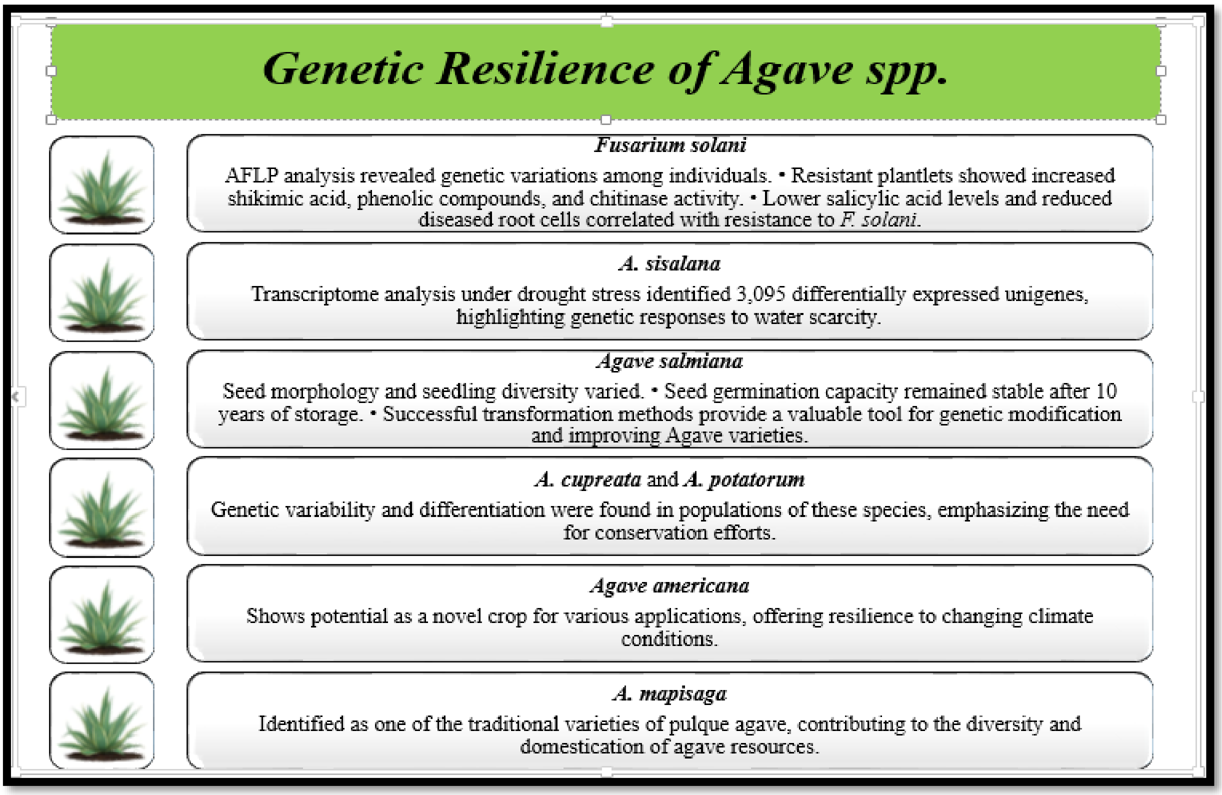

Figure: 3. Genetic resilience of agave species.

Agave plantlets exhibiting potential resistance *to Fusarium solani* demonstrated higher levels of shikimic acid, phenolic compounds, and chitinase activity. These biochemical responses were inversely correlated with salicylic acid levels and the prevalence of affected root cells after exposure to *F. solani* for 30 days. Agave plants have diverse applications in sectors such as food, agriculture, medicine, energy, textiles, cosmetics, and aesthetics, which could contribute to the Mexican economy. Transcriptome analysis of *A. sisalana* under drought stress identified 3,095 differentially expressed unigenes, highlighting genetic responses to water scarcity. Variability in seed appearance and seedling genomic variation was observed in *Agave salmiana* and alternative seed sources. The germination capacity of *A. salmiana* seeds remained stable even following a decade of storage period, providing valuable reference parameters for future seed analyses. While agave species have been understudied in terms of genetic improvement, hybridization techniques, and biotechnological tools hold promise for enhancing their genetic traits. Genetic variability and differentiation were found in *A. cupreata* and *A. potatorum* populations, emphasizing the need for conservation efforts. *Agave tequilana* exhibited high genomic diversity, with higher heterozygosity in adults compared to juveniles. *Agave americana* shows potential as a novel crop for various applications, offering resilience to changing climate conditions. Agave species employ molecular strategies to tolerate elevated temperatures and drought conditions, such as the over-expression of heat shock proteins and stress-responsive proteins, as well as the amassing of raffinose as an osmolyte. Agave's adaptability to challenging environments makes it valuable for agriculture in water-scarce regions, and tissue culture-based selection of elite individuals is a primary approach for improving productivity. Agave species are suitable for cultivation in dry and arid conditions, providing an alternative option for marginal lands. Detailed molecular-genetic research is required to fully exploit agave species as bioenergy crops, with genetic informations and transcriptome mining showing promise in bioenergy applications (Álvarez-Ríos, Pacheco-Torres, Figueredo-Urbina, Casas, & Ethnomedicine, 2020). The successful transformation of *Agave salmiana* using various methods offers a valuable tool for further research and the development of improved agave varieties through genetic modification. The identification of traditional agave varieties, along with an understanding of genetic groups and management categories, contributes to our knowledge of agave diversity and domestication (Álvarez-Ríos et al., 2020). Morphological analysis revealed distinct traits between wild-collected and cultivated varieties, indicating the presence of domestication syndrome. Considering both genetic and cultural factors is important for conserving and utilizing agave genetic resources. Directed

research efforts are needed to uncover the molecular-genetic aspects of agave species, unlocking their full potential as sustainable bioenergy. The successful transformation of *Agave salmiana* using different methods provides a valuable tool for further research and the development of improved agave varieties through genetic modification. Additionally, a study on conventional cultivars of pulque agave discovered 19 different varieties belonging to species for instance *Agave americana, A. salmiana*, and *A. mapisaga*. This study also revealed distinct genetic groups and management categories, shedding light on the diversity and domestication of these valuable agave resource crops. Morphological evaluation of the conventional agave cultivars showcased a gradient of traits, with wild-collected varieties displaying smaller sizes and cultivated varieties exhibiting traits linked to domestication syndrome. This assessment of genetic diversity among traditional cultivars and cultivation practices underscores the importance of considering both genetic and cultural factors in the conservation and utilization of agave genetic resources (Figueredo-Urbina, Álvarez-Ríos, García-Montes, & Octavio-Aguilar, 2021).
Furthermore, it is crucial to conduct focused research to unravel agave species' molecular-genetic aspects. These efforts will pave the way for fully harnessing agave species' potential as sustainable bioenergy crops. In particular, comprehensive molecular-genetic research is necessary, including the exploration of genomic resources and transcriptome mining, to facilitate the application of agave species in bioenergy applications (Simpson et al., 2011).
The presence of significant genetic variations among agave species has been confirmed through amplified fragment length polymorphism analysis. However, these genetic differences do not directly correlate with resistance phenotype variations. Plantlets exhibiting potential resistance to *Fusarium solani* demonstrate distinct biochemical responses, including elevated levels of shikimic acid, phenolic compounds, and chitinase activity. The transcriptome analysis of *A. sisalana* under drought stress provides insights into the genetic mechanisms underlying agave's ability to cope with water scarcity. Additionally, variability in seed morphology and genetic diversity among different seed origins highlights the potential for selective breeding and conservation strategies in agave species. Overall, further research is required to fully exploit the genetic potential of agave species. Innovative approaches such as hybridization techniques and biotechnological tools offer opportunities for enhancing their desirable traits. By understanding the genetic diversity and domestication of traditional agave varieties, along with their associated genetic groups and management categories, we can better conserve and utilize these valuable resources.
Directed research efforts focused on the molecular-genetic aspects of agave species will pave the way for their full potential as sustainable bioenergy crops while considering both genetic and cultural factors in the conservation and utilization of agave genetic resources.

3. Agave by-products exhibit diverse chemical compositions:

Agave is comprised of cellulose, hemicellulose, lignin, fructans, pectin, and simple carbohydrates. It possesses functional properties such as prebiotic and antioxidant capabilities. Agave fibers are employed to enhance polymer-based composites owing to their exceptional thermo-mechanical characteristics. Additionally, agave bagasse shows promise as a biofuel feedstock, owing to its impressive water efficiency and biomass yield, and carbohydrate content (Álvarez-Chávez, Villamiel, Santos-Zea, & Ramírez-Jiménez, 2021). Agave leaves offer promising bioactive substances, including saponins, phenolic elements, and terpenes. These substances have demonstrated diverse biological impacts for instance antimicrobial, antifungal, antioxidant, anti-inflammatory, antihypertensive, immunomodulatory, antiparasitic, and anticancer activity. However, the evaluation of agave extracts in culinary utilizations and pharmaceutical applications remains limited. This offers an opportunity for future exploration and development of agave plants as dietary enhancers and therapeutic remedies (López-Romero et al., 2018). *Agave salmiana* bagasse contains functional groups such as carboxyl, hydroxyl, sulfur, and nitrogen. Raw bagasse exhibits significant adsorption capacity for zinc, cadmium, and lead. Treatments involving HNO3 and NaOH can enhance bagasse adsorption capacity by 27-62% (Nieto Delgado, 2010). Ionic liquid (IL) pretreatment using 1-ethyl-3-methylimidazolium acetate ([C_2mim][OAc]) effectively removes calcium oxalate (CaC_2O_4) and reduces cellulose crystallinity in agave bagasse. This IL pretreatment significantly enhances enzymatic kinetics and leads to approximately an eightfold enhance in sugar production in contrast to unprocessed samples. It proves to be an efficient method for processing lignocellulosic biomass with high CaC_2O_4 levels (Perez-

Pimienta et al., 2015). Agave juice, known as aguamiel, comprises 11.5% by weight of dry substance, predominantly consisting of sugars (75 wt %). Fructo-oligosaccharides (FOS) account for 10 wt % of sugars, possessing significant prebiotic properties in the food industry. Other components found in aguamiel include free amino acids, proteins, and ashes (R. I. Ortiz-Basurto et al., 2008). All agave spirits contain notable oxalate concentrations. Tequila contains methanol, 2/3-methyl-1-butanol, and 2-phenyl ethanol concentrations. Mezcal, Sotol, and Bacanora exhibit distinct differences in other volatile constituents and anions (Lachenmeier, Sohnius, Attig, López, & chemistry, 2006).

Chemical composition	**Agave Species**	**Activity**
Saponins	*Agave americana* *Agave sisalana*	Antinutritional, anticancer, antifungal, and anti-inflammatory properties (Santos-Zea, Maria Leal-Diaz, Cortes-Ceballos, & Alejandra Gutierrez-Uribe, 2012).
Polyphenols	*Agave tequilana* *Agave angustifolia*	Antioxidant, antidiabetic, anti-inflammatory, antiparasitic, antimicrobial, prebiotic, and adjuvant properties (Santos-Zea et al., 2012).
Fructans	*Agave tequilana* Weber var. azul	Prebiotic properties (Lopez, Mancilla-Margalli, Mendoza-Díaz, & Chemistry, 2003).
Phenolic Compounds:	*Agave salmiana* *Agave sisalana*	Antimicrobial, antifungal, antioxidant, anti-inflammatory, antihypertensive, immunomodulatory, antiparasitic, and anticancer activity (López-Romero et al., 2018).
Kaempferol	*Agave sisalana*	It holds significance for the chemical and pharmaceutical industries (J. D. G. Santos, Vieira, Braz-Filho, & Branco, 2015).
Mannitol	*Agave sisalana*	It has various applications, including as a sweetener, stabilizer, and potential pharmaceutical excipient (J. D. G. Santos et al., 2015).
Succinic Acid	*Agave sisalana*	It has potential applications as a chemical building block in various industries (J. D. G. Santos et al., 2015).
Fructo-oligosaccharides (FOS)	*Agave tequilana*	It holds significant levels of FOS, which possess prebiotic properties in the food industry (R. I. Ortiz-Basurto et al., 2008).
Carbohydrates	*Agave americana* *Agave sisalana*	These carbohydrates (cellulose, hemicellulose, lignin) contribute to the functional properties of agave, such as prebiotic and antioxidant capabilities (Álvarez-Chávez et al., 2021).
Pectin	*Agave sisalana*	Pectin has various applications in the food and pharmaceutical industries due to its gelling, thickening, and stabilizing properties (J. D. G. Santos et al., 2015) (Santos et al., 2015).
Lignin		Lignin has potential applications in various industries, including as a precursor for biofuels and composite materials (Álvarez-Chávez et al., 2021).
Prebiotic Properties	*Agave americana* *Agave sisalana*	These fibers can stimulate the growth and activity of beneficial gut bacteria, promoting gut health and overall well-being (Álvarez-Chávez et al., 2021).

Table: 1. Composition of agave residual materials

Agro-industrial by-products derived from agave processing exhibit varied chemical makeup, in vitro digestible properties, and rumen microbial processes. Multivariate grouping analysis allows the categorization of these by-products into distinct groups based on their nutritive value. Many of these residuals show potential as alternative components in bovine diets (García-Rodríguez et al., 2019). Chemical sequential steps enable the extraction of pectin, mannitol, succinic acid, kaempferol, and a mixture of saponins from sisal biomass. Characterization of these substances is achieved using analytical techniques like infrared (IR), ultraviolet (UV), mass spectrometry (MS), and nuclear magnetic resonance (NMR). The sisal chemicals identified hold significance for the chemical and pharmaceutical industries (J. D. G. Santos et al., 2015).

The carbohydrate content and fructan distribution profiles in agave plants are affected by the plant's maturity and variety. Specimens aged between two and four years demonstrate the greatest free sugars and fructans levels, with a limited apparent degree of polymerization (DPa) of ≤9 monomers. In contrast, plants aged between ten and twelve years show lower concentrations of available sugars and fructans, achieving a peak DPa of 70 monomers, enabling the production of fractions with varying DPa (Aldrete-Herrera et al., 2019). Fatty acid analysis reveals sixteen fatty acids in different agave plants. Detected lipids comprise liberated fatty acids, campesterol, and different clusters of mono-, di-, and triacylglycerols. Multivariate analyses indicate close similarities between *A. cupreata* and *A. angustifolia* (Martínez-Aguilar, Pena-Alvarez, & chemistry, 2009). Agave is a provider of carbohydrate-laden syrups, inulin, saponins, polyphenols, and other valuable compounds. Saponins possess antinutritional, anticancer, antifungal, and anti-inflammatory properties. Polyphenols exhibit antioxidant, antidiabetic, anti-inflammatory, antiparasitic, antimicrobial, prebiotic, and adjuvant properties (Santos-Zea et al., 2012). Fructans from *Agave tequilana* Weber var. azul comprise multifaceted mixture containing beta (2 ≥ 1), beta (2 ≥ 6), and branch moieties. The length of polymer chains of fructans varies between 3 and 29 components. These fructans differ from fructooligosaccharide, oligofructans, fructooligomers previously thought to be present in *A. tequilana* Weber var. azul (Lopez et al., 2003).

4. The functional potential of agave encompasses and its ability:

Agave residues contain a wide range of biologically active substances, and their composition can vary based on factors such as agave cultivar, maturity, ecological surroundings, and extraction methods (Leal-Díaz et al., 2015). Fructans and saponins have been identified as key metabolites contributing to agave by-product bioactive properties. Fructans, particularly inulin, exhibit prebiotic effects by resisting digestion and stimulating beneficial gut bacteria. They have also been associated with benefits, including reduced blood sugar regulation, improved lipid metabolism, enhanced mineral uptake, and regulation of immune responses. (Santos-Zea, Gutiérrez-Uribe, & Benedito, 2019). Mature agave leaves from the mezcal industry contain significant fructan content. Agave fructans have been utilized as functional components in granola bars and as encapsulation agents. due to their high polymerization degree . Inulin, a type of fructan, is extracted from *A. americana* leaves (Bouaziz et al., 2020). It is known for its role as a readily fermentable material for intestinal microbiota, leading to short-chain fatty acids (SCFAs). Inulin has demonstrated prebiotic effects and is linked to reducing blood lipid and modifying blood sugar levels for metabolic disorders (Gibson, 2004).

Saponins, flavonoids, and terpenes are among the main phytochemicals discovered in agave by-products and are accountable for their physiological effects. Agave saponins have been associated with various health benefits, including hypocholesterolemia, anti-inflammatory properties, immunostimulation, anti-obesity effects, and antiparasitic activities (López-Romero et al., 2018). Foliage and bagasse from the agave plant contain saponins. Steroidal saponins, such as kammogenin glycosides and monogenic glycosides, along with antioxidant compounds, have been identified in *A. salmiana* bagasse using ultrasound-assisted extraction methods (Santos-Zea, Gutierrez-Uribe, & Benedito, 2021; Santos-Zea et al., 2019). Micellar extraction also recovered saponins from *A. sisalana* waste. Agave and its by-products contain other phytochemicals like phenolic compounds, including kaempferol, quercetin, hecogenin, diosgenin, chlorogenin, kammogenin, and gentrogenin (López-Romero et al., 2018; Ribeiro, Barreto, Coelho, & processing, 2015). Overall, agave waste materials exhibit a diverse array of biologically active substances with potential health benefits, making them valuable resources for a wide range of uses in both the culinary and pharmaceutical fields.

4.1. Antioxidant and Anti-inflammatory Activity:

The antioxidant properties of agave waste materials are linked to the occurrence of various compounds, including flavonoids including kaempferol and quercetin detected in the foliage (Hamissa et al., 2012). Additionally, pyranones and pyrazynes identified in bagasse have antioxidant effects in vitro studies (R. Ortiz-Basurto, Rubio-Ibarra, Ragazzo-Sanchez, Beristain, & Jiménez-Fernández, 2017). The agave genus, in general, possesses anti- inflammation properties attributed to saponins, phenolic compounds, and terpenes. Steroidal saponins derived from *A. attenuata* and *A. shevrei* have demonstrated anti-inflammatory effects in models involving cell membrane integrity triggered by acetic acid (Monterrosas-Brisson et al., 2013; Pereira Da Silva, Valente, & Paz Parente, 2006). A blend of sapogenins, for instance hecogenin and thiogenin, and canthalasaponin 1 found in *A. angustifolia* Haw, *A. tequilana* Weber, and *A. americana* contributes to their anti-inflammatory activity (Monterrosas-Brisson et al., 2013). *A. tequilana* and *A. salmiana* bagasse is enriched with saponins, flavonoids, and terpenes after the manufacturing of tequila and pulque (Ibarra-Cantún, Ramos-Cassellis, Marín-Castro, & Castelán-Vega, 2020; Santos-Zea et al., 2021). In a recent metabolomic profiling study, 56 metabolites were identified in the leaves of *A. americana* L., *A. americana* var. marginata Trel*, A. angustifolia* Haw. cv. marginata, *A. desmettiana* Jacobi, and *A. pygmaea* Gentry. The predominant phytochemicals in these waste materials include steroidal saponins, sapogenins, flavonols, homoisoflavonoids, phenolic acids (such as ferulic acid, p-coumaric acid, caffeic acid, p-hydroxybenzoic acid, and syringic acid), and fatty acids (El-Hawary, El-Kammar, Farag, Saleh, & El Dine, 2020). Agave leaf extracts inhibit acute inflammation due to spirostane saponins. Due to their antioxidant and anti-inflammatory activities, agave waste materials have shown potential as prospects for anticancer and anti-hypertensive treatments (Chiocchio, Mandrone, Tomasi, Marincich, & Poli, 2021)). Further research is needed to explore other potential biological effects. While numerous research endeavors have centered on discerning and measuring bioactive substances in agave by-products, the next step should involve validating their biological effects.

4.2. Antibacterial and Antifungal Activity:

Several studies have investigated the antimicrobial properties of various agave species and their by-products. Agave picta extracts demonstrated antibacterial activity against bacteria such as *E. coli*, *L. monocytogenes*, *S. aureus*, and *V. cholerae*. Additionally, all four Agave species inhibit yeast and mold. The active extracts showed minimum microbicidal concentrations ranging between 1.8 and 7.0 mg/ml. and inhibitory concentrations ranging from 3.0 to 6.0 mg/ml (Verástegui et al., 2008). Agave fructans, in "in vitro" experiments, showed antimicrobial activity against *Salmonella Typhimurium*. Different concentrations of Agave fructans significantly affected Salmonella growth, with the 25% concentration exhibiting the most notable impact compared to the control (Villagrán-de la Mora et al., 2019).

A. americana raw and solvent extracts demonstrated antibacterial activity comparable to gentamicin. They exhibited inhibition zones ranging from 17 to 40 mm. They also exhibited minimum inhibitory concentrations of 2.5 mg/ml for *S. aureus*, *P. aeruginosa*, *S. typhi*, and 10 mg/ml for *E. coli* strains. The phytochemical analysis identified alkaloids, saponins, tannins, polyphenols, and flavonoids as constituents of *A. americana*. Among the tested bacterial strains, *S. aureus* showed the highest susceptibility, while *E. coli* showed the lowest susceptibility to extracts (Shegute & Wasihun, 2020). Hydroalcoholic solution derived from agave foliage and sisal residue inhibited *Candida albicans*. However, the methanol extract from foliage exhibited a less potent inhibitory effect against *C. albicans*. Both extracts were inactive against other tested microorganisms (J. D. Santos et al., 2009). Different agave plant compounds were identified for their antimicrobial effects. Linalool displayed the best antibacterial properties, inhibiting seventeen different bacteria. Citral and geraniol showed the highest antifungal activity, inhibiting all twelve tested fungi. Other compounds, including cineole, geraniol, menthol, and citral, also exhibited antibacterial and antifungal activity to varying degrees (Suppakul, Miltz, Sonneveld, Bigger, & chemistry, 2003).

4.3. Agave offers a rich abundance of food ingredients:

Agave, a versatile plant highly valued in Mexican cuisine for its use in traditional beverages like Tequila, Mezcal, Pulque, and Bacanora, holds importance in various culinary and medicinal applications. It has been an integral part of Mexican cuisine for centuries, contributing to texture improvement, microencapsulation, and serving as a prebiotic ingredient in food. Residual leaves from tequila, mezcal, and pulque are commonly roasted or baked to attain a rich caramel color and flavor. They can also be boiled to create a bitter soup or used as a grilling material for meat products (Pérez-España et al., 2019). The thin and translucent cuticle, known as mixiote, is carefully separated from the plant and utilized in various preparations. This is where meats, sauces, and other ingredients are wrapped and steamed, resulting in delectable stews. Agave leaf extracts and bagasse have found applications in the food industry to enhance the techno-functional properties of certain food products. For instance, powdered *A. americana* leaves have been incorporated into steamed yogurt formulations, leading to improvements in color, texture, and viscosity (Bouaziz et al., 2021). Fructans extracted from *A. angustifolia* have been utilized as fat replacers in cookies. This results in reduced calorie and fat content increased soluble fiber, and enhanced sensory and texture properties. These cookies exhibited higher water and oil holding capacity without significant differences in overall preference compared to control cookies without fructan addition (Santiago-García et al., 2021).Agave fructans are known for their low glycemic index, isolated from agave syrup. However, their glycemic response to by-products is less studied. Research has indicated that *A. tequilana* fructans can improve glycemic response and increase satiety hormones when incorporated into the diet (Urias-Silvas et al., 2008). In the formulation of oat-based granola bars, the inclusion of *A. tequilana* fructans resulted in enhanced soluble fiber content and moderate glycemic index products. In vitro, fermentation of these bars demonstrated their prebiotic effect, as they produced beneficial short-chain fatty acids (SCFA) (Zamora-Gasga et al., 2015). Interestingly, incorporating agave bagasse into oat cookies increased fructooligosaccharide content and oil-holding capacity without impacting sensory and textural properties (Escobedo-García et al., 2020). Agave fructans have also shown potential as encapsulating agents, protecting food ingredients from degradation. They have been employed to encapsulate bioactive compounds such as anthocyanins, ensuring stability and preserving antioxidant capacity. Similarly, fructans have been utilized to encapsulate proteolytic extracts, reducing proteolytic activity loss during storage. Through electrospinning, mixtures of whey protein and agave fructans have been used to create encapsulated materials with reduced hygroscopicity, enhanced thermal stability, and controlled release of the encapsulated extract (R. Ortiz-Basurto et al., 2017). Agave bagasses, particularly isolated polysaccharides from *A. salmiana* bagasse, have been employed in the development and stabilization of indomethacin nanoemulsions. They have also shown improved cellular uptake in a human dermal fibroblast model, suggesting potential applications in dermal formulations. Agave by-products exhibit diverse functional properties and play a significant role in Mexican cuisine. Their incorporation enhances various food products, provides encapsulation benefits, and offers potential as prebiotic ingredients (Jiménez-Rodríguez et al., 2021).

5. Agave emerges as a promising biofuel feedstock:

Agave species have been identified as potential biofuel feedstocks in arid and degraded regions, with reported biomass yields ranging from <1 to 34 Mg ha^{-1} yr^{-1} without irrigation. The utilization of approximately 0.6 Mha of previously cultivated land for agave fibers could potentially yield 6.1 billion L of ethanol (Davis, Dohleman, & Long, 2011). Comparatively, *Agave tequilana* and *Opuntia ficus*-indica have shown high water and fertilizer-use efficiency, making them suitable for biofuel production. *A. tequilana* exhibited higher mass fractions of water-soluble constituents, structural carbohydrates, cellulose, hemicellulose, and lignin compared to *O. ficus*-indica. Both species demonstrated high amorphous and para-crystalline cellulose mass fractions, suggesting they are less recalcitrant to deconstruction compared to traditional lignocellulosic biomass feedstocks (!!! INVALID CITATION !!! {}). Agave cultivation in regions with limited rainfall, such as Australia, requires suitable production locations, efficient propagation methods, mechanized production, and viable business plans. Successful integration of Agave into Australian agriculture necessitates collaboration with Mexican researchers for a biofuels-focused breeding program (J. A. Holtum, Chambers, Morgan, & Tan, 2011). Agave's high productivity, low water and nutrient demands, and detailed chemical composition data make it a promising lignocellulosic feedstock for biofuels production on semi-arid lands. Agave exhibits low recalcitrance, with sugar release five to eight times greater than that of poplar wood and switchgrass, owing to its low lignin content and diverse non-cellulosic polysaccharides (Ibarra-Cantún et al., 2020). *Agave tequilana* Weber has been identified as a viable feedstock for sustainable ethanol production in Australia, with existing cultivars, agronomic systems, and fermentation technologies (J. Holtum & Chambers, 2010). Agave and Opuntia species are suitable and sustainable feedstocks for bioenergy and byproducts, particularly in marginal areas such as dry lands, deforested areas, agroforestry systems, and agricultural semi-terraces. Agave's potential as a bioenergy feedstock is attributed to its high land productivity, adaptation to high temperatures, and drought resistance (Honorato-Salazar, Aburto, & Amezcua-Allieri, 2021). Pre-treatment of Agave enhances overall yield in saccharification and fermentation, enabling the production of various liquid and gaseous biofuels, as well as value-added products like enzymes, lactic acid, and succinic acid. Agave bagasse can serve as a substitute for corn stubble in sheep diets, leading to improved weight gain, and can be utilized in the production of agave fiberboards with comparable properties to those made from other fibers (Pérez-Pimienta, López-Ortega, Sanchez, & Biorefining, 2017). The pretreatment-drying of *Agave tequilana* Weber leaves increases the release of reducing sugars, while the aqueous extract obtained after drying shows no presence of inhibitory compounds (Avila-Gaxiola et al., 2017). Agave's composition, including cellulose, hemicellulose, lignin, fructans, pectin, and simple carbohydrates, contributes to its functional properties such as prebiotic and antioxidant capabilities (Álvarez-Chávez et al., 2021). Agave fibers are utilized for their thermo-mechanical properties in polymer-based composite reinforcement. Agave bagasse is considered a promising biofuel feedstock due to its high-water efficiency, biomass productivity, and high carbohydrate content (Robles Barrios, 2017). Agave's performance in terms of land productivity, water-related impacts, fossil energy use, global warming impact, and land use surpasses that of current first-generation biofuel crops like corn and sugarcane (Chatzipavlidis et al., 2013). Agaves possess the potential to be utilized as feedstock for bioenergy production, offering the advantage of not competing with food and fodder production and can be grown on degraded land. Biophysical models, coupled with land availability estimates and economic projections, can be employed to determine the potential biomass availability from agaves, which can be utilized to produce various bioenergy products including ethanol, biodiesel, and biogas (Cushman, Davis, Yang, & Borland, 2015).

5.1. Agave drives sustainability with bioethanol fuel:

The production capacity of bioethanol from agave by-products is comparable to or even superior to other ethanol feedstocks such as maize, switchgrass, and sugarcane in terms of various factors including life cycle energy, water use, and greenhouse gas balances (Davis et al., 2011). The water-soluble carbohydrate (WSC) content of agave leaves, which is readily fermentable, is comparable to conventional lignocellulosic feedstocks like sugarcane bagasse and corn stover (Yang et al., 2015). Studies suggest that the cost of biofuel production from agave stems ranges from 0.5 to 9 USD per liter, but this cost can be significantly reduced if by-products like leaves and bagasse, which are typically considered waste, are utilized (Nunez, Rodriguez, & Khanna, 2011). A recent study reported a calculated cost of USD 1.68 per gallon of bioethanol produced from A. tequilana bagasse, which is lower than the theoretical value reported by the U.S. Department of Energy and the cost of bioethanol production from sugarcane bagasse (Barrera et al., 2016).
Bioethanol can be produced from various sources and is categorized into different generations. Second-generation (2G) bioethanol is derived from lignocellulosic materials (LCM) such as agro-industrial residues (Aguilar, Rodríguez-Jasso, Zanuso, de Rodríguez, et al., 2018; Aguilar, Rodríguez-Jasso, Zanuso, Lara-Flores, et al., 2018). The production of 2G bioethanol involves three main stages. The first stage is pretreatment, which aims to reduce the recalcitrance of the lignocellulosic material and enhance the accessibility of simple sugars. The next stage is enzymatic saccharification or hydrolysis, where enzymes convert cellulose into its monomeric form to obtain fermentable sugars. Finally, fermentation takes place with the help of microbial inoculum to convert sugars into ethanol (Aguilar, Rodríguez-Jasso, Zanuso, de Rodríguez, et al., 2018). Both bagasse and residual leaves of agave plants have been utilized for bioethanol production, with *A. tequilana, A. atrovirens*, and *A. salmiana* being commonly used substrates. Effective delignification through pretreatment is crucial for achieving high ethanol yields, along with efficient saccharification. Various methods have achieved ethanol yields ranging from 38.39 to 55.02 g/L (87-91%) using *A. tequilana* Weber bagasse (Aguilar, Rodríguez-Jasso, Zanuso, de Rodríguez, et al., 2018). Improved enzymatic saccharification processes have yielded a saccharification yield of 93% using A. salmiana leaves (Láinez, Ruiz, Arellano-Plaza, & Martínez-Hernández, 2019). The choice of microbial strain also impacts bioethanol conversion, with *Kluyveromyces marxianus* resulting in higher conversion rates (93%) compared to *Saccharomyces cerevisiae* strains (87%). Fermentation of carbohydrates from *A. tequilana* juice and bagasse with *Saccharomyces cerevisiae* yielded ethanol concentrations of 12.4 g/L and 38.6 g/L, corresponding to yields of 68% and 61%,

respectively, after 7 hours and 13 hours of fermentation (Rijal et al., 2016). Furthermore, fermented juice from *A. tequilana* leaves with Saccharomyces cerevisiae resulted in ethanol concentrations of 13.8 g/L (Aguilar, Rodríguez-Jasso, Zanuso, de Rodríguez, et al., 2018). In a nutshell, bioethanol production from agave by-products, including bagasse and residual leaves, shows promise as a cost-effective and environmentally friendly option. Agave feedstocks have comparable or superior characteristics in terms of energy, water use, and greenhouse gas balances when compared to other ethanol sources. Through appropriate pretreatment, saccharification, and fermentation processes, high ethanol yields can be achieved from agave plants, contributing to the development of second-generation bioethanol.

5.2. Agave: a source for hydrogen and methane production:

Two-stage anaerobic digestion outperformed single-stage processes for energy recovery from *Agave tequilana* bagasse hydrolysates, with the highest hydrogen yields obtained at 40% concentration and the highest methane yields obtained at 20% concentration (Arreola-Vargas, Flores-Larios, González-Álvarez, Corona-González, & Méndez-Acosta, 2016). The potential for hydrogen and methane production from Agave bagasse enzymatic hydrolysates was explored in batch mode, with Celluclast 1.5L and Zymapect demonstrating the highest hydrogen and methane productivities, respectively, offering cost-effective alternatives at the batch scale (Kumar & Ram, 2021). Anaerobic digestion of Tequila's vinasses can produce hydrogen and methane, with optimal conditions including thermophilic growth, a slightly acidic pH range, and longer hydraulic retention time, and mathematical models were found to describe the operational parameters' effect on each response variable (García-Depraect, Diaz-Cruces, & León-Becerril, 2020). Alkaline hydrogen peroxide (AHP) pretreatment of *Agave tequilana* bagasse achieved high delignification and recovery of cellulose and hemicellulose, and subsequent hydrolysis with enzymatic mixtures improved saccharification, resulting in higher hydrogen and methane yields (Galindo-Hernández et al., 2018). Diluted acid hydrolysis of cooked *Agave tequilana* bagasse demonstrated improved sugar extraction compared to uncooked bagasse, and nutrient addition in anaerobic sequencing batch reactors (AnSBR) affected methane production and the archaeal/bacterial ratio (Arreola-Vargas et al., 2015). Autohydrolysis pretreatment of *Agave lechuguilla* solids achieved significant solubilization of xylan and hydrolysis of glucan, and optimal conditions yielded a hydrogen yield of 3.48 mol H_2/mol glucose consumed (Rios-González, Morales-Martínez, Hernández-Enríquez, Rodríguez-De la Garza, & Moreno-Dávila, 2018). Enzymatic hydrolysate of *Agave tequilana* bagasse demonstrated potential for long-term continuous hydrogen production in both CSTR and TBR reactors, with increased organic loading rate enhancing volumetric hydrogen production rate and hydrogen molar yield (Contreras-Dávila, Méndez-Acosta, Arellano-García, Alatriste-Mondragón, & Razo-Flores, 2017). Consolidated bioprocessing of hydrogen production from agave biomass using *Clostridium acetobutylicum* and bovine ruminal fluid was feasible, with bovine ruminal fluid enhancing acid-pretreated agave hydrolysis and achieving maximum hydrogen production at specific conditions (Morales-Martínez et al., 2020). Steam explosion of *Agave tequilana* bagasse resulted in high reducible sugar generation, and optimization through mathematical surface response analysis yielded significant hydrogen production at elevated temperature and appropriate weight-based ratio (Weber, Estrada-Maya, Sandoval-Moctezuma, & Martínez-Cienfuegos, 2019).

5.3. ***Agave's Contribution to Nanocomposites and Nanocrystals:***

Agave by-products, specifically the remaining fibers from the stem after tequila and mezcal processing, as well as fibers obtained from leaves, exhibit remarkable thermo-mechanical properties, including tensile strength and thermal stability. However, natural fibers often have low thermal stability and weak bonding with hydrophobic polymers. To address this, certain chemical pretreatments have been used to modify the surface of agave by-products, improving their compatibility and bonding with hydrophobic polymers and enhancing their properties as composite materials (Madhu et al., 2020). Mercerization treatment, in combination with silane treatment, has been shown to enhance the tensile strength of A. americana fibers, making them suitable for the fabrication of roofing panels when combined with recycled high-density polyethylene (HDPE) (Thamae & Baillie, 2007). Cellulose crystallinity is another important aspect of agave fibers, with higher crystallinity indices typically associated with improved mechanical properties in composites. However, the relationship between fiber crystallinity and mechanical properties is not always consistent (A. Langhorst et al., 2019).

Heating or the application of chemical pre-treatments has been effectively utilized to reduce the amorphous components of *A. americana* leaf fibers. This process improves their compatibility with hydrophobic materials (Madhu et al., 2020), enhances the thermal resistance and crystallinity index of *A. tequilana* fiber-polypropylene composites (A. Langhorst et al., 2019), and increases the stiffness and flexural strength of these composites. In terms of thermal treatments, washing the fibers at a temperature of 85°C using water yielded better compatibility and fiber adhesion to synthetic polymers such as polyethylene, compared to steam heating (A. E. Langhorst et al., 2018). Agave fibers, such as those obtained from *A. tequilana* (commonly known as rambans), have shown promise as reinforcements for various materials, including polyester resins. These fibers have been used to create lightweight composites through mold forming. Researchers have explored the use of *A. tequilana* bagasse fibers in the production of polylactic acid-based composites, which involved extrusion and press molding processes. The addition of 20-40% agave fibers led to improved tensile and flexural strength, although it also increased brittleness and water absorption (Huerta-Cardoso et al., 2020). Another study focused on rotational molding of agave fiber and polylactic acid composites, resulting in lower density materials with increased porosity. However, press molding offered better thermal and mechanical properties, except for hardness, which was enhanced by rotational molding (Cisneros-López et al., 2018). Bioplastics, including poly (3-hydroxybutyrate) (PHB), have gained popularity due to their biodegradable nature. Recent works have investigated the use of PHB and *A. tequilana* bagasse in extruded composites. The inclusion of 25-30% bagasse significantly improved the mechanical properties, particularly tensile and flexural strength, while reducing brittleness (Smith et al., 2020; Torres-Tello et al., 2017). Hybrid composites comprising pine sawdust, agave bagasse, and high-density polyethylene (HDPE) were also fabricated using a twin-screw extruder. The incorporation of agave bagasse enhanced the flexural and tensile strength, while pine sawdust helped reduce water absorption and provide stability to the composites (Pérez-Fonseca et al., 2014). Agave by-products, such as leaves and bagasse, have the potential for nanoparticle production. The abundant cellulose in agave can be used to create nanomaterials with applications in various industries. Sonochemical acid hydrolysis was employed to convert *A. tequilana* leaves and bagasse into cellulose nanocrystals, while mechanical defibrillation was used to obtain cellulose nanofibers. Bagasse exhibited easier conversion into nanocrystals and fibers, likely due to pre-processing during tequila production. The yield was highest from the leaves (93% for crystals and 60.84% for fibers) (Robles et al., 2018). Nanoparticles have also been derived from residues of "pulque" production, where alkaline pretreatment and high-energy milling resulted in nanoparticles with an average size of approximately 3 nm and high crystallinity. Agave by-products hold promise as a valuable source of biomolecules and low-cost biomaterials. They can be utilized in the production of compostable and biodegradable composites, as well as renewable biofuels (Hernández-Varela, Chanona-Pérez, Benavides, Sodi, & Vicente-Flores, 2021).

6. Future prospects of Agave:

Agave species show great promise as economically competitive bioenergy crops, as they can thrive with minimal rainfall and inputs while still producing substantial biomass. In the future, their potential as biofuel feedstocks in arid and degraded regions can be further explored. While alcoholic beverages, sweeteners, fibers, and specialty chemicals are currently the main products derived from agave plants, there is scope for expanding their applications in the future. Research and development efforts can focus on identifying new uses and value-added products from agave (Escamilla-Treviño, 2012). The underutilized land previously used for agave fiber production presents an opportunity for biofuel production, with the potential to yield billions of liters of ethanol.

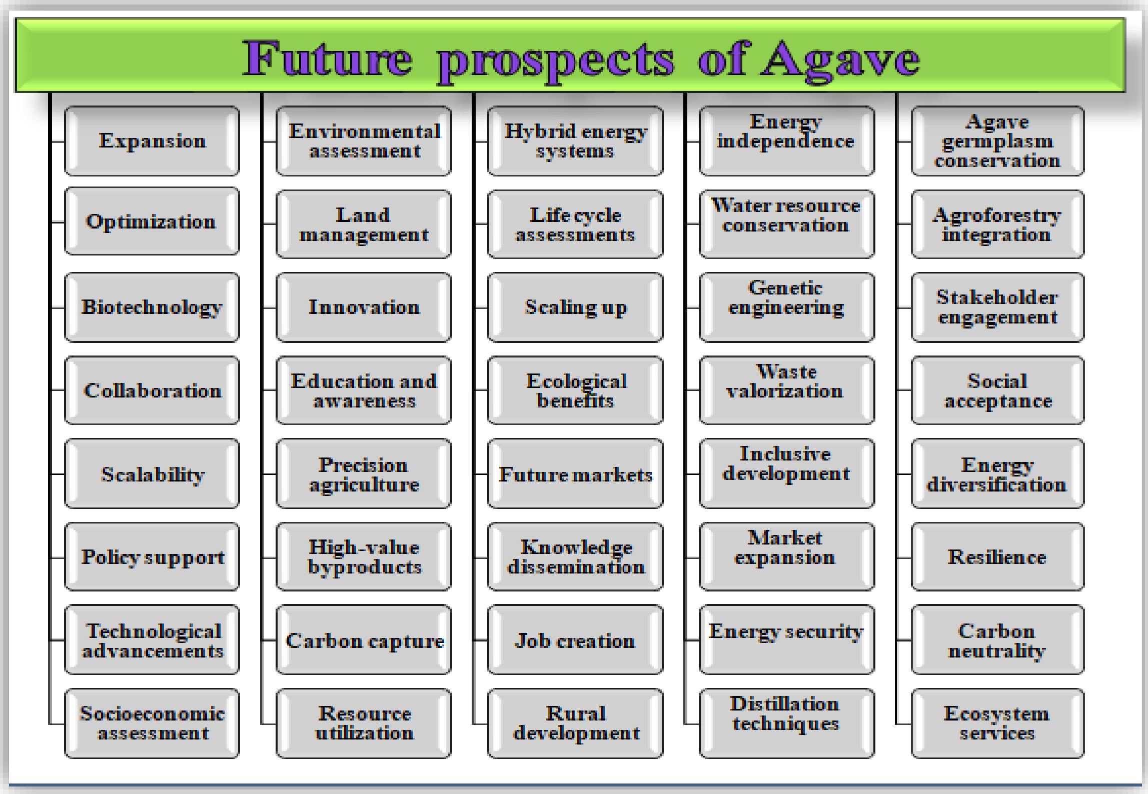

Figure: 4. Future prospects of Agave species

Exploring and optimizing the use of this land can contribute to future bioenergy production. Agave has the potential to be cultivated in regions of limited rainfall, such as Australia. Establishing viable agave farming systems will require suitable production regions, efficient propagation methods, mechanization, and sound business plans. Collaboration with Mexican researchers can aid in developing successful agave integration into Australian agriculture (Davis et al., 2011). The ecological, economic, social, and cultural significance of Agave pulque in Mexico calls for interdisciplinary efforts to value and preserve these plants for their various uses. Future research can explore innovative ways to leverage agave pulque for rural development and agroecological purposes (Blas-Yañez & Thomé-Ortiz, 2021). The cost of biofuel production from agave piña alone may be relatively high, but reducing costs through improved conversion efficiencies or utilizing sugars present in other parts of the plant. Additionally, exploring cellulosic biofuels using the entire plant biomass can offer potential cost reductions (M. Jin et al., 2016). Agave leaves contain a rich composition of valuable components, including sugars, cellulose, polysaccharides, lignin, and proteins. Future studies can focus on optimizing the extraction and utilization of these components for the production of biofuels and value-added products (Corbin et al., 2015)(Corbin et al., 2015). High land productivity, adaptability to high temperatures, and drought resistance make agave a promising bioenergy feedstock. Future research can delve into pre-treatment techniques to enhance scarification and fermentation, leading to improved yields of biofuels and value-added products. Agave holds cultural and economic significance in Mexico and offers potential for industrial applications (Pérez-Pimienta et al., 2017)

Agave biotechnology research can focus on expanding knowledge in production processes, agroecological management, and plant biochemistry and physiology, enabling the successful utilization of agave for various purposes. Agave's resistance to abiotic stress and pathogens makes it a valuable resource for germplasm conservation and biotechnological applications. Future efforts can explore the identified genes with the biotechnological potential to enhance fermentation, bioenergy production, fiber improvement, and biopolymer synthesis (Ibarra-Cantún et al., 2020)). Agave-derived ethanol demonstrates favorable energy and greenhouse gas balances, ethanol output, and net GHG offset per unit land area compared to other biofuels. Future prospects involve leveraging these advantages and exploring bioenergy production from agaves in arid or semi-arid regions with minimal impact on food production and water resources (Yan et al., 2011). Agave's low recalcitrance and high sugar release make it an attractive lignocellulosic feedstock for biofuel production on semi-arid lands. In the future, advancements in biological deconstruction techniques can further enhance sugar release and utilization from agave cell walls, expanding its potential as a bioenergy feedstock. Agave cultivation in arid and degraded regions holds promise for future biofuel production. By exploring suitable agave species and developing efficient cultivation methods, these regions can be transformed into bioenergy hubs, reducing the reliance on traditional fossil fuels (Li et al., 2014). The identification of genes with biotechnological potential in agave opens up opportunities for future genetic engineering and biotechnological applications. By manipulating these genes, researchers can enhance specific traits related to fermentation, fiber quality, and biopolymer production, unlocking the full potential of agave for various industries. Future research on agave should focus on optimizing the conversion efficiency of biomass to biofuels. By improving the pre-treatment processes and exploring innovative technologies for scarification and fermentation, the overall yield and cost-effectiveness of biofuel production from agave can be significantly enhanced (Tamayo-Ordóñez et al., 2018). The development of sustainable value chains and business models around agave-based bioenergy production holds promise for future economic growth. By integrating agave cultivation, processing, and distribution in a sustainable manner, local economies can benefit from job creation, increased income, and improved rural development (Jordan et al., 2007). Optimization and the utilization of different parts of the Agave plant for bioenergy production. While the piña (heart) is commonly used, exploring the sugars and biomass present in leaves stems, and other plant components can increase the overall efficiency and cost-effectiveness of biofuel production. Advances in biotechnology and genetic engineering techniques offer future prospects for enhancing the traits of Agave plants. By manipulating genes related to drought resistance, biomass production, and sugar content, researchers can develop improved Agave varieties that are even more suitable for bioenergy production (Mielenz, Rodriguez, Thompson, Yang, & Yin, 2015). Innovative and efficient harvesting, processing, and conversion technologies specifically tailored to agave biomass. By streamlining these processes, reducing energy requirements, and minimizing waste generation, the overall viability and competitiveness of agave-based bioenergy systems can be enhanced. The utilization of agave byproducts and waste streams for value-added products holds promise for future economic and environmental benefits. Exploring technologies for extracting additional valuable compounds from agave residues, such as bioactive compounds or biodegradable materials, can contribute to a circular and sustainable economy (Yamakawa, Qin, Mussatto, & Bioenergy, 2018). Collaborative research and knowledge exchange between countries with expertise in agave production, such as Mexico, and regions interested in developing their bioenergy sector can facilitate the transfer of best practices and accelerate the adoption of agave-based bioenergy systems worldwide (J. Holtum & Chambers, 2010). Continued efforts in public awareness and education programs can promote the benefits of agave-based bioenergy and foster support from various stakeholders, including policymakers, investors, and local communities. Creating a favorable regulatory and market environment can incentivize further research, investment, and implementation of agave-based bioenergy projects. Integration of remote sensing technologies, precision agriculture, and data analytics can optimize agave cultivation, resource management, and yield prediction. By utilizing advanced tools, farmers and researchers can make data-driven decisions to maximize productivity, reduce resource inputs, and improve sustainability in agave-based bioenergy systems (Escamilla-Treviño, 2012). Future research can focus on developing innovative uses for agave biomass beyond biofuels. Exploring the production of high-value bioproducts, such as bioplastics, bio-based chemicals, or pharmaceutical compounds from agave biomass, can diversify the revenue streams associated with agave cultivation and enhance the overall economic viability of the bioenergy sector. Agave bioenergy systems can be coupled with carbon capture and storage technologies to achieve negative emissions. By capturing and sequestering carbon dioxide emissions generated during the biofuel production process, agave bioenergy can contribute to climate change mitigation and help in achieving carbon neutrality goals (Kumar & Ram, 2021). The scalability of agave bioenergy systems presents future opportunities for commercialization and market expansion. As technological advancements drive down production costs and improve efficiency, agave biofuels can become more economically competitive, attracting investment and driving the growth of a global Agave bioenergy industry (Singh, Gu, & reviews, 2010). Agave bioenergy can play a significant role in achieving national and international renewable energy targets. Governments and policymakers can incentivize agave cultivation and biofuel production through supportive policies, financial incentives, and regulatory frameworks, creating an enabling environment for the growth of the agave bioenergy sector (Medina-Morales et al., 2011).. Technological advancements in the field of agave bioenergy can lead to the development of innovative and efficient conversion processes. Exploring novel enzymatic or microbial approaches for biomass conversion, as well as advanced fermentation and distillation techniques, can improve biofuel yields and enhance overall process efficiency (Rastogi, Shrivastava, & Reviews, 2017). Agave bioenergy systems can be designed to promote circular economy principles. By implementing co-product utilization and waste valorization strategies, such as using agave residues for biogas production or composting, the overall sustainability and resource efficiency of the bioenergy supply chain can be enhanced (Medina-Morales et al., 2011). Agave bioenergy systems can be integrated with other renewable energy sources to create hybrid energy systems. By combining agave-based biofuels with solar, wind, or geothermal energy, a more reliable and sustainable energy supply can be achieved, contributing to energy security and reducing greenhouse gas emissions (Malik, Awasthi, & Sinha, 2021). Agave-based bioenergy should include comprehensive socioeconomic assessments to evaluate the potential impacts on local communities and identify strategies for inclusive and equitable development. This includes considering the social, cultural, and economic implications of large-scale agave cultivation and biofuel production (Dale et al., 2013). The integration of agave bioenergy with sustainable land management practices can contribute to land restoration and biodiversity conservation. Agave cultivation can be combined with agroforestry systems, reforestation efforts, or conservation initiatives, creating multifunctional landscapes that deliver both energy and ecological benefits (Hastings et al., 2020). International collaboration and knowledge sharing can foster global innovation in agave bioenergy. Establishing networks, research partnerships, and information exchange platforms can accelerate the development and adoption of best practices, technologies, and policies, ultimately driving the widespread implementation of agave bioenergy systems worldwide (Reynolds & Borlaug, 2006).

7. Discussion:

The Agave genus has yielded numerous key findings that make contributions to our understanding of these plants. The study efficiently decoded agave's secrets by unveiling its genomic enigma, evolutionary history, and genetic resilience. This sheds mild at the unique genetic makeup and evolutionary diversifications of agave species, highlighting their ability to thrive in numerous environments. Regarding the chemical composition of agave through-products, the study reveals a extensive range of compounds, inclusive of sugars, phenolics, and saponins. Those findings show the wealthy chemical variety of agave plants, which have implications for diverse applications in industries together with food, pharmaceuticals, and cosmetics. The study highlights the antioxidant and anti-inflammatory activities of agave, indicating their capability therapeutic advantages. Moreover, the antibacterial and antifungal properties of agave suggest their use in antimicrobial applications. Furthermore, the identity of agave as a supply of food components opens up opportunities for novel and sustainable meals products. Agave's potential as a biofuel feedstock is explored in detail, specializing in bioethanol production, hydrogen and methane technology, in addition to its utility in nanocomposites and nanocrystals. These findings underscore the promising function of agave in renewable energy and materials, which can make contributions to a greater sustainable future. Inside the context of previous research, the findings of this assessment align with and extend upon current know-how approximately agave plants. They offer a complete assessment of agave's molecular traits, chemical composition, useful residences, and ability applications, adding depth to the present body of literature. For example, the overview closely is predicated on present literature, and the provision and fine of studies may also vary. Moreover, the scope of the overview might not embody all viable aspects of agave, leaving room for in addition exploration and research. In terms of potential follow-up research studies, future investigations may want to delve deeper into precise factors which include the molecular mechanisms underlying agave's functional properties or the optimization of biofuel production strategies. Furthermore, comparative studies among unique agave species or the exploration of untapped agave sources should yield precious insights. This comprehensive evaluation on the versatility and capacity of the agave genus highlights significant findings related to its genomic traits, chemical composition, functional properties, and biofuel potential. The research contributes to our understanding of agave and its diverse applications. The results of those findings amplify to diverse fields, which includes agriculture, medicine, biotechnology, and renewable energy. Overall, this evaluation underscores the significance of agave as a valuable and promising resource and emphasizes the want for in addition studies and innovation in this field.

8. Conclusion:

This comprehensive evaluate has delved into the flexibility and potential of the agave genus, uncovering considerable insights throughout various domains. The findings highlight the genomic enigma, evolutionary records, and genetic resilience of agave species, illuminating their specific diversifications and capacity to thrive in various environments. Moreover, the evaluation elucidates the various chemical compositions of agave by-products, emphasizing their potential implementations in industries including food, pharmaceuticals, and cosmetics.

The functional characteristics of agave are another exquisite element explored in this study, showcasing its antioxidant, anti inflammatory, antibacterial, and antifungal activities. These properties indicate the prospective healing advantages of agave and its role in antimicrobial applications. Additionally, the identity of agave as a supply of food ingredients gives interesting possibilities for novel and sustainable food products. The assessment also highlights agave's capability as a biofuel feedstock, with a focal point on bioethanol production, hydrogen and methane generation, and its utility in nanocomposites and nanocrystals. These findings underscore the promising function of agave in renewable energy and materials, contributing to a extra sustainable future. In precise, this complete study offers a holistic understanding of the agave genus, its molecular characteristics, chemical composition, functional properties, and potential applications. The knowledge received from this study contributes to the prevailing body of research and opens up avenues for further exploration and innovation.

As we part ways, it's far important to ask ourselves: How are we able to harness the total ability of agave to cope with modern challenges and promote sustainability in diverse industries? The opportunities offered by way of agave are monstrous, and it's miles crucial for researchers, policymakers, and enterprise experts to collaborate and capitalize on these findings. This study serves as a call to movement, urging further research and improvement in areas along with agave's molecular mechanisms, optimization of biofuel production, and exploration of untapped sources. By leveraging the versatility and ability of agave, we are able to make vast strides toward a greener and more sustainable future.

Looking in advance, the forecast for agave is promising. Persisted exploration, innovation, and implementation of the information gained from this assessment will pave the way for novel applications, progressed agricultural practices, and sustainable answers. The denouement of agave's story has only just begun, and it is up to us to write down the next chapter in its terrific journey.

References:

1. . (!!! INVALID CITATION !!! {}).
2. Aguilar, D. L., Rodríguez-Jasso, R. M., Zanuso, E., de Rodríguez, D. J., Amaya-Delgado, L., Sanchez, A., & Ruiz, H. A. J. B. t. (2018). Scale-up and evaluation of hydrothermal pretreatment in isothermal and non-isothermal regimen for bioethanol production using agave bagasse. 263, 112-119.
3. Aguilar, D. L., Rodríguez-Jasso, R. M., Zanuso, E., Lara-Flores, A. A., Aguilar, C. N., Sanchez, A., . . . Perception. (2018). Operational strategies for enzymatic hydrolysis in a biorefinery. 223-248.
4. Aguirre-Planter, E., Parra-Leyva, J. G., Ramírez-Barahona, S., Scheinvar, E., Lira-Saade, R., & Eguiarte, L. E. J. F. i. P. S. (2020). Phylogeography and genetic diversity in a southern North American desert: Agave kerchovei from the Tehuacán-Cuicatlán Valley, Mexico. 11, 863.
5. Aldrete-Herrera, P. I., López, M. G., Medina-Torres, L., Ragazzo-Sánchez, J. A., Calderón-Santoyo, M., González-Ávila, M., & Ortiz-Basurto, R. I. J. F. (2019). Physicochemical composition and apparent degree of polymerization of fructans in five wild agave varieties: Potential industrial use. 8(9), 404.
6. Álvarez-Chávez, J., Villamiel, M., Santos-Zea, L., & Ramírez-Jiménez, A. K. J. P. (2021). Agave by-products: An overview of their nutraceutical value, current applications, and processing methods. 2(3), 720-743.

7. Álvarez-Ríos, G. D., Pacheco-Torres, F., Figueredo-Urbina, C. J., Casas, A. J. J. o. E., & Ethnomedicine. (2020). Management, morphological and genetic diversity of domesticated agaves in Michoacán, México. 16, 1-17.
8. Arreola-Vargas, J., Flores-Larios, A., González-Álvarez, V., Corona-González, R. I., & Méndez-Acosta, H. O. J. I. J. o. H. E. (2016). Single and two-stage anaerobic digestion for hydrogen and methane production from acid and enzymatic hydrolysates of Agave tequilana bagasse. 41(2), 897-904.
9. Arreola-Vargas, J., Ojeda-Castillo, V., Snell-Castro, R., Corona-González, R. I., Alatriste-Mondragón, F., & Méndez-Acosta, H. O. J. B. T. (2015). Methane production from acid hydrolysates of Agave tequilana bagasse: evaluation of hydrolysis conditions and methane yield. 181, 191-199.
10. Avila-Gaxiola, E., Avila-Gaxiola, J., Velarde-Escobar, O., Ramos-Brito, F., Atondo-Rubio, G., & Yee-Rendon, C. J. J. o. F. P. E. (2017). Effect of drying temperature on Agave tequilana leaves: a pretreatment for releasing reducing sugars for biofuel production. 40(3), e12455.
11. Avila de Dios, E., Gomez Vargas, A. D., Damian Santos, M. L., & Simpson, J. J. F. i. P. S. (2015). New insights into plant glycoside hydrolase family 32 in Agave species. 6, 594.
12. Balleza, D., Alessandrini, A., & Beltrán García, M. J. J. T. J. o. m. b. (2019). Role of lipid composition, physicochemical interactions, and membrane mechanics in the molecular actions of microbial cyclic lipopeptides. 252(2-3), 131-157.
13. Barrera, I., Amezcua-Allieri, M. A., Estupiñan, L., Martínez, T., Aburto, J. J. C. E. R., & Design. (2016). Technical and economical evaluation of bioethanol production from lignocellulosic residues in Mexico: Case of sugarcane and blue agave bagasses. 107, 91-101.
14. Blas-Yañez, S., & Thomé-Ortiz, H. J. C. R. (2021). Agave pulquero (Agave salmiana), importância socioeconômica e agroecológica e suas perspectivas de desenvolvimento: uma revisão da literatura. 51.
15. Blears, M., De Grandis, S., Lee, H., Trevors, J. J. J. o. I. M., & Biotechnology. (1998). Amplified fragment length polymorphism (AFLP): a review of the procedure and its applications. 21, 99-114.
16. Bouaziz, M. A., Bchir, B., Chalbi, H., Sebii, H., Karra, S., Smaoui, S., . . . Characterization. (2021). Techno-functional characterization and biological potential of Agave americana leaves: impact on yoghurt qualities. 15, 309-326.
17. Bouaziz, M. A., Mokni, A., Masmoudi, M., Bchir, B., Attia, H., & Besbes, S. J. F. B. (2020). Gelling qualities of water soluble carbohydrate from Agave americana L. leaf extracts. 35, 100543.
18. Byers, C., Maughan, P. J., Clouse, J., & Stewart, J. R. J. A. i. p. s. (2014). Microsatellite primers in Agave utahensis (Asparagaceae), a keystone species in the Mojave Desert and Colorado Plateau. 2(9), 1400047.
19. Chatzipavlidis, I., Kefalogianni, I., Venieraki, A., Holzapfel, W. J. S., Conservation, T. o. t., & Processes, S. U. o. M. i. A. (2013). Commission on genetic resources for food and agriculture.
20. Chiocchio, I., Mandrone, M., Tomasi, P., Marincich, L., & Poli, F. J. M. (2021). Plant secondary metabolites: An opportunity for circular economy. 26(2), 495.
21. Cisneros-López, E. O., Pérez-Fonseca, A. A., González-García, Y., Ramírez-Arreola, D. E., González-Núñez, R., Rodrigue, D., & Robledo-Ortíz, J. R. J. A. i. P. T. (2018). Polylactic acid–agave fiber biocomposites produced by rotational molding: A comparative study with compression molding. 37(7), 2528-2540.
22. Coleman-Derr, D., Desgarennes, D., Fonseca-Garcia, C., Gross, S., Clingenpeel, S., Woyke, T., . . . Tringe, S. G. J. N. P. (2016). Plant compartment and biogeography affect microbiome composition in cultivated and native Agave species. 209(2), 798-811.
23. Contreras-Dávila, C. A., Méndez-Acosta, H. O., Arellano-García, L., Alatriste-Mondragón, F., & Razo-Flores, E. J. C. E. J. (2017). Continuous hydrogen production from enzymatic hydrolysate of Agave tequilana bagasse: Effect of the organic loading rate and reactor configuration. 313, 671-679.
24. Corbin, K. R., Byrt, C. S., Bauer, S., DeBolt, S., Chambers, D., Holtum, J. A., . . . Beahan, C. T. J. P. O. (2015). Prospecting for energy-rich renewable raw materials: Agave leaf case study. 10(8), e0135382.
25. Cushman, J. C., Davis, S. C., Yang, X., & Borland, A. M. J. J. o. E. B. (2015). Development and use of bioenergy feedstocks for semi-arid and arid lands. 66(14), 4177-4193.

26. Dale, V. H., Efroymson, R. A., Kline, K. L., Langholtz, M. H., Leiby, P. N., Oladosu, G. A., . . . Hilliard, M. R. J. E. I. (2013). Indicators for assessing socioeconomic sustainability of bioenergy systems: a short list of practical measures. 26, 87-102.
27. Davis, S. C., Dohleman, F. G., & Long, S. P. J. G. B. (2011). The global potential for Agave as a biofuel feedstock. 3(1), 68-78.
28. Deng, G., Huang, X., Xie, L., Tan, S., Gbokie Jr, T., Bao, Y., . . . Yi, K. J. G. (2019). Identification and expression of SAUR Genes in the CAM Plant Agave. 10(7), 555.
29. El-Hawary, S. S., El-Kammar, H. A., Farag, M. A., Saleh, D. O., & El Dine, R. S. J. S. (2020). Metabolomic profiling of five Agave leaf taxa via UHPLC/PDA/ESI-MS inrelation to their anti-inflammatory, immunomodulatory and ulceroprotective activities. 160, 108648.
30. Escamilla-Treviño, L. L. J. B. R. (2012). Potential of plants from the genus Agave as bioenergy crops. 5, 1-9.
31. Escobedo-García, S., Salas-Tovar, J. A., Flores-Gallegos, A. C., Contreras-Esquivel, J. C., González-Montemayor, Á. M., López, M. G., & Rodríguez-Herrera, R. J. P. F. f. H. N. (2020). Functionality of agave bagasse as supplement for the development of prebiotics-enriched foods. 75, 96-102.
32. Espinosa-Andrews, H., & Urias-Silvas, J. E. J. C. P. (2012). Thermal properties of agave fructans (Agave tequilana Weber var. Azul). 87(4), 2671-2676.
33. Figueredo-Urbina, C. J., Álvarez-Ríos, G. D., García-Montes, M. A., & Octavio-Aguilar, P. J. P. O. (2021). Morphological and genetic diversity of traditional varieties of agave in Hidalgo State, Mexico. 16(7), e0254376.
34. Figueredo, C. J., Casas, A., González-Rodríguez, A., Nassar, J. M., Colunga-GarcíaMarín, P., & Rocha-Ramírez, V. J. A. P. (2015). Genetic structure of coexisting wild and managed agave populations: implications for the evolution of plants under domestication. 7, plv114.
35. Galindo-Hernández, K. L., Tapia-Rodríguez, A., Alatriste-Mondragón, F., Celis, L. B., Arreola-Vargas, J., & Razo-Flores, E. J. I. J. o. H. E. (2018). Enhancing saccharification of Agave tequilana bagasse by oxidative delignification and enzymatic synergism for the production of hydrogen and methane. 43(49), 22116-22125.
36. García-Depraect, O., Diaz-Cruces, V. F., & León-Becerril, E. J. F. (2020). Upgrading of anaerobic digestion of tequila vinasse by using an innovative two-stage system with dominant lactate-type fermentation in acidogenesis. 280, 118606.
37. García-Rodríguez, J., Ranilla, M. J., France, J., Alaiz-Moretón, H., Carro, M. D., & López, S. J. A. (2019). Chemical composition, in vitro digestibility and rumen fermentation kinetics of agro-industrial by-products. 9(11), 861.
38. Gibson, G. R. J. C. N. S. (2004). Fibre and effects on probiotics (the prebiotic concept). 1(2), 25-31.
39. Gross, S. M., Martin, J. A., Simpson, J., Abraham-Juarez, M. J., Wang, Z., & Visel, A. J. B. g. (2013). De novo transcriptome assembly of drought tolerant CAM plants, Agave deserti and Agave tequilana. 14(1), 1-14.
40. Hamissa, A. M. B., Seffen, M., Aliakbarian, B., Casazza, A. A., Perego, P., Converti, A. J. F., & processing, b. (2012). Phenolics extraction from Agave americana (L.) leaves using high-temperature, high-pressure reactor. 90(1), 17-21.
41. Hastings, Z., Ticktin, T., Botelho, M., Reppun, N., Kukea-Shultz, K., Wong, M., . . . Practice. (2020). Integrating co-production and functional trait approaches for inclusive and scalable restoration solutions. 2(9), e250.
42. Hernández-Varela, J. D., Chanona-Pérez, J. J., Benavides, H. A. C., Sodi, F. C., & Vicente-Flores, M. J. C. P. (2021). Effect of ball milling on cellulose nanoparticles structure obtained from garlic and agave waste. 255, 117347.
43. Holtum, J., & Chambers, D. (2010). Feasibility of Agave as a feedstock for biofuel production in Australia (Vol. 10): Rural Industry Research and Development Corporation.
44. Holtum, J. A., Chambers, D., Morgan, T., & Tan, D. K. J. G. B. (2011). Agave as a biofuel feedstock in Australia. 3(1), 58-67.
45. Honorato-Salazar, J. A., Aburto, J., & Amezcua-Allieri, M. A. J. S. (2021). Agave and Opuntia species as sustainable feedstocks for bioenergy and byproducts. 13(21), 12263.

46. Huang, X., Xiao, M., Xi, J., He, C., Zheng, J., Chen, H., . . . Liang, Y. J. G. (2019). De novo transcriptome assembly of Agave H11648 by Illumina sequencing and identification of cellulose synthase genes in Agave species. 10(2), 103.
47. Huerta-Cardoso, O., Durazo-Cardenas, I., Longhurst, P., Simms, N. J., Encinas-Oropesa, A. J. I. c., & products. (2020). Fabrication of agave tequilana bagasse/PLA composite and preliminary mechanical properties assessment. 152, 112523.
48. Ibarra-Cantún, D., Ramos-Cassellis, M. E., Marín-Castro, M. A., & Castelán-Vega, R. d. C. J. J. o. F. (2020). Secondary metabolites and antioxidant activity of the solid-state fermentation in apple (Pirus malus L.) and agave mezcalero (Agave angustifolia H.) bagasse. 6(3), 137.
49. Jiménez-Rodríguez, A., Heredia-Olea, E., Barba-Dávila, B. A., Gutiérrez-Uribe, J. A., Antunes-Ricardo, M. J. F., & Processing, B. (2021). Polysaccharides from Agave salmiana bagasse improves the storage stability and the cellular uptake of indomethacin nanoemulsions. 127, 114-127.
50. Jin, G., Huang, X., Chen, T., Qin, X., Xi, J., & Yi, K. J. M. D. P. B. (2020). The complete chloroplast genome of agave hybrid 11648. 5(3), 2345-2346.
51. Jin, M., da Costa Sousa, L., Schwartz, C., He, Y., Sarks, C., Gunawan, C., . . . Dale, B. E. J. G. C. (2016). Toward lower cost cellulosic biofuel production using ammonia based pretreatment technologies. 18(4), 957-966.
52. Jordan, N., Boody, G., Broussard, W., Glover, J., Keeney, D., McCown, B., . . . Neal, J. J. S. (2007). Sustainable development of the agricultural bio-economy. 316(5831), 1570-1571.
53. King, J. (2000). Magical reels: a history of cinema in Latin America: Verso.
54. Kumar, A., & Ram, C. J. E. S. (2021). Agave biomass: a potential resource for production of value-added products. 4(2), 245-259.
55. Lachenmeier, D. W., Sohnius, E.-M., Attig, R., López, M. G. J. J. o. A., & chemistry, F. (2006). Quantification of selected volatile constituents and anions in Mexican Agave spirits (Tequila, Mezcal, Sotol, Bacanora). 54(11), 3911-3915.
56. Láinez, M., Ruiz, H. A., Arellano-Plaza, M., & Martínez-Hernández, S. J. R. e. (2019). Bioethanol production from enzymatic hydrolysates of Agave salmiana leaves comparing S. cerevisiae and K. marxianus. 138, 1127-1133.
57. Langhorst, A., Paxton, W., Bollin, S., Frantz, D., Burkholder, J., Kiziltas, A., & Mielewski, D. J. C. P. B. E. (2019). Heat-treated blue agave fiber composites. 165, 712-724.
58. Langhorst, A. E., Burkholder, J., Long, J., Thomas, R., Kiziltas, A., & Mielewski, D. J. B. (2018). Blue-agave fiber-reinforced polypropylene composites for automotive applications. 13(1), 820-835.
59. Leal-Díaz, A. M., Santos-Zea, L., Martínez-Escobedo, H. C., Guajardo-Flores, D., Gutiérrez-Uribe, J. A., Serna-Saldivar, S. O. J. J. o. a., & chemistry, f. (2015). Effect of Agave americana and Agave salmiana ripeness on saponin content from aguamiel (agave sap). 63(15), 3924-3930.
60. Li, H., Pattathil, S., Foston, M. B., Ding, S.-Y., Kumar, R., Gao, X., . . . Ragauskas, A. J. J. B. f. b. (2014). Agave proves to be a low recalcitrant lignocellulosic feedstock for biofuels production on semi-arid lands. 7(1), 1-11.
61. Lim, S. D., Lee, S., Choi, W.-G., Yim, W. C., & Cushman, J. C. J. F. i. P. S. (2019). Laying the foundation for crassulacean acid metabolism (CAM) biodesign: expression of the C4 metabolism cycle genes of CAM in Arabidopsis. 10, 101.
62. López-Romero, J. C., Ayala-Zavala, J. F., Peña-Ramos, E. A., Hernández, J., González-Ríos, H. J. J. o. f. s., & technology. (2018). Antioxidant and antimicrobial activity of Agave angustifolia extract on overall quality and shelf life of pork patties stored under refrigeration. 55, 4413-4423.
63. López-Romero, J. C., Ayala-Zavala, J. F., González-Aguilar, G. A., Peña-Ramos, E. A., González-Ríos, H. J. J. o. t. S. o. F., & Agriculture. (2018). Biological activities of Agave by-products and their possible applications in food and pharmaceuticals. 98(7), 2461-2474.
64. Lopez, M. G., Mancilla-Margalli, N. A., Mendoza-Díaz, G. J. J. o. A., & Chemistry, F. (2003). Molecular structures of fructans from Agave tequilana Weber var. azul. 51(27), 7835-7840.
65. Madhu, P., Sanjay, M., Jawaid, M., Siengchin, S., Khan, A., & Pruncu, C. I. J. P. T. (2020). A new study on effect of various chemical treatments on Agave Americana fiber for composite reinforcement: Physico-chemical, thermal, mechanical and morphological properties. 85, 106437.

66. Malik, P., Awasthi, M., & Sinha, S. J. I. J. o. E. R. (2021). Biomass-based gaseous fuel for hybrid renewable energy systems: an overview and future research opportunities. 45(3), 3464-3494.
67. Martínez-Aguilar, J. F., Pena-Alvarez, A. J. J. o. a., & chemistry, f. (2009). Characterization of five typical agave plants used to produce mezcal through their simple lipid composition analysis by gas chromatography. 57(5), 1933-1939.
68. Martínez-Rodríguez, J. d. C., Mora-Amutio, M. D. l., Plascencia-Correa, L. A., Audelo-Regalado, E., Guardado, F. R., Hernández-Sánchez, E., . . . Ogura, T. J. B. J. o. M. (2014). Cultivable endophytic bacteria from leaf bases of Agave tequilana and their role as plant growth promoters. 45, 1333-1339.
69. Medina-Morales, M. A., Contreras-Esquivel, J., Garza-Toledo, H., Rodriguez, R., Aguilar, C. N. J. A. J. o. A., & Sciences, B. (2011). Enzymatic bioconversion of agave leaves fiberhydrolysis using Plackett-Burman Design. 6(4), 480-485.
70. Mielenz, J. R., Rodriguez, M., Thompson, O. A., Yang, X., & Yin, H. J. B. f. b. (2015). Development of Agave as a dedicated biomass source: production of biofuels from whole plants. 8(1), 1-13.
71. Monterrosas-Brisson, N., Ocampo, M. L. A., Jiménez-Ferrer, E., Jiménez-Aparicio, A. R., Zamilpa, A., Gonzalez-Cortazar, M., . . . Herrera-Ruiz, M. J. M. (2013). Anti-inflammatory activity of different Agave plants and the compound Cantalasaponin-1. 18(7), 8136-8146.
72. Morales-Martínez, T. K., Medina-Morales, M. A., Ortíz-Cruz, A. L., Rodríguez-De la Garza, J. A., Moreno-Dávila, M., López-Badillo, C. M., & Ríos-González, L. J. I. J. o. H. E. (2020). Consolidated bioprocessing of hydrogen production from agave biomass by Clostridium acetobutylicum and bovine ruminal fluid. 45(26), 13707-13716.
73. Nagarajan, M. (2017). Metagenomics: perspectives, methods, and applications: Academic Press.
74. Nieto Delgado, C. (2010). Production of activated carbon from agave salmiana bagasse and its modification to remove arsenic from water.
75. Nobel, P. S. J. E. B. (1990). Environmental influences on CO2 uptake by agaves, CAM plants with high productivities. 44(4), 488-502.
76. Nunez, H. M., Rodriguez, L. F., & Khanna, M. J. G. B. (2011). Agave for tequila and biofuels: an economic assessment and potential opportunities. 3(1), 43-57.
77. Ortiz-Basurto, R., Rubio-Ibarra, M., Ragazzo-Sanchez, J., Beristain, C., & Jiménez-Fernández, M. J. C. P. (2017). Microencapsulation of Eugenia uniflora L. juice by spray drying using fructans with different degrees of polymerisation. 175, 603-609.
78. Ortiz-Basurto, R. I., Pourcelly, G., Doco, T., Williams, P., Dornier, M., Belleville, M.-P. J. J. o. A., & Chemistry, F. (2008). Analysis of the main components of the aguamiel produced by the maguey-pulquero (Agave mapisaga) throughout the harvest period. 56(10), 3682-3687.
79. Pereira Da Silva, B., Valente, A. P., & Paz Parente, J. J. N. P. R. (2006). A new steroidal saponin from Agave shrevei. 20(04), 385-390.
80. Pérez-España, V., Cuervo-Parra, J., Paz-Camacho, C., Morales-Ovando, M., Gómez-Aldapa, C., Rodríguez-Jimenes, G., . . . Management, S. (2019). General characterization of cuticular membrane isolated from Agave salmiana. 10(1), 46-52.
81. Pérez-Fonseca, A., Robledo-Ortíz, J., Ramirez-Arreola, D., Ortega-Gudiño, P., Rodrigue, D., González-Núñez, R. J. M., & Design. (2014). Effect of hybridization on the physical and mechanical properties of high density polyethylene–(pine/agave) composites. 64, 35-43.
82. Perez-Pimienta, J. A., Lopez-Ortega, M. G., Chavez-Carvayar, J. A., Varanasi, P., Stavila, V., Cheng, G., . . . bioenergy. (2015). Characterization of agave bagasse as a function of ionic liquid pretreatment. 75, 180-188.
83. Pérez-Pimienta, J. A., López-Ortega, M. G., Sanchez, A. J. B., Bioproducts, & Biorefining. (2017). Recent developments in Agave performance as a drought-tolerant biofuel feedstock: agronomics, characterization, and biorefining. 11(4), 732-748.
84. Pimienta, E., Hernandez, G., Domingues, A., & Nobel, P. S. J. T. p. (1998). Growth and development of the arborescent cactus Stenocereus queretaroensis in a subtropical semiarid environment, including effects of gibberellic acid. 18(1), 59-64.
85. Rangel-Landa, S., Casas, A., Dávila, P. J. F. E., & Management. (2015). Facilitation of Agave potatorum: An ecological approach for assisted population recovery. 347, 57-74.

86. Rastogi, M., Shrivastava, S. J. R., & Reviews, S. E. (2017). Recent advances in second generation bioethanol production: An insight to pretreatment, saccharification and fermentation processes. 80, 330-340.
87. Reynolds, M., & Borlaug, N. J. T. J. o. A. S. (2006). Applying innovations and new technologies for international collaborative wheat improvement. 144(2), 95-110.
88. Ribeiro, B. D., Barreto, D. W., Coelho, M. A. Z. J. F., & processing, b. (2015). Use of micellar extraction and cloud point preconcentration for valorization of saponins from sisal (Agave sisalana) waste. 94, 601-609.
89. Rijal, D., Vancov, T., McIntosh, S., Ashwath, N., Stanley, G. A. J. I. C., & Products. (2016). Process options for conversion of Agave tequilana leaves into bioethanol. 84, 263-272.
90. Rios-González, L. J., Morales-Martínez, T. K., Hernández-Enríquez, G. G., Rodríguez-De la Garza, J. A., & Moreno-Dávila, M. J. B. (2018). Hydrogen production by anaerobic digestion from Agave lechuguilla hydrolysates. 13(4), 7766-7779.
91. Robles Barrios, J. E. (2017). Obtention and functionalization of cellulose nanofibers from agave tequilana weber var. azul.
92. Robles, E., Fernández-Rodríguez, J., Barbosa, A. M., Gordobil, O., Carreño, N. L., & Labidi, J. J. C. P. (2018). Production of cellulose nanoparticles from blue agave waste treated with environmentally friendly processes. 183, 294-302.
93. Rocha, M., Good-Ávila, S. V., Molina-Freaner, F., Arita, H. T., Castillo, A., García-Mendoza, A., . . . Botany, F. (2006). Pollination biology and adaptive radiation of Agavaceae, with special emphasis on the genus Agave. 22(1), 329-344.
94. Santiago-García, P. A., Mellado-Mojica, E., León-Martínez, F. M., Dzul-Cauich, J. G., López, M. G., & García-Vieyra, M. I. J. L. (2021). Fructans (agavins) from Agave angustifolia and Agave potatorum as fat replacement in yogurt: Effects on physicochemical, rheological, and sensory properties. 140, 110846.
95. Santos-Zea, L., Gutierrez-Uribe, J. A., & Benedito, J. J. F. E. R. (2021). Effect of solvent composition on ultrasound-generated intensity and its influence on the ultrasonically assisted extraction of bioactives from Agave bagasse (Agave salmiana). 13(3), 713-725.
96. Santos-Zea, L., Gutiérrez-Uribe, J. A., & Benedito, J. J. T. J. o. S. F. (2019). Effect of ultrasound intensification on the supercritical fluid extraction of phytochemicals from Agave salmiana bagasse. 144, 98-107.
97. Santos-Zea, L., Maria Leal-Diaz, A., Cortes-Ceballos, E., & Alejandra Gutierrez-Uribe, J. J. C. B. C. (2012). Agave (Agave spp.) and its traditional products as a source of bioactive compounds. 8(3), 218-231.
98. Santos, J. D., Branco, A., Silva, A. F., Pinheiro, C. S., Neto, A. G., Uetanabaro, A. P., . . . Osuna, J. T. J. A. J. o. B. (2009). Antimicrobial activity of Agave sisalana. 8(22).
99. Santos, J. D. G., Vieira, I. J. C., Braz-Filho, R., & Branco, A. J. I. J. o. M. S. (2015). Chemicals from Agave sisalana biomass: isolation and identification. 16(4), 8761-8771.
100. Sarwar, M. B., Ahmad, Z., Rashid, B., Hassan, S., Gregersen, P. L., Leyva, M. D. l. O., . . . Husnain, T. J. S. r. (2019). De novo assembly of Agave sisalana transcriptome in response to drought stress provides insight into the tolerance mechanisms. 9(1), 396.
101. Saxena, M., Pappu, A., Haque, R., Sharma, A. J. C. F. B.-a. n.-p. c. G. c., & technology. (2011). Sisal fiber based polymer composites and their applications. 589-659.
102. Shegute, T., & Wasihun, Y. J. J. o. E. p. (2020). Antibacterial activity and phytochemical components of leaf extracts of Agave americana. 447-454.
103. Simpson, J., Martinez Hernandez, A., JAZMÍN ABRAHAM JUÁREZ, M., Delgado Sandoval, S., Sanchez Villarreal, A., & Cortes Romero, C. J. G. B. (2011). Genomic resources and transcriptome mining in Agave tequilana. 3(1), 25-36.
104. Singh, J., Gu, S. J. R., & reviews, s. e. (2010). Commercialization potential of microalgae for biofuels production. 14(9), 2596-2610.
105. Smith, M. K., Paleri, D. M., Abdelwahab, M., Mielewski, D. F., Misra, M., & Mohanty, A. K. J. G. C. (2020). Sustainable composites from poly (3-hydroxybutyrate)(PHB) bioplastic and agave natural fibre. 22(12), 3906-3916.
106. Suppakul, P., Miltz, J., Sonneveld, K., Bigger, S. W. J. J. o. a., & chemistry, f. (2003). Antimicrobial properties of basil and its possible application in food packaging. 51(11), 3197-3207.

107. Tamayo-Ordóñez, M., Ayil-Gutiérrez, B., Tamayo-Ordóñez, Y., Rodríguez-Zapata, L., Monforte-González, M., De la Cruz-Arguijo, E., . . . Sánchez-Teyer, L. J. B. P. (2018). Review and in silico analysis of fermentation, bioenergy, fiber, and biopolymer genes of biotechnological interest in Agave L. for genetic improvement and biocatalysis. 34(6), 1314-1334.
108. Thamae, T., & Baillie, C. J. C. I. (2007). Influence of fibre extraction method, alkali and silane treatment on the interface of Agave americana waste HDPE composites as possible roof ceilings in Lesotho. 14(7-9), 821-836.
109. Torres-Tello, E. V., Robledo-Ortíz, J. R., González-García, Y., Pérez-Fonseca, A. A., Jasso-Gastinel, C. F., Mendizábal, E. J. I. c., & products. (2017). Effect of agave fiber content in the thermal and mechanical properties of green composites based on polyhydroxybutyrate or poly (hydroxybutyrate-co-hydroxyvalerate). 99, 117-125.
110. Urias-Silvas, J. E., Cani, P. D., Delmée, E., Neyrinck, A., López, M. G., & Delzenne, N. M. J. B. J. o. N. (2008). Physiological effects of dietary fructans extracted from Agave tequilana Gto. and Dasylirion spp. 99(2), 254-261.
111. Verástegui, Á., Verde, J., García, S., Heredia, N., Oranday, A., Rivas, C. J. W. J. o. M., & Biotechnology. (2008). Species of Agave with antimicrobial activity against selected pathogenic bacteria and fungi. 24, 1249-1252.
112. Verhoek, S. (1989). Environmental Biology of Agaves and Cacti. In: University of Chicago Press.
113. Villagrán-de la Mora, Z., Nuño, K., Vázquez-Paulino, O., Avalos, H., Castro-Rosas, J., Gómez-Aldapa, C., . . . Villarruel-López, A. J. A. (2019). Effect of a synbiotic mix on intestinal structural changes, and Salmonella Typhimurium and Clostridium perfringens colonization in broiler chickens. 9(10), 777.
114. Weber, B., Estrada-Maya, A., Sandoval-Moctezuma, A. C., & Martínez-Cienfuegos, I. G. J. J. o. e. m. (2019). Anaerobic digestion of extracts from steam exploded Agave tequilana bagasse. 245, 489-495.
115. Yamakawa, C. K., Qin, F., Mussatto, S. I. J. B., & Bioenergy. (2018). Advances and opportunities in biomass conversion technologies and biorefineries for the development of a bio-based economy. 119, 54-60.
116. Yan, X., Tan, D. K., Inderwildi, O. R., Smith, J., King, D. A. J. E., & Science, E. (2011). Life cycle energy and greenhouse gas analysis for agave-derived bioethanol. 4(9), 3110-3121.
117. Yang, L., Lu, M., Carl, S., Mayer, J. A., Cushman, J. C., Tian, E., . . . Bioenergy. (2015). Biomass characterization of Agave and Opuntia as potential biofuel feedstocks. 76, 43-53.
118. Zamora-Gasga, V. M., Loarca-Piña, G., Vázquez-Landaverde, P. A., Ortiz-Basurto, R. I., Tovar, J., Sáyago-Ayerdi, S. G. J. L.-F. S., & Technology. (2015). In vitro colonic fermentation of food ingredients isolated from Agave tequilana Weber var. azul applied on granola bars. 60(2), 766-772.