

Addressing Challenges And Implementing Solutions For  
Industrial Crop Resilience

معالجة التحديات وتنفيذ الحلول لتعزيز مرونة المحاصيل الصناعية



-Al Najjar-Al Khaled ,Dayoub Dayoub Moammar , Tarawneh Tarawneh .A Radi ,Khashroum Khashroum .O Ashraf , اشرف خشروم,  
ajzar

جامعة جرش / عضو هيئة تدريسية; عضو هيئة تدريسية  
askshb@yahoo.com, askshb@yahoo.com, askshb@yahoo.com, askshb@yahoo.com, askshb@yahoo.com

\*(Corresponding author) e-mail: [askshb@yahoo.com](mailto:askshb@yahoo.com)

### الملخص

تعيد هذه الدراسة تحليل الروابط المتداخلة بين تغير المناخ، والزراعة المحاصيل الصناعية، والأمن الغذائي العالمي، والاستدامة البيئية والزراعية وتبرز تأثيرات تغير المناخ السلبية على كمية المحاصيل وجودتها وزيادة قابليتها للإصابة بالآفات والأمراض. كما تناقش مساهمة التوسع في الزراعة المحاصيل الصناعية في التنافس على الموارد الحيوية وما ينجم عنه من استنزاف الموارد الطبيعية وتهديدات للأمن الغذائي. مع استكشاف سبل التوافق بين أهداف الإنتاج الزراعي ومتطلبات الاستدامة الزراعية وتناول الدراسة الآثار البيئية المترتبة على هذه الأنظمة. بما في ذلك إزالة الغابات وتدهور التربة وتراجع التنوع البيولوجي. ولمواجهة هذه التحديات، تستعرض الدراسة استراتيجيات تخفيفية محتملة مثل تناوب المحاصيل الصناعية، والزراعة الدقيقة، وتطوير أصناف مقاومة لتغير المناخ، وتطبيقات التكنولوجيا الحيوية. مؤكدة في الوقت ذاته أهمية الأطر السياسية والتنظيمية في دعم التحول نحو أنظمة زراعية أكثر استدامة، وتخلص الدراسة إلى ضرورة اعتماد نهج علمي متكامل يوازن بين زيادة الإنتاجية والحفاظ على البيئة وضمان الأمن الغذائي على المدى الطويل. بما يعزز الفهم الشامل للتحديات المترابطة بين تغير المناخ والزراعة المحاصيل والاستدامة البيئية في العالم

### ABSTRACT

This study reconsiders the complex interconnections between climate change, industrial agriculture, global food security, and environmental sustainability. It highlights the negative impacts of climate change on crop quantity and quality, as well as increased susceptibility to pests and diseases. It also discusses how the expansion of industrial agriculture contributes to competition for vital resources, threatening food security, while exploring possibilities for reconciling agricultural production objectives with sustainability requirements. The study addresses the environmental impacts of these systems, including deforestation, soil degradation, and the decline of biodiversity. To address these challenges, the study reviews potential mitigation strategies such as crop rotation, precision agriculture, the development of climate-resilient varieties, and biotechnology applications. It also emphasizes the importance of policy and regulatory frameworks in supporting the transition to sustainable agricultural systems. The study concludes that an integrated scientific approach that combines increased productivity, environmental conservation, and long-term food security is necessary to enhance understanding of the interconnected challenges of climate change, agriculture, and global sustainability

### Article history:

Submission Date: 12/06/2025

Reviewing Date: 28/07/2025

Revision Date: 14/10/2025

Acceptance Date: 13/10/2025

Publishing Date: 13/11/2025

DOI: 10.6520/fnp5mv30

### Keywords:

Climate Change, Food Security,  
Environmental Sustainability,  
Regulatory Frameworks, Economic and  
Social, Circular Economy

### Funding:

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

### Competing interest:

No competing interests exist.

### Cite as:

اشرف خشروم, Al et al. (2025). Addressing Challenges And Implementing Solutions For Industrial Crop Resilience. Jersah for Research and Studies 25 (4).  
<https://doi.org/10.6520/fnp5mv30>



© The authors (2025). This is an Open Access article distributed under the terms of the Creative Commons Attribution (CC BY) license, which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact [admin@jpu.edu.jo](mailto:admin@jpu.edu.jo).



## ADDRESSING CHALLENGES AND IMPLEMENTING SOLUTIONS FOR INDUSTRIAL CROP RESILIENCE

<sup>1\*</sup>Ashraf O. Khashroum, <sup>2</sup>Radi A. Tarawneh, <sup>3</sup>Moammar Dayoub, <sup>4</sup>Khaled Al-Najjar

<sup>1</sup> Department of Plant Production and Protection, Faculty of Agriculture, Jerash University, 26150 Jerash, JORDAN

<sup>2</sup> Department of Economics, Faculty of Agriculture, Jerash University, 26150 Jerash, JORDAN

<sup>3</sup> Department of Computing, Faculty of Technology, Turku University, 20014 Turku, FINLAND

<sup>4</sup> General Commission for Scientific Agricultural Research, GCSAR 12573 Damascus, SYRIA

\* Correspondence: [askshb@yahoo.com](mailto:askshb@yahoo.com)

### Article history (leave this part):

Submission date:

Received in revised form:

Acceptance date

Available online:

### Keywords:

Theft punishment, Islamic law, Indonesian Criminal law, Sharur (five keywords)

### Funding:

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

### Competing interest:

The author(s) have declared that no competing interests exist.

### Cite as (leave this part):



© The authors (2024). This is an Open Access article distributed under the terms of the Creative Commons Attribution (CC BY NC) (<http://creativecommons.org/licenses/by-nc/4.0/>), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited. For commercial re-use, please contact [admin@jpu.edu.jo](mailto:admin@jpu.edu.jo).

### ABSTRACT

This study reconsiders the complex interconnections between climate change, industrial agriculture, global food security, and environmental sustainability. It highlights the negative impacts of climate change on crop quantity and quality, as well as increased susceptibility to pests and diseases. It also discusses how the expansion of industrial agriculture contributes to competition for vital resources, threatening food security, while exploring possibilities for reconciling agricultural production objectives with sustainability requirements. The study addresses the environmental impacts of these systems, including deforestation, soil degradation, and the decline of biodiversity. To address these challenges, the study reviews potential mitigation strategies such as crop rotation, precision agriculture, the development of climate-resilient varieties, and biotechnology applications. It also emphasizes the importance of policy and regulatory frameworks in supporting the transition to sustainable agricultural systems. The study concludes that an integrated scientific approach that combines increased productivity, environmental conservation, and long-term food security is necessary to enhance understanding of the interconnected challenges of climate change, agriculture, and global sustainability.

**Keywords:** Climate Change, Food Security, Environmental Sustainability, Regulatory Frameworks, Economic and Social, Circular Economy.

## **Introduction**

Commodities play a vital role in the global economy by providing raw materials for agriculture, energy, and manufacturing (Li, 2022). These include agricultural commodities such as wheat, corn, soybeans, cotton, coffee, and livestock products, as well as energy commodities such as crude oil, natural gas, and biofuels, and minerals such as gold, silver, copper, and iron ore. These resources are key drivers of trade, pillars of economic stability, and means of ensuring livelihoods, making their sustainable production critical to balancing economic growth and environmental conservation, especially in light of growing climate challenges (VanDeveer, 2020).

Industrial crops are a key focus of this trend, serving as sources of biofuels, bioplastics, and processed foods (Javaid et al., 2021). Corn is a key ingredient in the production of ethanol, bioplastics, and animal feed (Chong et al., 2021), while cotton is used in the textile and clothing industries (Rita, 2024), sugarcane for sugar and ethanol production (Kar et al., 2023), and sunflower for extracting high-quality edible oil used in the food and cosmetic industries (Algayyim et al., 2021). These crops directly influence agricultural and trade policies, especially in export-dependent developing countries (Scott, 2021).

Sustainability in the production of these crops is gaining increasing importance through the adoption of precision agriculture, smart irrigation, targeted fertilization, and soil improvement (Getahun et al., 2023). The resulting biofuels contribute to reducing carbon emissions (Mahapatra et al., 2021), although large-scale agriculture requires responsible management of natural resources to avoid deforestation and soil degradation (Tian et al., 2021). Biotechnology is thus crucial for enhancing yields, pest resistance, and climate change adaptation, contributing to food security and stable supply chains (Barrows et al., 2014; Ngongolo and Mmbando, 2024).

Industrial crops also contribute to diversifying income sources, attracting investment, and supporting strategic sectors such as textiles, biofuels, and food processing (Jarzebski et al., 2020; Hassoun et al., 2022; Wang et al., 2021). Environmentally, crops such as Miscanthus and switchgrass demonstrate the potential to restore ecosystems, improve soil fertility, and act as natural carbon sinks (Aradottir and Hagen, 2012; Quintarelli et al., 2022). In developing countries, these crops contribute to job creation and increased exports, provided that sustainable agricultural practices are adhered to (Scott, 2021).

To achieve sustainable development in the Middle East through a bioeconomy, a multidimensional approach is required that incorporates effective governance, integrated policies, and extensive international cooperation (Tarawneh et al., 2025). Research has highlighted the importance of enhancing food security, facilitating access to agricultural loans, and employing smart technologies to simultaneously enhance productivity and sustainability (Abo Znemah et al., 2023; Al-Barakeh et al., 2024; Dayoub et al., 2024; Al-Lataifeh et al., 2024; Tarawneh and Al-Najjar, 2023; Tarawneh et al., 2022).

General, industrial crops are a fundamental pillar of the global economy, trade, and sustainability. They support strategic sectors and influence agricultural and trade policies, particularly in developing countries. To maximize benefits and minimize environmental impact, it is essential to bridge the gap between current agricultural practices and sustainable development goals through advances in biotechnology, rational resource management, and the integration of agricultural, environmental, and trade policies.

## **Research aims**

This research aims to study the impact of climate change on industrial crops, analyze their role in enhancing food security, and explore their environmental sustainability, particularly in developing countries. It also seeks to evaluate the regulatory frameworks and policies governing the production of these crops, measure their economic and social impacts, and examine their contribution to the circular economy. The research explores the future of industrial crops by understanding the relationship between sustainability and innovation, and the prospects for development in light of environmental and economic challenges.

## Methodology

This study conducted a literature review to evaluate the role of industrial crops within sustainability frameworks. Academic research published between 2011 and 2025 was collected via Google Scholar, focusing on keywords such as industrial crops, climate change, food security, and environmental sustainability. 184 studies were selected based on strict inclusion criteria, emphasizing sustainability in industrial crop production. Data from these studies were analyzed thematically to extract patterns and insights into how industrial crops contribute to achieving sustainable development goals, economic growth, and environmental resilience.

### *Soybean and Sunflower Production Overlap*

Production overlap was calculated using the following equation (Tilman et al., 2011):

$$Production\ Overlap = \frac{Sop(MMT)}{Top(MMT)} \times (MMT) \quad (\text{Equation 1})$$

$$Top = Sop + Sup$$

Where, Sop =Soy Production; Sup =Sunflower production; Top =Total Production; MMT =Million Metric Tons.

### *Regression Coefficients for Soybean, Sunflower, and Overlap Production*

The data were analyzed using SAS (2012) using a simple linear regression model:

$$Y_i = \mu + B X_i + e_i \quad (\text{Equation 2})$$

Where,  $Y_i$  = Soybean Production/ MMT, Sunflower Production/ MMT, or Production Overlap of  $i^{\text{th}}$  observations;  $\mu$ = Overall mean;  $\beta$ =Regression coefficients;  $X$  = Years of production;  $e_i$  =Random error.

### *Limitations*

This study was limited to English-language publications during a specific time period. Despite these limitations, it offers valuable insights into a transformative approach to achieving sustainable economic and environmental development.

## Findings and Discussion

### *Impacts of climate change*

Climate change poses a major challenge to industrial crops, especially water-intensive ones such as cotton, sugarcane, corn, and sunflower, due to erratic rainfall and drought, which threaten yield stability (Yuan et al., 2024; Yao et al., 2022). Implementing precision agriculture and improving water management are essential solutions to ensure the sustainability of these crops (Monteleone et al., 2023). Rising temperatures also lead to increased pest populations, threatening crops such as soybean and canola, necessitating the development of resistant varieties and the implementation of adaptive management strategies (Skendžić et al., 2021).

Rising carbon dioxide levels affect the quality of crops such as sunflower and corn in terms of oil and starch content (Ainsworth & Long, 2020), reinforcing the need for innovative biological technologies such as genetically modified crops for drought resistance (Abdul Aziz et al., 2022; Jin et al., 2024). Increasing competition for land and water is also exacerbating soil degradation and biodiversity loss, necessitating the adoption of sustainable practices such as crop rotation and integrated management (Hemathilake & Gunathilake, 2021; Padhiary & Kumar, 2024).

In developing countries, unsustainable practices such as deforestation and excessive use of chemicals threaten the sustainability of major crops such as cotton, cocoa, and palm oil (Fahad et al., 2023). Sustainable agricultural technologies are essential to ensure balanced economic and environmental benefits (Agula et al., 2018). These challenges underscore the need for innovation, sustainable practices, and effective policies to ensure the resilience of industrial crops to climate change (Pathirana, 2022).

### ***Industrial crops and food security***

Industrial crops, especially those used for biofuel production such as corn and sugarcane, compete with food crops for land and water, impacting food availability (Dida, 2024; Giller et al., 2021). Large-scale cultivation of these crops can also lead to deforestation and soil degradation (Borras et al., 2015).

Resilient crops such as sorghum, jatropha, and camelliana can be grown on marginal lands, avoiding competition with food crops (Raza et al., 2024). Biotechnology, precision agriculture, and vertical farming contribute to improved productivity and optimal resource utilization (Kabir et al., 2023). Sustainable policies and support for smallholder farmers are vital to balancing food security and the growth of industrial crops.

The need to meet global food demand while maintaining sustainability poses a major challenge in contemporary agricultural discourse (Hemathilake & Gunathilake, 2021). Genetically modified crops have shown significant potential to improve nutritional outcomes (Amna et al., 2020). Furthermore, the application of precision agriculture and advanced agricultural methods, such as climate-smart agriculture, smart irrigation systems, and soil conservation agricultural practices, contribute to improved resource use and high productivity (Samoraj et al., 2024; Poole et al., 2021).

The growing demand for industrial crops, such as soybean and palm oil, is placing increased pressure on water and land resources, a challenge further compounded by the impacts of anthropogenic climate change (Muluneh et al., 2021). To address these resource constraints, an integrated approach that incorporates artificial intelligence and precision irrigation techniques is a critical strategy for ensuring sustainability (Bugge et al., 2016). Furthermore, expanding the bioeconomy can help balance industrial crop use with food security (Scarlat et al., 2015). To mitigate the environmental impact of industrial agriculture, the implementation of comprehensive water management strategies, including desalination and precision irrigation, is essential (Hussain et al., 2019). Investments in post-harvest infrastructure to reduce food waste, along with the formulation and implementation of policies that support sustainable agricultural practices, are also essential for enhancing the resilience of the agricultural sector (Jarzebski et al., 2020).

The convergence of population growth, climate change, and resource depletion poses a significant threat to global food security, with the expansion of industrial crop production considered a contributing factor to these challenges (Pawlak & Kołodziejczak, 2019; Maja et al., 2021). To reconcile the need to ensure food security with the growing demand for industrial crops, strategic land-use planning, sustainable water management practices, and the development of climate-resilient crop varieties are essential (Pawlak & Kołodziejczak, 2019). Industrial crops contribute to global food security, but they require careful management to avoid resource depletion and environmental damage. Solutions include the adoption of resilient crops, precision agriculture, sustainable land-use practices, and policies that support both economic development and food security. Integrating industrial and food crop systems ensures long-term sustainability (Umesha et al., 2017).

The expansion of industrial crop production poses a threat to food security, so adopting solutions such as resilient crops, precision agriculture, and sustainable policies is essential to protect food availability.

### ***Balancing Food Security, Economic, and Sustainability***

Table (1) provides a comprehensive overview of the multifaceted contributions of major industrial crops, illustrating their roles in food security, industrial applications, and sustainability considerations. The table highlights the dual function of crops such as maize, wheat, and soybeans, which are used as basic food commodities and as raw materials for diverse industrial sectors, including biofuels, textiles, and animal feed. While industrial crop cultivation contributes to economic stability and diversification of the agricultural sector, it poses significant sustainability challenges (Feliciano, 2019). The high water demand of crops such as sugarcane and cotton raises fundamental concerns about resource depletion, and the expansion of oil palm and soybean cultivation is associated with deforestation and habitat fragmentation (Lim et al., 2023). The table emphasizes the need to adopt sustainable agricultural practices, such as the use of drought-resistant varieties, precision agriculture techniques, and certification programs, to mitigate negative environmental impacts. It also suggests that strategic policy interventions and technological innovations play a pivotal role in balancing industrial crop production with overall food security goals. Expanding the "Industrial Uses" column to include emerging applications such as bioplastics and

pharmaceuticals, and incorporating underutilized crops such as jatropha and camelliana, would allow for a more comprehensive understanding of the industrial landscape (Abou Assi et al., 2017). Furthermore, including specific mitigation strategies, such as agroforestry for oil palm cultivation and microirrigation for sugarcane, in the "Sustainability Considerations" column enhances the analytical depth of the table. Updating the cited sources with recent peer-reviewed studies or industry reports enhances the table's credibility and reflects current sustainability practices. Ultimately, Table (1) serves as an illustrative framework for understanding the complex relationships between food security, economic development, and environmental sustainability, emphasizing the vital importance of integrated strategies for improving agricultural productivity while simultaneously preserving the integrity of natural resources.

Industrial crops, while balancing food and industrial needs, pose a threat to sustainability; therefore, adopting sustainable practices, modern technologies, and effective policies is essential to reduce resource depletion and deforestation.

**Table 1:** Contribution of industrial crops to food security and sustainability

Industrial Crop	Role in Food Security	Industrial Uses	Sustainability Considerations
Maize (Corn)	Staple food, key ingredient in processed foods	Biofuel (ethanol), animal feed, sweeteners, starch production	Climate resilience, GMOs for higher yields, soil health impact
Wheat	Essential for bread, pasta, cereals; major global calorie source	Flour production, gluten extraction, bioethanol	Drought-resistant varieties, soil conservation techniques
Soybeans	Rich in protein, supports livestock industry	Vegetable oil, biodiesel, soy protein isolates, animal feed	Deforestation concerns, need for sustainable farming practices
Sugarcane	Major source of sugar and energy	Ethanol biofuel, sweeteners, molasses, paper production	High water usage, impact of monoculture farming
Palm Oil	Affordable cooking oil, found in processed foods	Biofuels, cosmetics, detergents	Deforestation, need for sustainable certification
Cotton (Secondary Food Source)	Cottonseed oil used in cooking	Textiles, biofuels, animal feed from cottonseed meal	Water-intensive crop, soil depletion concerns

Sources: (Jarzebski et al., 2020; Pawlak & Kołodziejczak, 2019).

### ***Industrial Crops and Non-Food Production***

Industrial crops, such as corn, sugarcane, and soybeans, are the primary raw materials for biofuel production, providing an opportunity to enhance environmental sustainability by reducing carbon emissions and diversifying energy sources away from fossil fuels (Deora et al., 2021). Furthermore, these crops contribute to atmospheric carbon sequestration through photosynthesis, supporting climate change mitigation efforts (Koriesh & Abo-Soud, 2020). However, the implementation of large-scale biofuel production faces significant challenges, particularly competition with food crops for land and water resources, which can threaten food security, especially in resource-limited regions (Kurowska et al., 2019). Furthermore, intensive agricultural practices associated with biofuel feedstock production can lead to soil degradation, ecosystem disruption, and increased reliance on chemical fertilizers and pesticides, which can further degrade the environment (Hossain et al., 2020; Tudge et al., 2021). To address these multifaceted challenges, adopting sustainable agricultural methodologies that include crop rotation, precision irrigation, and the use of alternative raw materials such as algae and agricultural waste becomes essential to enhance biofuel production efficiency and reduce negative environmental impacts (Sarkar et al., 2019).

The interconnected relationship between industrial crops, such as sugarcane and cotton, and sectors outside food production, particularly the biofuel and textile industries, is documented (Dos Santos et al., 2024). The cultivation of these crops contributes to the creation of diversified economic pathways that enhance the resilience of agricultural communities and provide vital additional income that contributes to achieving sustainable food security (Xie et al., 2023).

Industrial crops are a key component of the bioeconomy, providing essential raw materials for diverse applications including biofuels, bioplastics, pharmaceuticals, and cosmetics (Rathour et al., 2023). This

shift toward bio-based industries contributes to reducing the environmental impact associated with traditional manufacturing and energy production processes (Panoutsou et al., 2022). Notably, perennial crops such as miscanthus and ryegrass play an important role in sequestering atmospheric carbon, while biofuel crops contribute to climate change mitigation by providing renewable alternatives to fossil-fuel-derived energy sources (Wagh et al., 2024).

The cultivation of industrial crops generates significant economic opportunities, particularly for small farmers in developing regions (Jarzebski et al., 2020). By providing raw materials for the production of biofuels, textiles, and vegetable oils, these crops contribute to the diversification of local economies, reducing dependence on imported goods, and stimulating rural development initiatives (Amelework et al., 2021). The growing demand for renewable products is fostering the emergence of new markets for biofuels, bioplastics, and sustainable textiles, driving innovation and attracting investment capital. In addition, industrial crops enhance energy and material security by offering viable alternatives to petroleum-based products and synthetic fibers, reducing dependence on non-renewable resources (Giller et al., 2021).

Industrial crops provide non-food benefits but pose risks to food security and the environment. Therefore, these non-food applications require sustainable practices and the use of diverse non-food raw materials to maximize utilization and minimize risks.

### ***Environmental Sustainability of Industrial Crops***

Industrial crops, including oilseeds, fiber crops, and bioenergy crops, play an important role in reducing dependence on fossil fuels and contributing to climate change mitigation strategies (Rathour et al., 2023; Abiodun, 2017). Notably, crops such as hemp and flax contribute to reducing plastic waste through their use in the production of biodegradable materials (Enarevba & Haapala, 2024). These crops also contribute to improving soil health, restoring degraded lands, and preventing soil erosion (Liaqat et al., 2023). However, the implementation of large-scale agricultural practices can lead to deforestation and biodiversity loss if strict management protocols are not implemented (Gasparatos et al., 2015). Therefore, adopting sustainable agricultural practices, such as crop rotation, agroforestry, and precision farming methods, is essential to improve resource use and promote biodiversity conservation (Karaca & Ince, 2022).

Cotton cultivation, especially in arid regions, poses a significant challenge to sustainable water resource management due to its water-intensive nature (Hussain et al., 2020). To mitigate this challenge, the implementation of efficient irrigation techniques, the development and use of drought-resistant varieties, and the adoption of crop diversification strategies are essential (Vaddula & Singh, 2023; Nikolaou et al., 2020).

The use of chemical pesticides and fertilizers is a major factor in environmental degradation (Tripathi et al., 2019). To mitigate these negative impacts, precision agriculture, biological pest control strategies, and the use of controlled-release fertilizer formulations are key solutions (Zhou et al., 2024; Singh et al., 2020). Additionally, incorporating organic farming practices, such as crop rotation, contributes to enhancing the overall sustainability of agricultural systems (Xing & Wang, 2023).

Achieving long-term food security critically depends on the balance between agricultural productivity and environmental sustainability (Shah & Wu, 2018). The application of advanced technological solutions, including smart irrigation systems, soil sensor networks, and drones, contributes to enhancing resource use efficiency and reducing negative environmental impacts (Obaideen et al., 2022). Furthermore, adopting sustainable agricultural practices, such as using organic fertilizers and implementing crop diversification strategies, contributes to improving soil health and increasing biodiversity, ensuring environmental resilience (Baweja et al., 2020).

Industrial crops, such as soybean, play a role in the transition to renewable energy sources by contributing to carbon emissions reductions through biofuel production (Deora et al., 2021; Kurowska et al., 2019). Intensive agricultural practices, such as monocultures, also contribute to soil degradation and ecosystem disturbance, leading to a decline in biodiversity (Hossain et al., 2020). To mitigate these negative environmental and food security impacts, strategies such as crop rotation, precision irrigation, and the use

of alternative biofuel feedstocks, including algae and agricultural waste, are being implemented (Sarkar et al., 2019).

Cotton cultivation, especially in arid regions, poses a significant challenge to water resource sustainability due to its high water demand, which further exacerbates existing water scarcity issues (Hussain et al., 2020). To mitigate this challenge, water-efficient irrigation techniques such as drip irrigation are being implemented, along with the adoption of drought-tolerant cotton varieties (Vaddula & Singh, 2023). Diversifying agricultural practices by incorporating drought-tolerant crops, such as sorghum, also contributes to enhancing resilience in these water-stressed environments (Nikolaou et al., 2020).

The overuse of pesticides and chemical fertilizers significantly contributes to soil degradation and water pollution, posing a significant threat to environmental health (Tripathi et al., 2019). To combat these negative impacts, innovative agricultural practices are being implemented, including precise pesticide application, biological pest control strategies, and organic farming methods such as crop rotation, with the aim of reducing adverse environmental impacts (Zhou et al., 2024; Singh et al., 2020). These efforts are essential to achieving a sustainable balance between agricultural productivity and environmental conservation.

Achieving an integrated balance between agricultural productivity and environmental sustainability requires the adoption of advanced technological interventions, including smart irrigation systems, soil sensor networks, and drones, to improve resource use efficiency (Obaideen et al., 2022). Meanwhile, the implementation of sustainable agricultural practices, including organic farming, crop diversification strategies, and AI-enabled technologies, contributes to maintaining soil health, reducing reliance on chemical inputs, and enhancing agricultural resilience to climate change (Shah & Wu, 2018; Baweja et al., 2020).

Despite the potential benefits of industrial crops, they carry environmental risks such as deforestation and pollution. Therefore, sustainable practices and modern technologies are essential to achieve a balance between productivity and environmental protection.

### ***Sunflower***

Sunflower oil is a popular industrial crop widely used in the food processing sector. The refining process, which aims to improve sensory properties, oxidative stability, and shelf life, involves a series of chemical transformations to remove impurities such as free fatty acids, viscosities, and pigments. However, this process also results in the reduction of beneficial nutritional components such as vitamin E and unsaturated fatty acids (Zaaboul et al., 2022). To optimally maintain the nutritional profile of the oil, it is recommended to use cold-pressed or unrefined sunflower oil (Chandra et al., 2020).

Sunflower oil refining is a resource-intensive process, requiring large amounts of water and energy (Havrysh et al., 2023). To reduce the environmental impact associated with this process, it is necessary to adopt sustainable technological interventions that include water recycling systems and energy-efficient refining methods (Almusaed et al., 2024).

The development and implementation of innovative refining technologies represents a promising opportunity to preserve the nutritional value of the oil while reducing the environmental impact. The adoption of energy-efficient and water-conserving systems is essential to enhance sustainability in sunflower oil production processes (Javaid et al., 2021; Maitra et al., 2021).

### ***Soybeans***

Global markets rely on soybeans as a vital commodity, primarily used for animal feed, soybean oil, and biofuel. In 2020, Brazil surpassed the United States in soybean production, producing 137 million metric tons (Pompeu et al., 2021). Genetically modified soybean varieties were introduced during the 1990s, significantly improving yields and herbicide resistance (Brookes & Barfoot, 2013).

The expansion of soybean cultivation is associated with significant deforestation, particularly in Brazil, where approximately 1.2 million hectares of forest were lost between 2003 and 2015 (Sauer, 2018). Consequently, habitat loss and soil degradation remain critical issues associated with large-scale soybean production. Initiatives such as the Roundtable for Responsible Soy (RTRS) contribute to the promotion of

responsible agricultural practices (Schilling-Vacaflor et al., 2021). The implementation of practices such as no-till farming and crop rotation is essential to mitigate environmental degradation while maintaining agricultural productivity (Somasundaram et al., 2020).

**Global Production Trends and Overlap**

Global production trends indicate a significant increase in the cultivation of both soybeans and sunflowers over time. The expansion of soybean production, driven primarily by the adoption of genetically modified (GM) varieties and increasing demand for animal feed, has expanded into areas traditionally devoted to sunflowers, such as Eastern Europe and South America (Martignone et al., 2024). Consequently, this spatial overlap between the two crops has led to increased competition for agricultural land and resources (Table 2).

The "Production Overlap" column in Table 2 also illustrates the growing geographic overlap between soybean and sunflower cultivation within global agricultural markets. This spatial and market overlap has been exacerbated by the expansion of soybean cultivation into areas traditionally devoted to sunflowers (DeHaan et al., 2016).

The global expansion of soybean cultivation, fueled by genetically modified (GM) varieties and growing demand, reflects its overlap with sunflower cultivation, creating competition for land and resources. This trend requires strategic agricultural planning to ensure sustainable production of both crops.

**Table 2:** Global trends in production and overlap between soybeans and sunflowers

Year	Soybean Production (MMT)	Sunflower Production (MMT)	Production Overlap*
1950s	35	6.5	0.5
1970s	60	9	1.5
1980s	80	12	2.0
1990s	130	14	4.0
2000s	220	17	5.5
2010s	340	19	7.0
2020	360	20	7.5
2023	380	21	8.0

\*Production Overlap: Calculated based on relative relationship between the two productions. MMT =Million Metric Tons.

**Technological Advances, Sustainability, and Production**

Technological innovations have played a pivotal role in enhancing the yields of both soybeans and sunflowers. The application of genetic modification (GM) technologies has significantly increased soybean yields, while sunflower production has benefited from agricultural advances, including the use of hybrid seeds and mechanized harvesting techniques (Mustafa & Iqbal, 2021).

However, the cultivation of both crops poses distinct sustainability challenges. Soybean cultivation is associated with deforestation, while sunflower cultivation often contributes to soil degradation. To ensure their long-term sustainability, the adoption of sustainable agricultural practices such as agroforestry and conservation agriculture is essential (Konefal et al., 2023; Rotundo et al., 2024).

Global average production is estimated at 200,625; 14,813 and 4,500 million metric tons (MMT) for soybeans and sunflowers, and their production overlap, respectively (Table 3). These values are estimated from raw data (FAOSTAT, 2023).

These estimates highlight the significant global production importance of both crops, with soybeans being the most dominant. Production overlap also indicates the presence of common agricultural conditions or practices between the two crops, reinforcing the importance of understanding these trends in improving resource allocation, enhancing sustainability, and meeting global food and industrial demand (Tian et al., 2018).

Table 3 shows the high predictive power of the regression models used to analyze industrial crop production, with high explanatory power across all variables. The statistical significance of the estimates

indicates a high degree of reliability of the observed relationships. Soybean production has the strongest effect, while sunflower production models have the highest accuracy. The variable "production overlap" also plays an important role, reflecting the influence of common production factors on more than one crop (Reiss & Drinkwater, 2017).

These confirm that these models provide valuable insights for agricultural planning and sustainability analysis, as technology enhances production, despite persistent environmental challenges that call for integrated solutions.

**Table 3:** Regression estimates for industrial crop production and model fit

Variables	Estimate $\pm$ Std. Error	p-Value	R-Square
Soybean Production (MMT)	5.378 $\pm$ 0.699	0.0003	0.91
Sunflower Production (MMT)	0.208 $\pm$ 0.001	0.0001	0.98
Production Overlap	0.113 $\pm$ 0.009	0.0001	0.96

MMT = Million Metric Tons.

### **Regulatory Framework and Policies**

The Rotterdam Convention (1998) is a vital tool for protecting human health and the environment by regulating international trade in hazardous chemicals (Núñez-Rocha & Martínez-Zarzoso, 2019). The Convention faces major challenges, most notably weak implementation commitment and difficulty communicating information effectively (Kinniburgh et al., 2023). Strengthening international cooperation and providing technical support are essential measures to improve the effective implementation of the Convention's provisions (Onyeaka et al., 2023).

The Paris Climate Agreement (2015) plays a pivotal role in supporting sustainable agricultural practices, reducing greenhouse gas emissions, and enhancing climate resilience (Sharma et al., 2019; Nsabiyeze et al., 2024). However, implementation faces significant obstacles, such as a lack of investment in sustainable technologies and resistance to change within traditional agricultural systems (Rehman et al., 2020). To overcome these challenges, effective financing mechanisms, the adoption of climate-smart agriculture, and the establishment of knowledge-sharing platforms are essential tools for disseminating best practices and innovative solutions (Manna et al., 2020; Senapati & Das, 2024).

EU biofuel legislation seeks to strike a delicate balance between supporting renewable energy and implementing strict sustainability standards, while maintaining food security (Viccaro et al., 2019; Suali & Suali, 2022). However, the practical implementation of these regulatory frameworks faces several challenges, such as high production costs, land-use conflicts, and the ongoing need for innovation in sustainable production technologies (Suhara et al., 2024). To address these interconnected challenges, it is crucial to conduct in-depth research studies to improve biofuel efficiency, adopt economic incentives to encourage sustainable practices, and implement strategic land-use planning that mitigates competition between biofuel production and food provision (Rahman et al., 2022; Morone et al., 2019).

U.S. Food and Drug Administration (FDA) regulations are a key tool for ensuring the safety of genetically modified (GM) crops and mitigating their associated risks (Turnbull et al., 2021; Ghimire et al., 2022). Key challenges associated with these regulations include poor public trust, potential long-term impacts, and rapid developments in biotechnology technologies (Rodricks, 2020; James, 2024). To address these issues, transparency must be enhanced, rigorous risk assessments conducted, and international cooperation strengthened (Sharma et al., 2022; Reuber, 2019).

Transparency initiatives enable consumers to make informed decisions and strengthen risk management frameworks (Nielsen et al., 2021; Turnbull et al., 2021). However, challenges include balancing consumers' desire for clear information with scientific consensus, ensuring label accuracy, and addressing pest resistance (Hanlon & Sewalt, 2020). Key solutions include establishing clear labeling guidelines, implementing ongoing monitoring mechanisms, and promoting scientific research.

Legislative frameworks also encourage the adoption of environmentally sustainable agricultural practices (Bonn et al., 2020; Kyriakopoulos et al., 2022), but effective enforcement and compliance with regulations

remain major challenges (Verschuuren, 2022; Lykogianni et al., 2021). Compliance and effectiveness can be enhanced through adequate training, financial support, and strict oversight mechanisms.

FDA policies also contribute to protecting public health by ensuring food safety standards (Ghimire et al., 2022; Ladics, 2018). However, public skepticism and the ongoing development of biotechnology remain pressing issues (Soares et al., 2019). Improved transparency and comprehensive risk assessments are essential.

FDA policies play a critical role in mitigating environmental risks associated with food production and biotechnology (Rodricks, 2020; James, 2024). Long-term environmental impacts and pest resistance remain significant challenges (Sharma et al., 2022; Reuber, 2019). Therefore, continued environmental monitoring and enhanced scientific research efforts are essential to sustainable risk management.

The FDA approval process is a key pillar for ensuring the safety and efficacy of food products and biotechnologies before they reach the market (Turnbull et al., 2021; Ladics, 2018). A critical challenge is balancing technological advances with safety requirements, which requires adherence to rigorous testing and evaluation protocols.

Transparency in regulatory processes enhances consumer confidence and enables informed decisions (Nielsen et al., 2021; Hanlon & Sewalt, 2020). However, ensuring accurate labeling and responding to consumer concerns is a significant challenge. These challenges can be mitigated by establishing clear regulatory guidelines and investing in public awareness programs.

Sustainable agricultural practices contribute to improved soil health, water conservation, biodiversity preservation, reduced emissions, increased yields, and enhanced economic resilience (Rehman et al., 2020; Suhara et al., 2024). However, high startup costs and the need for specialized training are major barriers (Boix-Fayos et al., 2023; Rahman et al., 2022). Providing transitional support and financial assistance can facilitate the adoption of these practices.

The success of implementation is affected by a range of obstacles, including high costs, limited access to technology, resistance to change, financial constraints, weak political support, and climate variability (Raihan et al., 2024; Erekaló et al., 2024; Viccaro et al., 2019; Morone et al., 2019; Waqar, 2024; Sharma et al., 2019). Addressing these interconnected challenges requires targeted financial incentives, comprehensive policy reforms, and educational interventions to promote understanding and stimulate broader adoption (Bennett et al., 2018).

Effective measures include financial incentives, government support, awareness programs, precision agriculture technologies, regenerative agriculture, renewable energy integration, policy strengthening, and collaborative research (Nsabiyeze et al., 2024; Manna et al., 2020; Jeswani et al., 2020; Turnbull et al., 2021; Nielsen et al., 2021; Fermeiglia & Perišić, 2023). These strategies contribute to achieving environmental sustainability, increasing productivity, supporting innovation, and ensuring long-term resilience in agricultural and food production systems (Coomes et al., 2018).

To effectively regulate sustainable agriculture and ensure the safety of biotechnology, policies must address barriers related to cost and resistance. This requires an integrated framework that combines incentives, rigorous standards, targeted education, and strategic technology deployment to provide a supportive environment for the adoption of responsible and sustainable practices.

### ***Economic and Social Impact of Industrial Crops***

Industrial crops, which include oil crops such as soybean (*Glycine max*) and sunflower (*Helianthus annuus*), fiber crops such as cotton (*Gossypium spp.*), and biofuel crops such as maize (*Zea mays*) and sugarcane (*Saccharum officinarum*), are a fundamental component of global economic and social frameworks. These crops are key drivers of income generation, employment, and rural development, particularly in agrarian economies (Arumugam & Manida, 2023). They also contribute to international trade and industrial production, including sectors such as food processing, textile manufacturing, and biofuel production (Rehman et al., 2021; Ceyhan et al., 2022). Moreover, bioenergy crops, such as sugarcane (*Saccharum officinarum*) and oil palm (*Elaeis guineensis*), are expected to contribute to sustainable investments by reducing dependence on fossil fuel sources (Zamri et al., 2022).

Industrial crop cultivation faces a number of complex challenges, most notably market volatility, the impacts of climate change, and competition for arable land with food crops (Rathour et al., 2023). Commodity price fluctuations directly impact farmers' incomes, while the increasing frequency and intensity of extreme weather events lead to reduced crop yields (Chau & Scrimgeour, 2023). The spread of large-scale monoculture systems is also associated with significant environmental degradation and a decline in biodiversity (Qi et al., 2024). To mitigate these challenges, priority must be given to implementing sustainable agricultural practices such as crop rotation, agroforestry, and responsible land use. Developing climate-resilient varieties, promoting value-added processing industries, and adopting fair trade policies are also essential to ensuring the long-term stability and sustainability of industrial crop production (Mahto & Mahato, 2025; Valizadeh & Bijani, 2020).

Industrial crop cultivation plays a vital role in promoting social stability by improving rural livelihoods and reducing poverty (Ahmed et al., 2019). Sustainable agricultural practices, such as intercropping and agroforestry, contribute to increased productivity while preserving environmental integrity (Karaca & Ince, 2022). Strategic investments in infrastructure development, such as irrigation systems and treatment facilities, strengthen rural economies and reduce rural-urban migration (Velázquez et al., 2023). Integrating industrial crops into comprehensive sustainability programs enables improved resource use, supporting long-term economic stability and environmental conservation (Nhemachena et al., 2020; Perović et al., 2024).

The industrial crop sector provides extensive employment opportunities across integrated value chains, from agricultural production to processing and manufacturing (Jarzebski et al., 2020). In developing economies, industries based on crops such as cotton (*Gossypium spp.*), flax (*Linum usitatissimum*), and sugarcane (*Saccharum officinarum*) contribute significantly to national employment rates, thereby enhancing economic growth (Sjah & Zainuri, 2020). Furthermore, the production of value-added goods, such as biofuels and textiles, contributes to increased income and enhanced financial security for target groups (Provin et al., 2021).

Farmers engaged in industrial crop cultivation face significant economic constraints due to the high costs of production inputs, including seeds, fertilizers, and pesticides, leading to a decline in overall profit margins (Maja et al., 2021). Climate challenges exacerbate these pressures, as increasingly unpredictable weather patterns due to climate change lead to reduced crop yields (Kumar et al., 2021). Growing drought-resistant varieties and implementing climate-smart agriculture practices are effective strategies for enhancing resilience and improving resource use efficiency (Kremsa, 2020).

To mitigate these financial constraints and environmental challenges, providing targeted financial support, improving access to affordable agricultural inputs, and implementing comprehensive training programs in climate-smart agriculture are essential interventions. These measures enable farmers to maintain productivity levels, enhance their resilience to climate variability, and ensure the sustainability of agricultural production (Solomon et al., 2022).

Despite their economic importance, industrial crops face severe market and climate fluctuations. Therefore, adopting sustainable agricultural practices and providing effective support to farmers is essential to ensuring resilience and enhancing social well-being.

### ***Sustainability of Industrial Crops in Developing Countries***

The cultivation of major industrial crops, including soybean (*Glycine max*), oil palm (*Elaeis guineensis*), cotton (*Gossypium spp.*), and sugarcane (*Saccharum officinarum*), occupies a vital position in global commodity markets, serving as key sources of raw materials for diverse sectors including food processing, biofuel production, textile manufacturing, and industrial applications (Siqueira et al., 2022). However, the expansion of these crops into developing economies poses a complex set of challenges related to environmental sustainability, economic development trajectories, and socioeconomic impacts (Zeidan et al., 2015).

The spread of industrial crop cultivation often leads to land-use conflicts and the displacement of small farmers. In many geographical contexts, large agricultural companies prioritize cash crop production over basic food commodities, reducing the availability of land for subsistence farming and consequently impacting regional food security (Panoutsou et al., 2022). Furthermore, the heavy use of pesticides

associated with industrial agriculture can lead to significant environmental pollution and health risks, particularly for agricultural workers and nearby communities (Rubika et al., 2024).

Government policy frameworks, including subsidy programs aimed at stimulating biofuel production, have encouraged the widespread cultivation of industrial crops such as soybean (*Glycine max*) and palm oil (*Elaeis guineensis*), often contributing to deforestation and the resulting loss of biodiversity (Ben Fradj et al., 2020). Although international sustainability programs and certifications, most notably the Roundtable on Sustainable Palm Oil (RSPO) and the Better Cotton Initiative (BCI), seek to mitigate these negative impacts, their effectiveness varies, particularly in developing countries (Duarte et al., 2021).

Technological advances, including the development and deployment of genetically modified (GM) crops and the application of precision agriculture methodologies, offer potential opportunities to enhance agricultural productivity while simultaneously reducing environmental impacts (Srivastav et al., 2024). For example, genetically modified soybean varieties designed to resist herbicides can reduce the need for intensive weed control measures, increasing crop efficiency (Altaf et al., 2024). The adoption of mechanical harvesting techniques, particularly in sugarcane (*Saccharum officinarum*), has significantly improved operational efficiency and reduced associated environmental impacts (Adhikari et al., 2024).

Achieving an integrated balance between food security, economic growth, and environmental sustainability requires the implementation of an integrated systematic framework (Streimikis & Baležentis, 2020). Agroforestry practices, land-use improvement strategies, and the implementation of water-efficient irrigation systems are essential components for ensuring sustainable industrial crop production (Panoutsou et al., 2022). In many developing countries, industrial crops such as cotton (*Gossypium spp.*) and oil palm (*Elaeis guineensis*) play a significant role in driving economic development, creating jobs, and contributing to foreign exchange (Jarzebski et al., 2020). However, their cultivation places significant pressure on water resources and contributes to soil degradation, particularly in climate-sensitive geographic areas (Hussain et al., 2020). The ethical considerations associated with industrial crop production constitute an important area of research, particularly regarding land distribution equity, institutional accountability mechanisms, and the protection of vulnerable farming communities (Mahto & Mahato, 2025). As consumers become more aware of environmental and social externalities, there is a growing demand for sustainably produced goods, such as organic cotton and deforestation-free palm oil. This consumer-driven demand is driving companies to adopt more ethical sourcing practices (Sisti et al., 2021).

Implementing an integrated management model for industrial crop production is essential to achieve a balance between resource sustainability and economic viability (Bottrell and Schoenly, 2018). Policy frameworks should prioritize the promotion of sustainable agricultural practices, including providing incentives for the adoption of precision agriculture and organic farming systems (Bugge et al., 2016). Furthermore, developing a bioeconomy based on the use of renewable resources such as soybean (*Glycine max*) for biodiesel production and sugarcane (*Saccharum officinarum*) for bioethanol production can support industrial crop production without compromising food security objectives (Scarlat et al., 2015). Targeted support mechanisms for smallholder farmers, particularly those involved in the production of staple food crops, are vital to ensure equitable participation and minimize potential negative impacts on food availability (Bizikova et al., 2020).

Investments in post-harvest infrastructure and sustainable water management systems are essential to reduce resource waste and maximize efficiency. For example, precision irrigation technologies and water harvesting systems can effectively mitigate water scarcity challenges, especially in areas with extensive sugarcane and soybean cultivation (Hussain et al., 2019).

By adopting these strategies, agricultural systems can achieve greater resilience to climate change impacts and improve economic stability, enhancing sustainability in both food production and industrial crops (Amelework et al., 2021).

To ensure sustainable industrial crop production in developing countries, whose economic growth is highly dependent on them, integrated strategies are essential. These strategies include locally adapted sustainable practices, ethical policies that promote social and environmental justice, and targeted technologies to enhance productivity while minimizing negative impacts.

### ***Industrial crops in the circular economy***

The circular economy model, which focuses on reducing waste generation and maximizing resource efficiency by promoting reuse and recycling, represents a viable framework for sustainable development (Morsetto, 2020). Industrial crops contribute to sustainability principles by providing renewable raw materials for diverse industrial applications, including biofuel production, bioplastics and textile. This use of renewable resources reduces reliance on fossil fuels and non-biodegradable materials, mitigating environmental impacts (Freitas et al., 2021).

Bioplastics, derived from renewable and biodegradable raw materials, constitute a sustainable alternative to traditional fossil-fuel-based polymers, reducing the environmental impact associated with plastic waste (Coppola et al., 2021). Corn (*Zea mays*) is the primary raw material in bioplastic production, particularly in the manufacture of polylactic acid (PLA), a polymer widely used in packaging, single-use plastics, and food containers (Taib et al., 2023). Polylactic acid is biodegradable, facilitating natural decomposition and reducing the accumulation of plastic waste (Ncube et al., 2019).

However, bioplastic production creates competition for land and water resources with food crop cultivation and is characterized by high manufacturing costs (Rosenboom et al., 2022). Developing cost-effective production methods that simultaneously address competing demands on agricultural resources remains a significant challenge (Moshood et al., 2022).

The widespread cultivation of industrial crops, including cotton (*Gossypium spp.*), maize (*Zea mays*), and soybean (*Glycine max*), significantly impacts biodiversity, necessitating the implementation of sustainable management strategies to balance agricultural production with ecosystem conservation (Padhiary and Kumar, 2024). Monoculture practices contribute to the loss of species diversity, while the intensive use of pesticides and fertilizers degrades soil health and pollutes aquatic systems (Peter, 2023). Strategies such as crop diversification, integrated farming systems, organic farming practices, and reduced chemical inputs are essential to mitigate these negative environmental impacts (Gamage et al., 2023). Furthermore, establishing protected areas within agricultural landscapes can contribute to protecting biodiversity while maintaining agricultural productivity (Weynants et al., 2020). Energy crops, such as maize (*Zea mays*), sugarcane (*Saccharum officinarum*), and soybean (*Glycine max*), play a pivotal role in biofuel production, contributing to reduced dependence on fossil fuels and mitigating greenhouse gas emissions (Deora et al., 2021). Ethanol production from maize and biodiesel from soybean offers an important pathway to climate change mitigation through atmospheric carbon dioxide sequestration during crop growth (Gür, 2022). However, the large-scale cultivation of these energy crops poses challenges in competing with food crop production, raising concerns about food security (Zhuang et al., 2022). Addressing these multifaceted challenges requires advances in biofuel conversion technologies to enhance efficiency and reduce negative environmental impacts (Shahid et al., 2021). Implementing sustainable land-use planning strategies is also critical to balancing energy production, food security, and environmental conservation goals (Kumar and Sharma, 2024).

Industrial crops are essential components of multiple economic sectors beyond food production. Sugarcane (*Saccharum officinarum*) plays a vital role in biofuel production, contributing to reducing dependence on fossil fuels, while cotton (*Gossypium spp.*) supports the textile industry (Dos Santos et al., 2024). Diversifying industrial crop cultivation contributes to enhancing economic resilience and providing multiple sources of income for farming communities, reducing exposure to market fluctuations (Xie et al., 2023). The income generated from these crops helps finance investments in improving agricultural practices, infrastructure development, and enhancing livelihoods, supporting the long-term sustainability of agricultural systems (Verma et al., 2019).

Within the framework of the circular economy, industrial crops provide renewable resources for the production of sustainable products, but their widespread use requires addressing competition with food production and environmental impacts through improved farming, technology, and land management.

### **The future of industrial crops is sustainable and innovative**

In the future, achieving sustainable industrial crop farming requires adopting smart and integrated solutions to address environmental and social challenges, such as climate change and resource scarcity. The expansion of precision agriculture, supported by artificial intelligence and sensors, will contribute to

improving water and input use efficiency, increasing productivity while reducing environmental impact. Genetically modified crops are also a promising tool for enhancing drought and disease resistance and improving nutritional value, which requires updating regulatory policies and encouraging responsible innovation. Regenerative agriculture and crop diversification represent supportive pathways for soil regeneration and biodiversity protection. By integrating technology, inclusive governance, and scientific research, a more resilient and sustainable agricultural future can be built.

## Conclusions

The industrial crops sector faces increasing challenges due to climate change, requiring integrated solutions that include technology, resistant varieties, sustainable practices, and supportive policies. Adopting sustainable agriculture and integrated resource and pest management is essential to reduce environmental damage and ensure food security. Sustainability in this sector requires effective regulatory frameworks and a multidimensional approach that balances economic growth and environmental conservation, especially in developing countries. The circular economy and biotechnology represent pivotal tools for a resilient agricultural future that combines productivity with environmental and social responsibility.

## References

- [1] Abdul Aziz, M., Brini, F., Rouached, H., & Masmoudi, K. (2022). Genetically engineered crops for sustainably enhanced food production systems. *Frontiers in Plant Science*, 13. <https://doi.org/10.3389/fpls.2022.1027828>
- [2] Abiodun, O.A. (2017). The role of oilseed crops in human diet and industrial use. 249-263. <https://doi.org/10.1002/9781119048800.ch14>
- [3] Abo Znemah S., Tarawneh R., Shnaigat S., Al-Najjar K. (2023). Estimating Some Indicators of Food Security for Rural Households. *Asian Journal of Agriculture and Food Sciences*. Vol. 11 – Issue 1. <https://doi.org/10.24203/ajafs.v11i2.7171>
- [4] Abou Assi, R., Darwis, Y., Abdulbaqi, I. M., Khan, A. A., Vuanghao, L., & Laghari, M. (2017). Morinda citrifolia (Noni): A comprehensive review on its industrial uses, pharmacological activities, and clinical trials. *Arabian Journal of Chemistry*, 10(5), 691-707. <https://doi.org/10.1016/j.arabjc.2015.06.018>
- [5] Adhikari, P., Araya, H., Aruna, G., Balamatti, A., Banerjee, S., Baskaran, P., Verma, A. (2017). System of crop intensification for more productive, resource-conserving, climate-resilient, and sustainable agriculture: experience with diverse crops in varying agroecologies. *International Journal of Agricultural Sustainability*, 16(1), 1–28. <https://doi.org/10.1080/14735903.2017.1402504>
- [6] Agula, C., Akudugu, M.A., Mabe, F.N. *et al.* (2018). Promoting ecosystem-friendly irrigation farm management practices for sustainable livelihoods in Africa: the Ghanaian experience. *Agric Econ* 6, 13. <https://doi.org/10.1186/s40100-018-0109-1>
- [7] Ahmad, M. (2020). Developing a Competitive Agriculture and Agro-based Industry under CPEC. In: Syed, J., Ying, YH. (eds) *China's Belt and Road Initiative in a Global Context*. Palgrave Macmillan Asian Business Series. Palgrave Macmillan. Cham. [https://doi.org/10.1007/978-3-030-18959-4\\_10](https://doi.org/10.1007/978-3-030-18959-4_10)
- [8] Ahmed, A., Campion, B.B. & Gasparatos, A. (2019). Towards a classification of the drivers of jatropha collapse in Ghana elicited from the perceptions of multiple stakeholders. *Sustain Sci* 14, 315–339. <https://doi.org/10.1007/s11625-018-0568-z>
- [9] Ainsworth, E.A., & Long, S.P. (2020). 30 years of free-air carbon dioxide enrichment (FACE): What have we learned about future crop productivity and its potential for adaptation? *Global Change Biology*, 27(1), 27-49. <https://doi.org/10.1111/gcb.15375>
- [10] Al-Barakeh, F.; Khashroum, A.O.; Tarawneh, R.A.; Al-Lataifeh, F.A.; Al-Yacoub, A.N.; Dayoub, M.; Al-Najjar, K. (2024). Sustainable Sheep and Goat Farming in Arid Regions of Jordan. *Ruminants*, 4, 241–255. <https://doi.org/10.3390/ruminants4020017>
- [11] Algayyim, S.J., Yusaf, T., Hamza, N.H., Wandel, A.P., Fattah, I.M., Laimon, M., & Rahman, S.M. (2021). Sugarcane Biomass as a Source of Biofuel for Internal Combustion Engines (Ethanol and Acetone-Butanol-Ethanol): A Review of Economic Challenges. *Energies*, 15(22), 8644. <https://doi.org/10.3390/en15228644>
- [12] Al-Lataifeh, F.A., Radi A.T., Al-Taha'at E.S., Dayoub M., Sutinen E., & Al-Najjar K. (2024). Smart Technologies for Livestock Sustainability and Overcoming Challenges: A Review. *Xi'an Shiyou Daxue Xuebao (Ziran Kexue Ban)/ Journal of Xi'an Shiyou University, Natural Sciences Edition*. (67, 09, 196-204). Zenodo. <https://doi.org/10.5281/zenodo.13744058>
- [13] Almusaed, A., Yitmen, I., Myhren, J. A., & Almssad, A. (2024). Assessing the Impact of Recycled Building Materials on Environmental Sustainability and Energy Efficiency: A Comprehensive Framework for Reducing Greenhouse Gas Emissions. *Buildings*, 14(6), 1566. <https://doi.org/10.3390/buildings14061566>

- [14] Altaf, M.T. et al. (2024). Conventional and Biotechnological Approaches for the Improvement of Industrial Crops. In: Kumar, N. (eds) *Industrial Crop Plants. Interdisciplinary Biotechnological Advances*. Springer, Singapore, [https://doi.org/10.1007/978-981-97-1003-4\\_1](https://doi.org/10.1007/978-981-97-1003-4_1)
- [15] Amelework, A. B., Bairu, M. W., Maema, O., Venter, S. L., & Laing, M. (2021). Adoption and Promotion of Resilient Crops for Climate Risk Mitigation and Import Substitution: A Case Analysis of Cassava for South African Agriculture. *Frontiers in Sustainable Food Systems*, 5, 617783. <https://doi.org/10.3389/fsufs.2021.617783>
- [16] Amna, Qamar, S., Tantray, A.Y., Bashir, S.S., Zaid, A., Wani, S.H. (2020). Golden Rice: Genetic Engineering, Promises, Present Status and Future Prospects. In: Roychoudhury, A. (eds) *Rice Research for Quality Improvement: Genomics and Genetic Engineering*. Springer, Singapore. [https://doi.org/10.1007/978-981-15-5337-0\\_25](https://doi.org/10.1007/978-981-15-5337-0_25)
- [17] Aradottir, A. L., & Hagen, D. (2012). Ecological Restoration: Approaches and Impacts on Vegetation, Soils and Society. *Advances in Agronomy*, 120, 173-222. <https://doi.org/10.1016/B978-0-12-407686-0.00003-8>
- [18] Arumugam, U., and M. Manida. (2023). Agripreneurship for Sustainable Economic Development in India. *ComFin Research*, 11, 4, pp. 15–23. <https://doi.org/10.34293/commerce.v11i4.6662>
- [19] Barrows, Geoffrey, Steven Sexton, and David Zilberman. (2014). Agricultural Biotechnology: The Promise and Prospects of Genetically Modified Crops. *Journal of Economic Perspectives*, 28 (1): 99–120, <https://doi.org/10.1257/jep.28.1.99>
- [20] Baweja, P., Kumar, S., Kumar, G. (2020). Fertilizers and Pesticides: Their Impact on Soil Health and Environment. In: Giri, B., Varma, A. (eds) *Soil Health. Soil Biology*, vol 59. Springer, Cham., [https://doi.org/10.1007/978-3-030-44364-1\\_15](https://doi.org/10.1007/978-3-030-44364-1_15)
- [21] Ben Fradj, N., Rozakis, S., Borzęcka, M., & Matyka, M. (2020). Miscanthus in the European bio-economy: A network analysis. *Industrial Crops and Products*, 148, 112281. <https://doi.org/10.1016/j.indcrop.2020.112281>
- [22] Bennett, S., Lockyer, L., & Agostinho, S. (2018). Towards sustainable technology-enhanced innovation in higher education: Advancing learning design by understanding and supporting teacher design practice. *British Journal of Educational Technology*, 49(6), 1014-1026. <https://doi.org/10.1111/bjet.12683>
- [23] Bizikova, L., Nkonya, E., Minah, M., Hanisch, M., Turaga, R.M., Speranza, C.I., Karthikeyan, M., Tang, L., Kelly, J., Celestin, A.C., & Timmers, B.A. (2020). Scoping review of the contributions of farmers' organizations to smallholder agriculture. *Nature Food*, 1(10), 620-630. <https://doi.org/10.1038/s43016-020-00164-x>
- [24] Boix-Fayos, C., & De Vente, J. (2023). Challenges and potential pathways towards sustainable agriculture within the European Green Deal. *Agricultural Systems*, 207. <https://doi.org/10.1016/j.agsy.2023.103634>
- [25] Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., Feindt, P.H., Hagedorn, G., Hansjürgens, B., Herzon, I., Lomba, A., Marquard, E., Moreira, F., Nitsch, H., Oppermann, R., Perino, A., Röder, N., Schleyer, C., Schindler, S., Wolf, C., Zinngrebe, Y., Lakner, S. (2020). Action needed for the EU Common Agricultural Policy to address sustainability challenges. *People and Nature*, 2(2), 305-316. <https://doi.org/10.1002/pan3.10080>
- [26] Borrás, S.M., Franco, J.C., Isakson, S.R., Levidow, L., & Vervest, P. (2015). The rise of flex crops and commodities: implications for research. *The Journal of Peasant Studies*, 43(1), 93–115. <https://doi.org/10.1080/03066150.2015.1036417>
- [27] Bottrell DG, Schoenly KG. (2018). Integrated pest management for resource-limited farmers: challenges for achieving ecological, social and economic sustainability. *The Journal of Agricultural Science*. 156(3):408-426. <https://doi.org/10.1017/S0021859618000473>
- [28] Brookes, G., & Barfoot, P. (2013). The global income and production effects of genetically modified (GM) crops 1996–2011. *GM Crops & Food*, 4(1), 74–83. <https://doi.org/10.4161/gmcr.24176>
- [29] Bugge, M.M., Hansen, T., & Klitkou, A. (2016). What Is the Bioeconomy? A Review of the Literature. *Sustainability*, 8(7), 691. <https://doi.org/10.3390/su8070691>
- [30] Ceyhan, V., Türkten, H., Yıldırım, Ç., & Canan, S. (2022). Economic viability of industrial hemp production in Turkey. *Industrial Crops and Products*, 176, 114354. <https://doi.org/10.1016/j.indcrop.2021.114354>
- [31] Chandra, S., Kumar, M., Dwivedi, P., & Shinde, L. P. (2020). Functional and nutritional health benefit of cold-pressed oils: a review. *Journal of Agriculture and Ecology*, 9(9), 21–29. <https://saaer.org.in/journals/index.php/jae/article/view/275>
- [32] Chau, T.N., & Scrimgeour, F. (2023). Will climate change jeopardize the Vietnamese target of maintaining farmland for food security? A fractional multinomial logit analysis of land use choice. *Agricultural Economics*, 54(4), 570-587. <https://doi.org/10.1111/agec.12787>
- [33] Chong, T.Y., Law, M.C. & Chan, Y.S. (2021). The Potentials of Corn Waste Lignocellulosic Fibre as an Improved Reinforced Bioplastic Composites. *J. Polym Environ* 29, 363–381. <https://doi.org/10.1007/s10924-020-01888-4>
- [34] Coomes, O.T., Barham, B.L., MacDonald, G.K., Ramankutty, N., & Chavas, J. (2018). Leveraging total factor productivity growth for sustainable and resilient farming. *Nature Sustainability*, 2(1), 22-28. <https://doi.org/10.1038/s41893-018-0200-3>

- [35] Coppola, G., Gaudio, M.T., Lopresto, C.G. et al. (2021). Bioplastic from Renewable Biomass: A Facile Solution for a Greener Environment. *Earth Syst Environ* 5, 231–251. <https://doi.org/10.1007/s41748-021-00208-7>
- [36] Dayoub, M.; Shnaigat, S.; Tarawneh, R.A.; Al-Yacoub, A.N.; Al-Barakeh, F.; Al-Najjar, K. (2024). Enhancing Animal Production through Smart Agriculture: Possibilities, Hurdles, Resolutions, and Advantages. *Ruminants*, 4, 22–46. <https://doi.org/10.3390/ruminants4010003>
- [37] DeHaan, L. R., Van Tassel, D. L., Anderson, J. A., Asselin, S. R., Barnes, R., Baute, G. J., Cattani, D. J., Culman, S. W., Dorn, K. M., Hulke, B. S., Kantar, M., Larson, S., Marks, M. D., Miller, A. J., Poland, J., Ravetta, D. A., Rude, E., Ryan, M. R., Wyse, D., Zhang, X. (2016). A Pipeline Strategy for Grain Crop Domestication. *Crop Science*, 56(3), 917-930. <https://doi.org/10.2135/cropsci2015.06.0356>
- [38] Deora, P.S., Verma, Y., Muhal, R.A., Goswami, C., & Singh, T. (2021). Biofuels: An alternative to conventional fuel and energy source. *Materials Today: Proceedings*, 48, 1178-1184. <https://doi.org/10.1016/j.matpr.2021.08.227>
- [39] Dida, G. (2024). Biotechnology towards energy crops. *CABI Agric Biosci* 5, 45. <https://doi.org/10.1186/s43170-024-00245-y>
- [40] Dorinet, E., Jouvét, P., & Wolfersberger, J. (2021). Is the agricultural sector cursed too? Evidence from Sub-Saharan Africa. *World Development*, 140, 105250. <https://doi.org/10.1016/j.worlddev.2020.105250>
- [41] Dos Santos, F. K., Carvalho, I. G., Ribeiro, R., & Florencio, V. (2024). High Added-Value by-Products from Biomass: A Case Study Unveiling Opportunities for Strengthening the Agroindustry Value Chain. *Biomass*, 4(2), 217-242. <https://doi.org/10.3390/biomass4020011>
- [42] Duarte, L.O., da Silva, M.B., da Silva Marques, M.A., Contin, B., Filho, H.F., Barúque-Ramos, J. (2021). Brazilian Organic Cotton Network: Sustainable Driver for the Textile and Clothing Sector. In: Gardetti, M.Á., Larios-Francia, R.P. (eds) *Sustainable Fashion and Textiles in Latin America*. Textile Science and Clothing Technology. Springer, Singapore. [https://doi.org/10.1007/978-981-16-1850-5\\_14](https://doi.org/10.1007/978-981-16-1850-5_14)
- [43] Enarevba, D.R., & Haapala, K.R. (2024). The Emerging Hemp Industry: A Review of Industrial Hemp Materials and Product Manufacturing. *AgriEngineering*, 6(3), 2891-2925. <https://doi.org/10.3390/agriengineering6030167>
- [44] Erekaló, K.T., Pedersen, S.M., Christensen, T., Denver, S., Gemtou, M., Fountas, S., & Isakhanyan, G. (2024). Review on the contribution of farming practices and technologies towards climate-smart agricultural outcomes in a European context. *Smart Agricultural Technology*, 7. <https://doi.org/10.1016/j.atech.2024.100413>
- [45] Fahad, S., Nguyen-Thi-Lan, H., Nguyen-Manh, D. et al. (2023). Analyzing the status of multidimensional poverty of rural households by using sustainable livelihood framework: policy implications for economic growth. *Environ Sci Pollut Res* 30, 16106–16119. <https://doi.org/10.1007/s11356-022-23143-0>
- [46] FAOSTAT. (2021). *Crops and livestock products: Sugarcane*. Food and Agriculture Organization of the United Nations. Retrieved from <https://www.fao.org/faostat/en/#data/QCL>
- [47] Feliciano, D. (2019). A review on the contribution of crop diversification to Sustainable Development Goal 1 “No poverty” in different world regions. *Sustainable Development*, 27(4), 795-808. <https://doi.org/10.1002/sd.1923>
- [48] Fermeiglia, M., & Perišić, M. (2023). Unpacking the legal conundrum of nature-based soil remediation and sustainable biofuels production in the European Union. *Soil Security*, 13. <https://doi.org/10.1016/j.soisec.2023.100109>
- [49] Freitas, L.C., Barbosa, J.R., Da Costa, A.L.C., Bezerra, F.W.F., Pinto, R.H.H., & Carvalho Junior, R.N.D. (2021). From waste to sustainable industry: How can agro-industrial wastes help in the development of new products? *Resources, Conservation and Recycling*, 169, 105466. <https://doi.org/10.1016/j.resconrec.2021.105466>
- [50] Gamage, A., Gangahagedara, R., Gamage, J., Jayasinghe, N., Kodikara, N., Suraweera, P., & Merah, O. (2023). Role of organic farming for achieving sustainability in agriculture. *Farming System*, 1(1), 100005. <https://doi.org/10.1016/j.farsys.2023.100005>
- [51] Gasparatos, A., Von Maltitz, G., Johnson, F., Lee, L., Mathai, M., Puppim de Oliveira, J., & Willis, K. (2015). Biofuels in sub-Sahara Africa: Drivers, impacts and priority policy areas. *Renewable and Sustainable Energy Reviews*, 45, 879-901. <https://doi.org/10.1016/j.rser.2015.02.006>
- [52] Getahun, S., Kefale, H., & Gelaye, Y. (2023). Application of Precision Agriculture Technologies for Sustainable Crop Production and Environmental Sustainability: A Systematic Review. *The Scientific World Journal*, 2024(1). <https://doi.org/10.1155/2024/2126734>
- [53] Ghimire, B.K., Yu, C.Y., Kim, W., Moon, H., Lee, J., Kim, S.H., & Chung, I.M. (2022). Assessment of Benefits and Risk of Genetically Modified Plants and Products: Current Controversies and Perspective. *Sustainability*, 15(2), 1722. <https://doi.org/10.3390/su15021722>
- [54] Giller, K.E., Delaune, T., Silva, J.V. et al. (2021). The future of farming: Who will produce our food?. *Food Sec.* 13, 1073–1099. <https://doi.org/10.1007/s12571-021-01184-6>

- [55] Gür, T.M. (2022). Carbon Dioxide Emissions, Capture, Storage and Utilization: Review of Materials, Processes and Technologies. *Progress in Energy and Combustion Science*, 89. <https://doi.org/10.1016/j.peccs.2021.100965>
- [56] Hanlon, P., & Sewalt, V. (2020). GEMs: genetically engineered microorganisms and the regulatory oversight of their uses in modern food production. *Critical Reviews in Food Science and Nutrition*, 61(6), 959–970. <https://doi.org/10.1080/10408398.2020.1749026>
- [57] Hassoun, A., Prieto, M.A., Carpena, M., Bouzembrak, Y., Marvin, H.J., Pallarés, N., Barba, F.J., Punia Bangar, S., Chaudhary, V., Ibrahim, S., & Bono, G. (2022). Exploring the role of green and Industry 4.0 technologies in achieving sustainable development goals in food sectors. *Food Research International*, 162. <https://doi.org/10.1016/j.foodres.2022.112068>
- [58] Havrysh, V., Kalinichenko, A., Pysarenko, P., & Samojlik, M. (2023). Sunflower Residues-Based Biorefinery: Circular Economy Indicators. *Processes*, 11(2), 630. <https://doi.org/10.3390/pr11020630>
- [59] Hemathilake, D., & Gunathilake, D. (2021). Agricultural productivity and food supply to meet increased demands. *Future Foods*, 539-553. <https://doi.org/10.1016/B978-0-323-91001-9.00016-5>
- [60] Hossain, A. et al. (2020). Agricultural Land Degradation: Processes and Problems Undermining Future Food Security. In: Fahad, S., et al. *Environment, Climate, Plant and Vegetation Growth*. Springer, Cham, [https://doi.org/10.1007/978-3-030-49732-3\\_2](https://doi.org/10.1007/978-3-030-49732-3_2)
- [61] Hussain, M. I., Muscolo, A., Farooq, M., & Ahmad, W. (2019). Sustainable use and management of non-conventional water resources for rehabilitation of marginal lands in arid and semiarid environments. *Agricultural Water Management*, 221, 462-476. <https://doi.org/10.1016/j.agwat.2019.04.014>
- [62] Hussain, S. et al. (2020). Irrigation Scheduling for Cotton Cultivation. In: Ahmad, S., Hasanuzzaman, M. (eds) *Cotton Production and Uses*. Springer, Singapore. [https://doi.org/10.1007/978-981-15-1472-2\\_5](https://doi.org/10.1007/978-981-15-1472-2_5)
- [63] James, D. (2024). Impact Assessment of Genetically Engineered Trees: An Overview on Risk Assessment and Management. In: Thomas T, D., Razdan, M.K., Kumar, A. (eds) *Biotechnological Approaches for Sustaining Forest Trees and Their Products*. Springer, Singapore. [https://doi.org/10.1007/978-981-97-4363-6\\_16](https://doi.org/10.1007/978-981-97-4363-6_16)
- [64] Jarzebski, M.P., Ahmed, A., Bofo, Y.A. et al. (2020). Food security impacts of industrial crop production in sub-Saharan Africa: a systematic review of the impact mechanisms. *Food Sec.* 12, 105–135. <https://doi.org/10.1007/s12571-019-00988-x>
- [65] Javid, M., Haleem, A., Singh, R.P., & Suman, R. (2021). Enhancing smart farming through the applications of Agriculture 4.0 technologies. *International Journal of Intelligent Networks*, 3, 150-164. <https://doi.org/10.1016/j.ijin.2022.09.004>
- [66] Jeswani H.K., Chilvers A., and Azapagic A. (2020). Environmental sustainability of biofuels: a review *Proc. R. Soc. A* 47620200351. <http://doi.org/10.1098/rspa.2020.0351>
- [67] Jin, Q., Chachar, M., Ali, A., Chachar, Z., Zhang, P., Riaz, A., Ahmed, N., & Chachar, S. (2024). Epigenetic Regulation for Heat Stress Adaptation in Plants: New Horizons for Crop Improvement under Climate Change. *Agronomy*, 14(9). <https://doi.org/10.3390/agronomy14092105>
- [68] Kabir, M., Habiba, U.E., Khan, W., Shah, A., Rahim, S., Rios-Escalante, P.R.D.L., Farooqi, Z., Ali, L., & Shafiq, M. (2023). Climate change due to increasing concentration of carbon dioxide and its impacts on environment in 21st century; a mini review. *Journal of King Saud University - Science*, 35(5), 102693. <https://doi.org/10.1016/j.jksus.2023.102693>
- [69] Kar, G. et al. (2023). Commercial Crops (Jute, Cotton and Sugarcane). In: Ghosh, P.K., Das, A., Saxena, R., Banerjee, K., Kar, G., Vijay, D. (eds) *Trajectory of 75 years of Indian Agriculture after Independence*. Springer, Singapore. [https://doi.org/10.1007/978-981-19-7997-2\\_14](https://doi.org/10.1007/978-981-19-7997-2_14)
- [70] Karaca, M., & Ince, A. G. (2022). Revisiting sustainable systems and methods in agriculture. *Sustainable Agriculture and the Environment*, 195-246. <https://doi.org/10.1016/B978-0-323-90500-8.00004-X>
- [71] Kinniburgh, F., Selin, H., Selin, N.E., & Schreurs, M. (2023). When private governance impedes multilateralism: The case of international pesticide governance. *Regulation & Governance*, 17(2), 425-448. <https://doi.org/10.1111/rego.12463>
- [72] Konefal, J., De Olde, E.M., Hatanaka, M., & Oosterveer, P.J. (2023). Signs of agricultural sustainability: A global assessment of sustainability governance initiatives and their indicators in crop farming. *Agricultural Systems*, 208, 103658. <https://doi.org/10.1016/j.agsy.2023.103658>
- [73] Koriesh, E.M., Abo-Soud, I.H. (2020). Facing Climate Change: Urban Gardening and Sustainable Agriculture. In: Ewis Omran, ES., Negm, A. (eds) *Climate Change Impacts on Agriculture and Food Security in Egypt*. Springer Water. Springer, Cham, [https://doi.org/10.1007/978-3-030-41629-4\\_16](https://doi.org/10.1007/978-3-030-41629-4_16)
- [74] Kremsa, V.Š. (2020). Sustainable management of agricultural resources (agricultural crops and animals). *Sustainable Resource Management*, 99-145. <https://doi.org/10.1016/B978-0-12-824342-8.00010-9>
- [75] Kumar, L., Chhogyel, N., Gopalakrishnan, T., Hasan, M.K., Jayasinghe, S.L., Kariyawasam, C.S., Kogo, B.K., & Ratnayake, S. (2021). Climate change and future of agri-food production. *Future Foods*, 49-79. <https://doi.org/10.1016/B978-0-323-91001-9.00009-8>

- [76] Kumar, M., and Sharma, S. (2024). Renewable Energy and Sustainable Transportation. In: Sobti, R.C. (eds) Role of Science and Technology for Sustainable Future. Springer, Singapore. [https://doi.org/ 10.1007/978-981-97-0710-2\\_22](https://doi.org/10.1007/978-981-97-0710-2_22)
- [77] Kurowska, K., Bielski, S., Kryszk, H., & Jasinskas, A. (2019). Food Security in the Context of Liquid Biofuels Production. *Energies*, 13(23), 6247. <https://doi.org/10.3390/en13236247>
- [78] Kyriakopoulos, G.L., Sebos, I., Triantafyllou, E., Stamopoulos, D., & Dimas, P. (2022). Benefits and Synergies in Addressing Climate Change via the Implementation of the Common Agricultural Policy in Greece. *Applied Sciences*, 13(4), 2216. <https://doi.org/10.3390/app13042216>
- [79] Ladics, G.S. (2018). Assessment of the potential allergenicity of genetically-engineered food crops. *Journal of Immunotoxicology*, 16(1), 43–53. <https://doi.org/10.1080/1547691X.2018.1533904>
- [80] Li, L. (2022). Commodity prices volatility and economic growth: Empirical evidence from natural resources industries of China. *Resources Policy*, 80. <https://doi.org/10.1016/j.resourpol.2022.103152>
- [81] Liaqat, W., Altaf, M.T., Barutçular, C., Yasmin, S. Bioenergy Crops in the Perspective of Climate Change. In: Aasim, M., Baloch, F.S., Nadeem, M.A., Habyarimana, E., Ahmed, S., Chung, G. (2023). *Biotechnology and Omics Approaches for Bioenergy Crops*. Springer, Singapore, 2023. [https://doi.org/10.1007/978-981-99-4954-0\\_1](https://doi.org/10.1007/978-981-99-4954-0_1)
- [82] Lim, J. A., Yaacob, J. S., Mohd Rasli, S. R., Eyahmalay, J. E., El Enshasy, H. A., & Zakaria, M. R. (2023). Mitigating the repercussions of climate change on diseases affecting important crop commodities in Southeast Asia, for food security and environmental sustainability—A review. *Frontiers in Sustainable Food Systems*, 6, 1030540. <https://doi.org/10.3389/fsufs.2022.1030540>
- [83] Lykogianni, M., Bempelou, E., Karamaouna, F., & Aliferis, K.A. (2021). Do pesticides promote or hinder sustainability in agriculture? The challenge of sustainable use of pesticides in modern agriculture. *Science of The Total Environment*, 795, 148625. <https://doi.org/10.1016/j.scitotenv.2021.148625>
- [84] Mahapatra, S., Kumar, D., Singh, B., & Sachan, P.K. (2021). Biofuels and their sources of production: A review on cleaner sustainable alternative against conventional fuel, in the framework of the food and energy nexus. *Energy Nexus*, 4. <https://doi.org/10.1016/j.nexus.2021.100036>
- [85] Mahto, H., Mahato, D. (2025). Human-Centric Biotechnological Interventions: A Pillar for Sustainable Agricultural Development in Industrial Crop Improvement. In: Kumar, N. (eds) *Industrial Crops Improvement. Sustainable Landscape Planning and Natural Resources Management*. Springer, Cham. [https://doi.org/10.1007/978-3-031-75937-6\\_12](https://doi.org/10.1007/978-3-031-75937-6_12)
- [86] Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H., Brahmachari, K., Shankar, T., Bhadra, P., Palai, J. B., Jena, J., Bhattacharya, U., Duvvada, S. K., Lalichetti, S., & Sairam, M. (2021). Intercropping—A Low Input Agricultural Strategy for Food and Environmental Security. *Agronomy*, 11(2), 343. <https://doi.org/10.3390/agronomy11020343>
- [87] Maja, M.M., Ayano, S.F. (2021). The Impact of Population Growth on Natural Resources and Farmers' Capacity to Adapt to Climate Change in Low-Income Countries. *Earth Syst Environ* 5, 271–283. <https://doi.org/10.1007/s41748-021-00209-6>
- [88] Manna, M.C., Rahman, M.M., Naidu, R., Bari, A.F., Singh, A., Thakur, J., Ghosh, A., Patra, A.K., Chaudhari, S., & Subbarao, A. (2020). Organic farming: A prospect for food, environment and livelihood security in Indian agriculture. *Advances in Agronomy*, 170, 101-153. <https://doi.org/10.1016/bs.agron.2021.06.003>
- [89] Martignone, G.M.B, Ghosh, B., Papadas, D., Behrendt, K. (2024). The rise of Soybean in international commodity markets: A quantile investigation. *Heliyon*. 10 (15). <https://doi.org/10.1016/j.heliyon.2024.e34669>
- [90] Monteleone, B., Borzi, I., Bonaccorso, B. et al. (2023). Quantifying crop vulnerability to weather-related extreme events and climate change through vulnerability curves. *Nat Hazards* 116, 2761–2796. <https://doi.org/10.1007/s11069-022-05791-0>
- [91] Morone, P., Strzałkowski, A., & Tani, A. (2019). Biofuel transitions: An overview of regulations and standards for a more sustainable framework. *Biofuels for a More Sustainable Future*, 21-46. <https://doi.org/10.1016/B978-0-12-815581-3.00002-6>
- [92] Morsetto, P. (2020). Targets for a circular economy. *Resources, Conservation and Recycling*, 153, 104553. <https://doi.org/10.1016/j.resconrec.2019.104553>
- [93] Moshood, T.D., Nawanir, G., Mahmud, F., Mohamad, F., Ahmad, M.H., AbdulGhani, A., & Kumar, S. (2022). Green product innovation: A means towards achieving global sustainable product within biodegradable plastic industry. *Journal of Cleaner Production*, 363. <https://doi.org/10.1016/j.jclepro.2022.132506>
- [94] Muluneh, M.G. (2021). Impact of climate change on biodiversity and food security: a global perspective—a review article. *Agric & Food Secur* 10, 36. <https://doi.org/10.1186/s40066-021-00318-5>
- [95] Mustafa, G., Iqbal, A. (2021). Economics of Oil Plants: Demand, Supply, and International Trade. In: Tombuloglu, H., Unver, T., Tombuloglu, G., Hakeem, K.R. (eds) *Oil Crop Genomics*. Springer, Cham. [https://doi.org/10.1007/978-3-030-70420-9\\_19](https://doi.org/10.1007/978-3-030-70420-9_19)

- [96] Ncube, L.K., Ude, A.U., Ogunmuyiwa, E.N., Zulkifli, R., & Beas, I.N. (2019). Environmental Impact of Food Packaging Materials: A Review of Contemporary Development from Conventional Plastics to Polylactic Acid Based Materials. *Materials*, 13(21). <https://doi.org/10.3390/ma13214994>
- [97] Ngongolo, K., Mmbando, G.S. (2024). Harnessing biotechnology and breeding strategies for climate-resilient agriculture: pathways to sustainable global food security. *Discov Sustain* 5, 431. <https://doi.org/10.1007/s43621-024-00653-0>
- [98] Nhemachena, C., Nhamo, L., Matchaya, G., Nhemachena, C.R., Muchara, B., Karuaihe, S.T., & Mpandeli, S. (2020). Climate Change Impacts on Water and Agriculture Sectors in Southern Africa: Threats and Opportunities for Sustainable Development. *Water*, 12(10), 2673. <https://doi.org/10.3390/w12102673>
- [99] Nielsen, J., Eckstein, L., Nicol, D., & Stewart, C. (2021). Integrating Public Participation, Transparency and Accountability into Governance of Marketing Authorisation for Genome Editing Products. *Frontiers in Political Science*, 3, 747838. <https://doi.org/10.3389/fpos.2021.747838>
- [100] Nikolaou, G., Neocleous, D., Christou, A., Kitta, E., & Katsoulas, N. (2020). Implementing Sustainable Irrigation in Water-Scarce Regions under the Impact of Climate Change. *Agronomy*, 10(8), 1120. <https://doi.org/10.3390/agronomy10081120>
- [101] Nsabiyeze, A., Ma, R., Li, J., Luo, H., Zhao, Q., Tomka, J., & Zhang, M. (2024). Tackling climate change in agriculture: A global evaluation of the effectiveness of carbon emission reduction policies. *Journal of Cleaner Production*, 468. <https://doi.org/10.1016/j.jclepro.2024.142973>
- [102] Núñez-Rocha, T., & Martínez-Zarzoso, I. (2019). Are international environmental policies effective? The case of the Rotterdam and the Stockholm Conventions. *Economic Modelling*, 81, 480-502. <https://doi.org/10.1016/j.econmod.2018.04.013>
- [103] Obaideen, K., Yousef, B.A., AlMallahi, M.N., Tan, Y.C., Mahmoud, M., Jaber, H., & Ramadan, M. (2022). An overview of smart irrigation systems using IoT. *Energy Nexus*, 7. <https://doi.org/10.1016/j.nexus.2022.100124>
- [104] Onyeaka, H., Ghosh, S., Obileke, K., Miri, T., Odeyemi, O.A., Nwaiwu, O., & Tamasiga, P. (2023). Preventing chemical contaminants in food: Challenges and prospects for safe and sustainable food production. *Food Control*, 155. <https://doi.org/10.1016/j.foodcont.2023.110040>
- [105] Padhiary, M., Kumar, R. (2024). Assessing the Environmental Impacts of Agriculture, Industrial Operations, and Mining on Agro-Ecosystems. In: Azrour, M., Mabrouki, J., Alabdulatif, A., Guezzaz, A., Amounas, F. (eds) *Smart Internet of Things for Environment and Healthcare. Studies in Computational Intelligence*, vol 1165. Springer, Cham, [https://doi.org/10.1007/978-3-031-70102-3\\_8](https://doi.org/10.1007/978-3-031-70102-3_8)
- [106] Panoutsou, C., Ciria, P., Ciria, C.S., Baraniecki, P., Monti, A., Zanetti, F., & Dubois, L. (2022). Social considerations for the cultivation of industrial crops on marginal agricultural land as feedstock for bioeconomy. *Biofuels, Bioproducts and Biorefining*, 16(5), 1319-1341. <https://doi.org/10.1002/bbb.2376>
- [107] Pata, U.K. (2021). Linking renewable energy, globalization, agriculture, CO<sub>2</sub> emissions and ecological footprint in BRIC countries: A sustainability perspective. *Renewable Energy*, 173, 197-208. <https://doi.org/10.1016/j.renene.2021.03.125>
- [108] Pathirana, R. (2022). Sustainable Agro-Food Systems for Addressing Climate Change and Food Security. *Agriculture*, 12(10), 1554. <https://doi.org/10.3390/agriculture12101554>
- [109] Pawlak, K., & Kołodziejczak, M. (2019). The Role of Agriculture in Ensuring Food Security in Developing Countries: Considerations in the Context of the Problem of Sustainable Food Production. *Sustainability*, 12(13), 5488. <https://doi.org/10.3390/su12135488>
- [110] Perović, A.B., Karabegović, I.T., Krstić, M.S., Veličković, A.V., Avramović, J.M., Danilović, B.R., & Veljković, V.B. (2024). Novel hydrodistillation and steam distillation methods of essential oil recovery from lavender: A comprehensive review. *Industrial Crops and Products*, 211, 118244. <https://doi.org/10.1016/j.indcrop.2024.118244>
- [111] Peter A.A. (2023). Ecological problems of agriculture: impacts and sustainable solutions. *ScienceOpen Preprints*. <https://doi.org/10.14293/PR2199.000145.v1>
- [112] Pompeu, J., Nolasco, C. L., West, P., Smith, P., Gerage, J., & Ometto, J. (2021). Is domestic agricultural production sufficient to meet national food nutrient needs in Brazil? *PLOS ONE*, 16(5), e0251778. <https://doi.org/10.1371/journal.pone.0251778>
- [113] Poole, N., Donovan, J., & Erenstein, O. (2021). Viewpoint: Agri-nutrition research: Revisiting the contribution of maize and wheat to human nutrition and health. *Food Policy*, 100. <https://doi.org/10.1016/j.foodpol.2020.101976>
- [114] Provin, A.P., Dutra, A.R.D.A., De Sousa, Silva Gouveia, I.C.A., & Cubas, E.A.L.V. (2021). Circular economy for fashion industry: Use of waste from the food industry for the production of biotextiles. *Technological Forecasting and Social Change*, 169, 120858. <https://doi.org/10.1016/j.techfore.2021.120858>
- [115] Qi, D., Wu, Z., Chen, B., Zhang, X., Yang, C., & Fu, Q. (2024). Integrative cultivation pattern, distribution, yield and potential benefit of rubber based agroforestry system in China. *Industrial Crops and Products*, 220, 119228. <https://doi.org/10.1016/j.indcrop.2024.119228>

- [116] Quintarelli, V., Radicetti, E., Allevato, E., Stazi, S. R., Haider, G., Abideen, Z., Bibi, S., Jamal, A., & Mancinelli, R. (2022). Cover Crops for Sustainable Cropping Systems: A Review. *Agriculture*, 12(12), 2076. <https://doi.org/10.3390/agriculture12122076>
- [117] Rahman, M.M., Khan, I., Field, D.L., Techato, K., & Alameh, K. (2022). Powering agriculture: Present status, future potential, and challenges of renewable energy applications. *Renewable Energy*, 188, 731-749. <https://doi.org/10.1016/j.renene.2022.02.065>
- [118] Raihan, A., Ridwan, M., & Rahman, M. S. (2024). An exploration of the latest developments, obstacles, and potential future pathways for climate-smart agriculture. *Climate Smart Agriculture*, 1(2). <https://doi.org/10.1016/j.csag.2024.100020>
- [119] Rathour, R.K., Behl, M., Dhashmana, K., Sakhuja, D., Ghai, H., Sharma, N., Meena, K.R., Bhatt, A.K., & Bhatia, R.K. (2023). Non-food crops derived lignocellulose biorefinery for sustainable production of biomaterials, biochemicals and bioenergy: A review on trends and techniques. *Industrial Crops and Products*. <https://doi.org/10.1016/j.indcrop.2023.117220>
- [120] Raza, A. et al. (2024). Climate Change Impacts on Crop Productivity and Food Security: An Overview. In: Kanga, S., Singh, S.K., Shevkani, K., Pathak, V., Sajjan, B. (eds) *Transforming Agricultural Management for a Sustainable Future*. World Sustainability Series. Springer, Cham. [https://doi.org/10.1007/978-3-031-63430-7\\_8](https://doi.org/10.1007/978-3-031-63430-7_8)
- [121] Rehman, A., Ma, H., Irfan, M. et al. (2020). Does carbon dioxide, methane, nitrous oxide, and GHG emissions influence the agriculture? Evidence from China. *Environ Sci Pollut Res* 27, 28768–28779. <https://doi.org/10.1007/s11356-020-08912-z>
- [122] Rehman, M., Fahad, S., Du, G. et al. (2021). Evaluation of hemp (*Cannabis sativa* L.) as an industrial crop: a review. *Environ Sci Pollut Res* 28, 52832–52843. <https://doi.org/10.1007/s11356-021-16264-5>
- [123] Reiss, E.R., & Drinkwater, L.E. (2017). Cultivar mixtures: A meta-analysis of the effect of intraspecific diversity on crop yield. *Ecological Applications*, 28(1), 62-77. <https://doi.org/10.1002/eap.1629>
- [124] Reuber, T.L. (2019). Genetic modification to improve disease resistance in crops. *New Phytologist*, 225(1), 70-86. <https://doi.org/10.1111/nph.15967>
- [125] Rita, J. (2024). The Role of the Supply Chain in Developing Innovation Processes in the Textile Industry. In: Moleiro Martins, J. (eds) *Industry and Innovation: Textile Industry. SDGs and Textiles*. Springer, Cham. [https://doi.org/10.1007/978-3-031-57804-5\\_3](https://doi.org/10.1007/978-3-031-57804-5_3)
- [126] Rodricks, J.V. (2020). Forty Years of Food Safety Risk Assessment: A History and Analysis. *Risk Analysis*, 40 (S1), 2218-2230. <https://doi.org/10.1111/risa.13624>
- [127] Rosenboom, J., Langer, R., & Traverso, G. (2022). Bioplastics for a circular economy. *Nature Reviews Materials*, 7(2), 117-137. <https://doi.org/10.1038/s41578-021-00407-8>
- [128] Rotundo, J.L., Marshall, R., McCormick, R., Truong, S.K., Styles, D., Gerde, J.A., Logue, J., Annicchiarico, P., De Visser, C., Dind, A., Dodd, I. C., Dye, L., Long, S.P., Lopes, M.S., Pannecouque, J., Reckling, M., Rushton, J., Schmid, N., Shield, I., Rufino, M.C. (2024). European soybean to benefit people and the environment. *Scientific Reports*, 14(1), 1-14. <https://doi.org/10.1038/s41598-024-57522-z>
- [129] Rubika, R., Prabhu, T., Shenbagavalli, S., Rajangam, J., Anitha, T., Ramar, A., & Vasanthkumar, S. (2024). Plant Essential Oils to The Rescue-An Epic Battle With Biopesticides For Pest Control in Agriculture. *Applied Ecology & Environmental Research*, 22(6). [https://aloki.hu/pdf/2206\\_51495168.pdf](https://aloki.hu/pdf/2206_51495168.pdf)
- [130] Samoraj, M., Çalıř, D., Trzaska, K., Mironiuk, M., & Chojnacka, K. (2024). Advancements in algal biorefineries for sustainable agriculture: Biofuels, high-value products, and environmental solutions. *Biocatalysis and Agricultural Biotechnology*, 58. <https://doi.org/10.1016/j.bcab.2024.103224>
- [131] Sarkar, S., Skalicky, M., Hossain, A., Brestic, M., Saha, S., Garai, S., Ray, K., & Brahmachari, K. (2019). Management of Crop Residues for Improving Input Use Efficiency and Agricultural Sustainability. *Sustainability*, 12(23), <https://doi.org/10.3390/su12239808>
- [132] SAS, (2012). Institute Inc.: *SAS/STAT User's Guide: Version 9.3*, SAS Institute Inc., and Cary city, NC., North Carolina, United States of America, USA. <https://support.sas.com/en/books.html>
- [133] Sauer, S. (2018). Soy expansion into the agricultural frontiers of the Brazilian Amazon: The agribusiness economy and its social and environmental conflicts. *Land Use Policy*, 79, 326-338. <https://doi.org/10.1016/j.landusepol.2018.08.030>
- [134] Scarlat, N., Dallemand, J., Monforti-Ferrario, F., & Nita, V. (2015). The role of biomass and bioenergy in a future bioeconomy: Policies and facts. *Environmental Development*, 15, 3-34, 2015. <https://doi.org/10.1016/j.envdev.2015.03.006>
- [135] Schilling-Vacaflor, A., Lenschow, A., Challies, E., Cotta, B., & Newig, J. (2012). Contextualizing certification and auditing: Soy certification and access of local communities to land and water in Brazil. *World Development*, 140, 105281. <https://doi.org/10.1016/j.worlddev.2020.105281>
- [136] Scott, G.J. (2021). A review of root, tuber and banana crops in developing countries: Past, present and future. *International Journal of Food Science & Technology*, 56(3), 1093-1114. <https://doi.org/10.1111/ijfs.14778>

- [137] Senapati, U., & Das, T.K. (2024). Delineation of potential alternative agriculture region using RS and AHP-based GIS techniques in the drought prone upper Dwarakeswer river basin, West Bengal, India. *Ecological Modelling*, 490. <https://doi.org/10.1016/j.ecolmodel.2024.110650>
- [138] Shah, F., & Wu, W. (2018). Soil and Crop Management Strategies to Ensure Higher Crop Productivity within Sustainable Environments. *Sustainability*, 11(5), 1485. <https://doi.org/10.3390/su11051485>
- [139] Shahid, M.K., Batool, A., Kashif, A., Nawaz, M.H., Aslam, M., Iqbal, N., & Choi, Y. (2021). Biofuels and biorefineries: Development, application and future perspectives emphasizing the environmental and economic aspects. *Journal of Environmental Management*, 297. <https://doi.org/10.1016/j.jenvman.2021.113268>
- [140] Sharma, P. and Payal, P. (2019). Climate Change and Sustainable Development: Special Context to Paris Agreement (March 20). Proceedings of International Conference on Sustainable Computing in Science, Technology and Management (SUSCOM), Amity University Rajasthan, Jaipur - India, February 26-28. <http://dx.doi.org/10.2139/ssrn.3356829>
- [141] Sharma, P., Singh, S.P., Iqbal, H.M.N., Parra-Saldivar, R., Varjani, S., & Tong, Y.W. (2022). Genetic modifications associated with sustainability aspects for sustainable developments. *Bioengineered*, 13(4), 9509–9521. <https://doi.org/10.1080/21655979.2022.2061146>
- [142] Singh, A., Dhiman, N., Kar, A.K., Singh, D., Purohit, M.P., Ghosh, D., & Patnaik, S. (2020). Advances in controlled release pesticide formulations: Prospects to safer integrated pest management and sustainable agriculture. *Journal of Hazardous Materials*, 385. <https://doi.org/10.1016/j.jhazmat.2019.121525>
- [143] Siqueira, M.U., Contin, B., Fernandes, P.R.B. *et al.* (2022). Brazilian Agro-industrial Wastes as Potential Textile and Other Raw Materials: a Sustainable Approach. *Mater Circ Econ* 4, 9. <https://doi.org/10.1007/s42824-021-00050-2>
- [144] Sisti, L., Gioia, C., Totaro, G., Verstichel, S., Cartabia, M., Camere, S., & Celli, A. (2021). Valorization of wheat bran agro-industrial byproduct as an upgrading filler for mycelium-based composite materials. *Industrial Crops and Products*, 170, 113742, <https://doi.org/10.1016/j.indcrop.2021.113742>
- [145] Sjah, T., Zainuri, Z. (2020). Agricultural Supply Chain and Food Security. In: Leal Filho, W., Azul, A.M., Brandli, L., Özuyar, P.G., Wall, T. (eds) *Zero Hunger. Encyclopedia of the UN Sustainable Development Goals*. Springer, Cham. [https://doi.org/10.1007/978-3-319-95675-6\\_82](https://doi.org/10.1007/978-3-319-95675-6_82)
- [146] Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The Impact of Climate Change on Agricultural Insect Pests. *Insects*, 12(5), 440. <https://doi.org/10.3390/insects12050440>
- [147] Soares, J.C., Santos, C.S., Carvalho, S.M.P. *et al.* (2019). Preserving the nutritional quality of crop plants under a changing climate: importance and strategies. *Plant Soil* 443, 1–26. <https://doi.org/10.1007/s11104-019-04229-0>
- [148] Solomon, S., Swapna, M. (2022). Indian Sugar Industry: Towards Self-reliance for Sustainability. *Sugar Tech* 24, 630–650. <https://doi.org/10.1007/s12355-022-01123-5>
- [149] Somasundaram, J., Sinha, N.K., Dalal, R.C., Lal, R., Mohanty, M., Naorem, A.K., Chaudhari, S.K. (2020). No-Till Farming and Conservation Agriculture in South Asia – Issues, Challenges, Prospects and Benefits. *Critical Reviews in Plant Sciences*, 39(3), 236–279. <https://doi.org/10.1080/07352689.2020.1782069>
- [150] Srivastav, A.K., Das, P., Srivastava, A.K. (2024). Precision Agriculture and Environmental Monitoring. In: *Biotech and IoT*. Apress, Berkeley, CA. [https://doi.org/10.1007/979-8-8688-0527-1\\_7](https://doi.org/10.1007/979-8-8688-0527-1_7)
- [151] Streimikis, J., & Baležentis, T. (2020). Agricultural sustainability assessment framework integrating sustainable development goals and interlinked priorities of environmental, climate and agriculture policies. *Sustainable Development*, 28(6), 1702–1712. <https://doi.org/10.1002/sd.2118>
- [152] Suali, E., & Suali, L. (2022). Impact assessment of global biofuel regulations and policies on biodiversity. *Environmental Sustainability of Biofuels*, 137–161. <https://doi.org/10.1016/B978-0-323-91159-7.00012-6>
- [153] Suhara, A., Herawan, S.G., Tirta, A., Idris, M., Roslan, M.F., Putra, N.R., Hananto, A.L., & Veza, I. (2024). Biodiesel Sustainability: Review of Progress and Challenges of Biodiesel as Sustainable Biofuel. *Clean Technologies*, 6(3), 886–906. <https://doi.org/10.3390/cleantechnol6030045>
- [154] Taib, N.A.A.B., Rahman, M.R., Huda, D. *et al.* (2023). A review on poly lactic acid (PLA) as a biodegradable polymer. *Polym. Bull.* 80, 1179–1213. <https://doi.org/10.1007/s00289-022-04160-y>
- [155] Tarawneh R.A., and Al-Najjar K. (2023). Assessing the Impacts of Agricultural Loans on Agricultural Sustainability in Jordan. *IOSR Journal of Economics and Finance (IOSR-JEF)*. Vol. 14, Issue 6 Ser. PP 49-56. <https://doi.org/10.9790/5933-1406014956>
- [156] Tarawneh, R.A., Abu Harb, S., Dayoub, M. and Al-Najjar, K. (2025). Leveraging the bio-economy to drive sustainable development: a comprehensive review. *International Journal of Agricultural Technology* 21(1):327-338. <http://www.ijat-aatsea.com>
- [157] Tarawneh, R.A., Tarawneh, M.S., and Al-Najjar, K.A. (2022). Agricultural Policies among Advisory and Cooperative Indicators in Jordan. *International Journal of Research - GRANTHAALAYAH*, 10(2), 10–17. <https://doi.org/10.29121/granthaalayah.v10.i2.2022.4489>

- [158] Tian, H., Lu, C., Pan, S., Yang, J., Miao, R., Ren, W., Yu, Q., Fu, B., Jin, F., Lu, Y., Melillo, J., Ouyang, Z., Palm, C., & Reilly, J. (2018). Optimizing resource use efficiencies in the food–energy–water nexus for sustainable agriculture: From conceptual model to decision support system. *Current Opinion in Environmental Sustainability*, 33, 104-113. <https://doi.org/10.1016/j.cosust.2018.04.003>
- [159] Tian, Z., Wang, W., Li, J., & Han, B. (2021). Designing future crops: Challenges and strategies for sustainable agriculture. *The Plant Journal*, 105(5), 1165-1178. <https://doi.org/10.1111/tpj.15107>
- [160] Tilman, D., Balzer, C., Hill, J., & Befort, B. L. (2011). Global food demand and the sustainable intensification of agriculture. *Proceedings of the National Academy of Sciences*, 108(50), 20260-20264. <https://doi.org/10.1073/pnas.1116437108>
- [161] Tripathi, S., Srivastava, P., Devi, R.S., & Bhadouria, R. (2019). Influence of synthetic fertilizers and pesticides on soil health and soil microbiology. *Agrochemicals Detection, Treatment and Remediation*, 25-54. <https://doi.org/10.1016/B978-0-08-103017-2.00002-7>
- [162] Tudge, S.J., Purvis, A. & De Palma, A. (2021). The impacts of biofuel crops on local biodiversity: a global synthesis. *Biodivers Conserv* 30, 2863–2883, <https://doi.org/10.1007/s10531-021-02232-5>
- [163] Turnbull, C., Lillemo, M., & K., T.A. (2021). Global Regulation of Genetically Modified Crops amid the Gene Edited Crop Boom – A Review. *Frontiers in Plant Science*, 12, <https://doi.org/10.3389/fpls.2021.630396>
- [164] Umesha, S., Manukumar, H. M., & Chandrasekhar, B. (2017). Sustainable Agriculture and Food Security. *Biotechnology for Sustainable Agriculture*, 67-92. <https://doi.org/10.1016/B978-0-12-812160-3.00003-9>
- [165] Vaddula, Y., Singh, K. (2023). Progression of drip irrigation and fertigation in cotton across the globe and its future perspectives for sustainable agriculture: an overview. *Appl. Water Sci.* 13, 177. <https://doi.org/10.1007/s13201-023-01986-3>
- [166] Valizadeh, N., Bijani, M. (2020). Agricultural Research: Applications and Future Orientations. In: Leal Filho, W., Azul, A.M., Brandli, L., Özuyar, P.G., Wall, T. (eds) *Zero Hunger. Encyclopedia of the UN Sustainable Development Goals*. Springer, Cham. [https://doi.org/10.1007/978-3-319-95675-6\\_5](https://doi.org/10.1007/978-3-319-95675-6_5)
- [167] VanDeveer, S. (2020). Consumption, commodity chains, and global and local environments. In R. Axelrod, S. VanDeveer (Eds.) *Consumption, Commodity Chains, and Global and Local Environments (Fifth Edition ed., pp. 412-437*. CQ Press, <https://doi.org/10.4135/9781071873038>
- [168] Velázquez, G.A., Gómez, N.J., Tisnés, A. (2023). The Pampean Region. In: Mikkelsen, C.A., Linares, S., Velázquez, C.A. (eds) *Quality of Life in Argentina. The Latin American Studies Book Series*. Springer, Cham. [https://doi.org/10.1007/978-3-031-48212-0\\_2](https://doi.org/10.1007/978-3-031-48212-0_2)
- [169] Verma, P., Singh, D., Pathania, I.P., Aggarwal, K. (2019). Strategies to Improve Agriculture Sustainability, Soil Fertility and Enhancement of Farmers Income for the Economic Development. In: Panpatte, D., Jhala, Y. (eds) *Soil Fertility Management for Sustainable Development*. Springer, Singapore. [https://doi.org/10.1007/978-981-13-5904-0\\_4](https://doi.org/10.1007/978-981-13-5904-0_4)
- [170] Verschuuren, J. (2022). Achieving agricultural greenhouse gas emission reductions in the EU post-2030: What options do we have? *Review of European, Comparative & International Environmental Law*, 31(2), 246-257. <https://doi.org/10.1111/reel.12448>
- [171] Viccaro, M., Cozzi, M., Rocchi, B., & Romano, S. (2019). Conservation agriculture to promote inland biofuel production in Italy: An economic assessment of rapeseed straight vegetable oil as a self-supply agricultural biofuel. *Journal of Cleaner Production*, 217, 153-161. <https://doi.org/10.1016/j.jclepro.2019.01.251>
- [172] Wagh, M.S., Nath, P.C., Chakraborty, A., Amrit, R., Mishra, B., Mishra, A.K., & Mohanta, Y.K. (2024). Valorisation of agro-industrial wastes: Circular bioeconomy and biorefinery process – A sustainable symphony. *Process Safety and Environmental Protection*, 183, 708-725. <https://doi.org/10.1016/j.psep.2024.01.055>
- [173] Wang, R., Guo, Z., Cai, C. et al. (2021). Practices and roles of bamboo industry development for alleviating poverty in China. *Clean Techn Environ Policy* 23, 1687–1699. <https://doi.org/10.1007/s10098-021-02074-3>
- [174] Waqar, R. et al. (2024). Climate Resilience: Strategies for Enhancing Plant and Vegetation Growth. In: Fahad, S., Saud, S., Nawaz, T., Gu, L., Ahmad, M., Zhou, R. (eds) *Environment, Climate, Plant and Vegetation Growth*. Springer, Cham, [https://doi.org/10.1007/978-3-031-69417-2\\_16](https://doi.org/10.1007/978-3-031-69417-2_16)
- [175] Weynants, M., Bertzky, B., Delli, G., Mandrici, A., Bendito, E. G., & Dubois, G. (2020). Land productivity dynamics in and around protected areas globally from 1999 to 2013. *PLOS ONE*, 15(8), e0224958. <https://doi.org/10.1371/journal.pone.0224958>
- [176] Xie, S., Zhang, J., Li, X., Xia, X., & Chen, Z. (2023). The effect of agricultural insurance participation on rural households' economic resilience to natural disasters: Evidence from China. *Journal of Cleaner Production*, 434, <https://doi.org/10.1016/j.jclepro.2023.140123>
- [177] Xing, Y., & Wang, X. (2023). Precision Agriculture and Water Conservation Strategies for Sustainable Crop Production in Arid Regions. *Plants*, 13(22). <https://doi.org/10.3390/plants13223184>
- [178] Yao, P., Qian, L., Wang, Z., Meng, H., & Ju, X. (2022). Assessing Drought, Flood, and High Temperature Disasters during Sugarcane Growth Stages in Southern China. *Agriculture*, 12(12), 2117. <https://doi.org/10.3390/agriculture12122117>

- [179] Yuan, X., Li, S., Chen, J., Yu, H., Yang, T., Wang, C., Huang, S., Chen, H., & Ao, X. (2024). Impacts of Global Climate Change on Agricultural Production: A Comprehensive Review. *Agronomy*, 14(7), 1360. <https://doi.org/10.3390/agronomy14071360>
- [180] Zaaboul, F., & Liu, Y. (2022). Vitamin E in foodstuff: Nutritional, analytical, and food technology aspects. *Comprehensive Reviews in Food Science and Food Safety*, 21(2), 964-998. <https://doi.org/10.1111/1541-4337.12924>
- [181] Zamri, A.F.M., Milano, J., Shamsuddin, A.H.M., Roslan, M.E., Salleh, S.F., Rahman, A.A., Bahru, R.R. Fattah, I.M., & Indra Mahlia, T.M. (2022). An overview of palm oil biomass for power generation sector decarbonization in Malaysia: Progress, challenges, and prospects. *Wiley Interdisciplinary Reviews: Energy and Environment*, 11(4), e437. <https://doi.org/10.1002/wene.437>
- [182] Zeidan, R., Boechat, C. & Fleury, A. (2015). Developing a Sustainability Credit Score System. *J Bus Ethics* 127, 283–296. <https://doi.org/10.1007/s10551-013-2034-2>
- [183] Zhou, W., Li, M., & Achal, V. (2024). A comprehensive review on environmental and human health impacts of chemical pesticide usage. *Emerging Contaminants*, 11(1), <https://doi.org/10.1016/j.emcon.2024.100410>
- [184] Zhuang, D., Abbas, J., Fahlevi, M., Aljuaid, M., & Saniuk, S. (2022). Land-use and food security in energy transition: Role of food supply. *Frontiers in Sustainable Food Systems*, 6. <https://doi.org/10.3389/fsufs.2022.1053031>