**The Ethics of Growth: Environmental and Moral Implications of Seed Technology in Modern Agriculture**

**Abstract**

The continuous evolution of seed technologies has not only revolutionised farming methods but has also brought forth ethical and environmental considerations of paramount importance. From the early days of selective breeding to the contemporary era of genetic engineering, seed technology has been a driving force in shaping the crops cultivated worldwide. This study examines the ethical landscape of seed technology and environmental considerations in seed technology. This study employs a qualitative analytical approach to synthesise perspectives from international treaties, national regulations, and scholarly literature. International agreements and treaties play a pivotal role in establishing the regulatory framework and guidelines that govern ethical and environmental considerations in seed technology. This study highlights several such international agreements and treaties that constitute a complex web of regulatory frameworks and guidelines, significantly influencing ethical and environmental decision-making in seed technology. For instance, the Nagoya Protocol, the Cartagena Protocol, the Convention on Biological Diversity and the World Trade Organisation (WTO) Agreements play vital roles. As seed technology continues to advance, robust national regulations play a pivotal role in fostering an ethical and environmentally conscious approach to its development and deployment. This discussion also delves into the significance of monitoring and enforcement within the context of regulatory frameworks in seed technology. Furthermore, this study also explores the challenges posed by climate change and innovative approaches in seed adaptation, considering ethical and environmental perspectives. It addresses the ongoing struggle to find a balance between ethical responsibilities and environmental sustainability in seed technology. Finding a balance between ethical considerations and environmental concerns in seed technology requires thoughtful integration of diverse perspectives, robust ethical guidelines, and transparent decision-making processes. The study emphasised that the seed technology sector can contribute to agricultural sustainability while upholding ethical principles.

**Keywords**: Seed technology, Genetic modification, Pesticide, Nagoya Protocol, Intellectual Property Rights

**Introduction**:

Seed technology is a cornerstone in global agriculture, playing a pivotal role in shaping crop productivity, ensuring food security, and fostering sustainable agricultural practices. The continuous evolution of seed technologies has not only revolutionised farming methods but has also brought forth ethical and environmental considerations of paramount importance. As the world confronts the challenge of feeding an ever-expanding population amid mounting environmental concerns, the ethical dimensions of seed technology have taken centre stage. The discovery of the CRISPR/Cas9 gene editing system has revolutionised research in animal and plant biology, with its utility in genome editing first demonstrated in 2012 in mammalian cells. This method of gene editing has been adopted in nearly 20 crop species so far for various traits, including yield improvement, biotic and abiotic stress management (Jaganathan et al., 2018). This exploration delves into the intricate facets of ethical and environmental considerations in seed technology, examining the challenges, opportunities, and the compelling need for responsible and sustainable agricultural practices.

**The Evolution of Seed Technology:** The historical narrative of agriculture is intricately woven with the tapestry of seed technology development. From the early days of selective breeding to the contemporary era of genetic engineering, seed technology has been a driving force in shaping the crops cultivated worldwide. The mid-20th-century Green Revolution, characterised by the widespread adoption of high-yielding varieties, marked a significant turning point in seed technology. Seed treatments may be applied commercially by the seed industry or, in some cases, “on farm” for crop protection and enhanced seedling growth. There is also a growing trend for the development and use of organically approved treatments for sustainable agriculture. Collectively, innovative seed coating technologies are needed as delivery systems for the application of active ingredients at effective dosages to crop seeds (Afzal et al., 2020; Brown et al., 2021). Although it ushered in increased crop yields, concerns about environmental impacts and ethical considerations, particularly related to the concentration of agricultural power, emerged. Moreover, the introduction of [genetically engineered foods](https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/genetically-modified-food) to the market in 1994 has evoked public discussion and controversies over their use, benefits, risks, environmental and health safety, and limitations (Sikora & Rzymski, 2021).

**The Ethical Landscape of Seed Technology:**

1. **Genetic Modification and Bioethics:** Genetic modification (GM) of crops has emerged as a focal point in ethical debates surrounding seed technology. While GM crops have the potential to bolster resistance to pests, diseases, and environmental stress, ethical questions persist regarding potential impacts on human health, biodiversity, and unintended consequences (Gustafson, 2018).
2. **Access to Genetic Resources:** The equitable distribution of benefits derived from seed technology raises ethical queries concerning access to genetic resources. Biopiracy, unauthorised use of genetic material, poses challenges to the rights of indigenous communities and local farmers. Ethical seed technology must prioritise fair and just sharing of benefits, recognising the contributions of diverse communities to genetic resources (Kloppenburg, 2010).
3. **Seed Patents and Intellectual Property Rights:** The issue of intellectual property rights in seed technology has spurred ethical debates. Seed patents can concentrate power in the hands of a few agribusiness corporations, limiting access for small-scale farmers. Striking a balance between rewarding innovation and ensuring widespread access to essential genetic resources remains a challenge in ethical seed technology.

**Environmental Considerations in Seed Technology:**

1. **Biodiversity Conservation:** The impact of seed technology on biodiversity is a critical environmental consideration. Monoculture, often associated with high-yielding varieties, can lead to the erosion of genetic diversity, rendering crops more susceptible to diseases and climate change. Sustainable seed technology should prioritise the conservation of diverse genetic resources to enhance the resilience of agricultural systems.
2. **Ecological Impact of Pesticide Use:** Many seed technologies are intertwined with the use of pesticides, raising environmental concerns. Excessive pesticide use can result in soil degradation, water pollution, and harm to non-target organisms. Sustainable seed technology should consider integrated pest management strategies, minimising the environmental footprint associated with pesticide application (Pimentel & Burgess, 2013).
3. **Resource Use Efficiency:** The efficiency of resource use in seed technology is central to environmental sustainability. Water-intensive crops and energy-intensive production processes can strain natural resources. Ethical seed technology should concentrate on developing resource-efficient varieties that require fewer inputs while maintaining high yields (Tilman et al., 2011).
4. **Climate Change Resilience:** Climate change poses a significant threat to global agriculture, necessitating the development of seed technologies that enhance crop resilience. Drought-resistant and heat-tolerant crop varieties can mitigate the impact of climate change on food production. Ethical considerations in seed technology should prioritise the development and dissemination of climate-resilient seeds to ensure long-term sustainability.

**Balancing Ethical and Environmental Imperatives:** Balancing the imperatives of technological innovation with ethical and environmental considerations in seed technology is imperative. Achieving sustainable agriculture mandates a holistic approach integrating the expertise of scientists, policymakers, farmers, and consumers. Ethical considerations, such as equitable access to genetic resources and fair benefit-sharing, must be integral to the development and deployment of seed technologies.

Concurrently, environmental considerations, encompassing biodiversity conservation and resource use efficiency, should guide the pursuit of innovative solutions for global food security (Gustafson, 2018). As we navigate the intricate landscape of seed technology, fostering interdisciplinary collaboration, public engagement, and ethical governance frameworks becomes crucial. By addressing these ethical and environmental considerations, we pave the way for a more sustainable and responsible future for agriculture, ensuring that seed technology becomes a force for positive change rather than a source of unintended harm.

**Regulatory framework and guidelines**

International agreements and treaties

International agreements and treaties play a pivotal role in establishing the regulatory framework and guidelines that govern ethical and environmental considerations in seed technology. As the global community faces the challenges of fostering sustainable agriculture, these agreements lay the groundwork for addressing crucial issues related to genetic modification, biodiversity conservation, and equitable access to genetic resources. This examination provides insights into key international agreements and treaties that significantly influence ethical and environmental considerations in seed technology, elucidating their impact on global agricultural practices.

1. **Convention on Biological Diversity (CBD):** The CBD, a landmark international treaty, places a strong emphasis on the conservation of biodiversity and the sustainable utilisation of genetic resources. It advocates for the fair and equitable sharing of benefits arising from the utilisation of these resources, thereby promoting ethical considerations within the realm of seed technology (CBD, 1992).
2. **Nagoya Protocol:** As an integral component of the CBD, the Nagoya Protocol focuses on regulating access to genetic resources and ensuring the fair and equitable sharing of benefits resulting from their utilisation. Specifically addressing concerns related to biopiracy, the protocol aims to guarantee fair compensation to local communities and indigenous people for the use of their genetic resources (Nagoya Protocol, 2010).
3. **International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA):** Commonly known as the Plant Treaty, this agreement establishes a global system to facilitate the fair and equitable sharing of plant genetic resources. It actively promotes sustainable agriculture by recognising the rights of farmers and fostering international cooperation in the conservation and utilisation of plant genetic resources (ITPGRFA, 2001).
4. **Cartagena Protocol on Biosafety:** Linked closely to the CBD, the Cartagena Protocol specifically addresses the safe transfer, handling, and utilisation of living modified organisms (LMOs) resulting from modern biotechnology. With a primary goal of protecting biological diversity, the protocol also considers ethical aspects associated with genetically modified organisms (Cartagena Protocol, 2000).
5. **World Trade Organisation (WTO) Agreements:** The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) within the WTO framework is instrumental in addressing intellectual property rights related to seed technology. This agreement carries implications for issues such as seed patents and ethical considerations regarding access to genetic resources (WTO, 1994).
6. **International Union for the Protection of New Varieties of Plants (UPOV):** UPOV provides a comprehensive framework for safeguarding plant breeders' rights, aiming to incentivise the development of new plant varieties. Within the ethical landscape of seed technology, it necessitates a delicate balance between the rights of breeders and the imperative of ensuring access to genetic resources (UPOV, 1991).
7. **FAO International Undertaking on Plant Genetic Resources:** Although not legally binding, the FAO International Undertaking encourages nations to adopt policies that endorse the conservation and sustainable use of plant genetic resources. It contributes significantly to the ethical and environmental aspects of governing seed technology (FAO, 1983).
8. **The Safe Use of Biological Control: Guidelines on Best Practices:** Published by the International Plant Protection Convention (IPPC), these guidelines specifically address the environmental considerations associated with the use of biological control agents. Aligned with ethical principles of sustainable agriculture, these guidelines contribute to fostering responsible practices within seed technology (IPPC, 2021).
9. **Biosafety Protocol to the Antarctic Treaty:** Concentrating on safeguarding the Antarctic environment, this protocol emphasises the necessity of averting adverse effects stemming from the introduction of non-indigenous species. It aligns with broader environmental considerations within the realm of seed technology (Antarctic Treaty, 1991).
10. **The Rome Declaration on Hunger:** Although not legally binding, the Rome Declaration advocates for a collective commitment to eradicate hunger and achieve sustainable food security. It underscores ethical responsibilities in seed technology to ensure universal access to food (FAO, 1996).

In summary, these international agreements and treaties collectively constitute a complex web of regulatory frameworks and guidelines that exert significant influence on ethical and environmental considerations in seed technology. They champion the sustainable use of genetic resources, fair benefit-sharing, and the conservation of biodiversity, reflecting a global dedication to responsible agricultural practices. As seed technology advances, the ethical and environmental principles embedded in these agreements offer invaluable guidance for navigating the intricate landscape of global agriculture.Top of Form

National regulations and compliance mechanisms constitute integral components of the regulatory framework governing ethical and environmental considerations in seed technology. As countries strive to balance technological innovation with ethical responsibility and environmental sustainability, these regulations play a crucial role in shaping the landscape of seed technology. This exploration underscores the significance of national regulations and compliance in fostering ethical practices and ensuring environmental stewardship within the realm of seed technology.

1. **Ethical Oversight:** National regulatory frameworks commonly incorporate stringent ethical oversight mechanisms to assess and monitor the development and deployment of seed technologies. These mechanisms aim to guarantee that both research and commercial activities adhere to established ethical standards. Ethical considerations encompass vital aspects such as biodiversity protection, fair benefit-sharing, and transparency in decision-making processes (Vanloqueren & Baret, 2009).
2. **Environmental Impact Assessment (EIA):** Many countries mandate Environmental Impact Assessments (EIAs) for seed technologies before their release into the environment. EIAs serve to evaluate potential environmental risks associated with the introduction of new seed varieties or technologies. This includes an assessment of impacts on non-target organisms, soil health, and the potential gene flow to wild relatives (Kareiva et al., 2007).
3. **Labelling and Traceability:** National regulations frequently stipulate clear labelling and traceability systems for genetically modified (GM) seeds. This ensures informed consumer choice and facilitates monitoring of seed movement in the market. Labelling is essential to making end-users aware of the specific characteristics and traits associated with a particular seed variety, contributing to transparency and responsible use (Smyth et al., 2017).
4. **Intellectual Property Rights (IPR):** National regulations governing intellectual property rights (IPR) play a significant role in seed technology. These regulations address issues such as seed patents, licensing, and the protection of plant breeders' rights. Achieving a balance between the interests of breeders, seed companies, and the broader public is a key consideration within the ethical framework of seed technology (Binenbaum et al., 2020).
5. **Compliance with International Agreements:** National regulations align with international agreements and treaties, ensuring compliance with overarching ethical and environmental principles. Adherence to agreements such as the Cartagena Protocol on Biosafety and the International Treaty on Plant Genetic Resources for Food and Agriculture reflects a commitment to global standards in the regulation of seed technologies.
6. **Biosafety Regulations:** National biosafety regulations are specifically designed to manage the risks associated with living modified organisms (LMOs), including GM seeds. These regulations assess potential impacts on biodiversity, human health, and ecosystems. Biosafety measures contribute to ethical governance in seed technology by minimising unintended consequences (Wolt et al., 2010).
7. **Farmers' Rights:** Some national regulatory frameworks explicitly recognise and protect the rights of farmers, including the right to save, use, exchange, and sell farm-saved seeds. Such provisions contribute to ethical considerations by acknowledging the crucial role of farmers as stewards of plant genetic resources.
8. **Public Consultation Processes:** National regulations may mandate public consultation processes for significant decisions related to seed technology. Involving stakeholders and the public in decision-making fosters transparency, addresses concerns, and ensures a diversity of perspectives are considered.
9. **Capacity Building and Education:** National regulatory frameworks often include provisions for capacity building and education initiatives. These efforts aim to enhance the understanding of ethical and environmental considerations among stakeholders, including farmers, researchers, and regulatory authorities (Miller & Smyth, 2008).

In summary, national regulations and compliance mechanisms are vital components of the regulatory framework governing ethical and environmental considerations in seed technology. These regulations serve as a crucial link between global ethical principles and local implementation, ensuring that seed technologies align with responsible practices, safeguard biodiversity, and contribute to sustainable agriculture. As seed technology continues to advance, robust national regulations play a pivotal role in fostering an ethical and environmentally conscious approach to its development and deployment.

**Monitoring and enforcement**

Monitoring and Enforcement: Effective national regulations include robust monitoring and enforcement mechanisms. Regular assessments and inspections help ensure that seed technologies comply with ethical standards and environmental protection measures. Enforcement actions deter non-compliance and safeguard the integrity of seed systems (Phillips et al., 2016). Monitoring and enforcement mechanisms within regulatory frameworks are essential pillars ensuring the ethical and environmentally responsible development and deployment of seed technology. These components play a pivotal role in upholding established guidelines, promoting transparency, and safeguarding biodiversity and ecosystems. This discussion delves into the significance of monitoring and enforcement within the context of regulatory frameworks for ethical and environmental considerations in seed technology.

**Monitoring:** Monitoring encompasses systematic assessments aimed at evaluating the adherence of seed technology practices to established ethical and environmental guidelines. It involves regular inspections, data collection, and analysis to track the entire life cycle of seed technologies – from research and development to commercialisation. On-site inspections verify compliance with ethical standards and environmental impact assessments, ensuring that practices align with established guidelines. Real-time data monitoring allows regulatory authorities to detect deviations promptly and assess the performance of seed technologies under various conditions, contributing to a proactive regulatory approach.

**Enforcement:** Enforcement mechanisms are critical in ensuring that regulatory guidelines are not merely recommendations but carry tangible consequences for non-compliance. Enforcement actions include a spectrum of measures, from fines and penalties to revocation of licenses. The severity of enforcement measures is often proportional to the nature and extent of the violation. By imposing consequences, regulatory bodies aim to deter non-compliance and create a culture of accountability within the seed technology sector. Robust enforcement reinforces the seriousness of adhering to ethical and environmental considerations, fostering responsible practices.

**The Synergy between Monitoring and Enforcement:** The synergy between monitoring and enforcement is crucial for the effectiveness of regulatory frameworks. Monitoring acts as a preventive tool, identifying potential issues before they escalate. Regular assessments allow for timely interventions, reducing the likelihood of adverse consequences. Enforcement, on the other hand, acts as a corrective and deterrent measure. It establishes accountability within the industry and communicates the regulatory body's commitment to upholding ethical and environmental standards.

**Continuous Improvement of Regulatory Frameworks:** Monitoring and enforcement contribute to the continuous improvement of regulatory frameworks. Insights gained from monitoring activities, feedback from stakeholders, and enforcement outcomes inform regulatory agencies about emerging challenges and opportunities for enhancement. This iterative process ensures that guidelines remain relevant, adaptive to technological advancements, and responsive to changing environmental contexts.

In summary, monitoring and enforcement are integral components of regulatory frameworks for ethical and environmental considerations in seed technology. The harmonious interplay between these mechanisms ensures the effectiveness of guidelines, contributes to the prevention of ethical breaches, and supports the continuous improvement of regulatory frameworks in response to evolving challenges.

**Future trends and challenges:**

Global Climate Change and Seed Adaptation:

Global climate change poses significant challenges to seed technology, requiring adaptation strategies to ensure the sustainability of agriculture and food security. As a pivotal aspect of future trends and challenges in ethical and environmental considerations in seed technology, addressing the impacts of climate change on seeds is imperative. This discussion explores the challenges posed by climate change and innovative approaches in seed adaptation, considering ethical and environmental perspectives.

**Challenges Posed by Climate Change:** Climate change introduces numerous challenges for seed technology, impacting seed quality, germination, and overall crop productivity. Altered temperature patterns, extreme weather events, and changing precipitation levels can disrupt traditional agricultural practices. The increased frequency of heatwaves, prolonged droughts, and erratic rainfall patterns can lead to decreased crop yields, affecting global food production and quality (Battisti & Naylor, 2009).

**Seed Adaptation Strategies:** To address the challenges posed by climate change, seed technology is evolving to develop climate-resilient seeds capable of thriving in new environmental conditions. Key strategies include:

1. **Breeding for Climate Resilience:** Seed breeders are actively engaged in developing climate-resilient crop varieties. This involves selecting and breeding plants with traits that enhance their adaptability to changing climatic conditions, such as drought tolerance, heat resistance, and pest resilience (Varshney et al., 2018).
2. **Precision Agriculture Technologies:** Integration of precision agriculture technologies, such as remote sensing and data analytics, facilitates real-time monitoring of environmental conditions. This information enables farmers to make informed decisions about seed selection, planting times, and other agronomic practices, optimising crop performance in changing climates.
3. **Genetic Modification:** Genetic engineering techniques contribute to seed adaptation by introducing specific genes that confer tolerance to environmental stresses. Traits such as improved water-use efficiency and resistance to pests and diseases are incorporated to enhance the adaptability of crops to changing climatic conditions.
4. **Conservation of Genetic Diversity:** Preserving and utilising the genetic diversity of seeds is essential for adaptation. Seed banks and conservation programs play a crucial role in safeguarding diverse genetic resources, ensuring the availability of a wide range of traits that can be utilised in breeding programs.

**Ethical and Environmental Considerations:** While pursuing seed adaptation strategies, it is crucial to navigate ethical considerations and minimise potential environmental impacts. Maintaining biodiversity, ensuring equitable access to adapted seeds, and addressing socio-economic implications are ethical imperatives. Additionally, evaluating the long-term environmental effects of genetically modified seeds and precision agriculture technologies is essential for sustainable seed adaptation.

**In** summary**,** addressing the challenges of global climate change through seed adaptation is a crucial facet of future trends and challenges in ethical and environmental considerations in seed technology. Innovative strategies, guided by ethical principles, are essential to ensure the resilience of agriculture in the face of climate uncertainty while minimising adverse environmental impacts.

**Balancing Ethical and Environmental Concerns:**

Balancing ethical considerations and environmental concerns is a critical aspect of navigating future trends and challenges in seed technology. As the field evolves, ethical dilemmas emerge alongside the imperative to protect the environment. This discussion explores the challenges and potential solutions in finding an equilibrium between ethical considerations and environmental sustainability within the realm of seed technology.

**Ethical Concerns in Seed Technology:** Ethical considerations in seed technology encompass a range of issues, including fair benefit-sharing, protection of farmers' rights, and transparency in decision-making processes. As technologies advance, questions arise about the equitable distribution of benefits derived from seed innovations and the potential socioeconomic impacts on farming communities (Vanloqueren & Baret, 2009). Ethical frameworks also extend to issues like intellectual property rights, addressing concerns about corporate control and access to genetic resources (Binenbaum et al., 2020).

**Environmental Concerns in Seed Technology:** Environmental considerations revolve around the ecological impact of seed technologies, including potential harm to biodiversity, soil health, and non-target organisms. The use of genetically modified organisms (GMOs) raises questions about unintended consequences, such as gene flow to wild relatives and the development of resistant pests (Kareiva et al., 2007). Sustainable seed technology should prioritise practices that contribute to environmental stewardship and align with broader goals of ecological sustainability.

**Challenges in Balancing Ethical and Environmental Considerations:** The intricate interplay between ethical and environmental considerations poses challenges. For instance, the protection of intellectual property rights, while essential for incentivising innovation, can clash with ethical principles of fair benefit-sharing and access to genetic resources. Additionally, the deployment of certain seed technologies may raise concerns about the unintended environmental impacts, creating a tension between ethical obligations and environmental responsibility.

**Potential Solutions and Strategies:**

1. **Integrated Ethical Assessments:** Incorporating ethical assessments into environmental impact evaluations can help identify potential conflicts and synergies. This integrated approach allows decision-makers to consider both ethical and environmental aspects simultaneously, fostering a comprehensive understanding of the consequences of seed technology.
2. **Public Engagement and Stakeholder Involvement:** Including diverse perspectives through public consultations and stakeholder engagement processes can enhance decision-making transparency. Involving farmers, local communities, and other stakeholders in discussions about seed technology ensures that ethical considerations and environmental concerns are adequately represented.
3. **Ethical Guidelines for Technology Developers:** Establishing clear ethical guidelines for technology developers can help navigate potential conflicts. These guidelines can address issues such as equitable benefit-sharing, transparency, and responsible technology deployment, providing a framework for developers to align their practices with ethical standards.

**Conclusion**

**In summary, finding a balance between ethical considerations and environmental concerns in seed technology requires thoughtful integration of diverse perspectives, robust ethical guidelines, and transparent decision-making processes. By navigating these challenges, the seed technology sector can contribute to agricultural sustainability while upholding ethical principles.**

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