

Review

Advances in Sweet Corn (*Zea mays* L. *saccharata*) Research from 2010 to 2025: Genetics, Agronomy, and Sustainable Production

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Abstract: Sweet corn (*Zea mays* L. *saccharata*) has emerged as a valuable crop not only for its economic potential but also for its role in sustainable food systems due to its high consumer demand and adaptability. As global agricultural systems face increasing pressure from climate change, resource scarcity, and nutritional challenges, a strategic synthesis of research is essential to guide future innovation. This review aims to critically assess and synthesize major advancements in sweet corn (*Zea mays* L. *saccharata*) research from 2010 to 2025, with the objectives of identifying key genetic improvements, evaluating agronomic innovations, and examining sustainable production strategies that collectively enhance crop performance and resilience. The analysis is structured around three core pillars: genetic improvement, agronomic optimization, and sustainable agriculture, each contributing uniquely to the enhancement of sweet corn productivity and environmental adaptability. In the genetics domain, recent breakthroughs such as CRISPR-Cas9 genome editing and marker-assisted selection have accelerated the development of climate-resilient hybrids with enhanced sweetness, pest resistance, and nutrient content. The growing emphasis on biofortification aims to improve the nutritional quality of sweet corn, aligning with global food security goals. Additionally, studies on genotype–environment interaction have provided deeper insights into varietal adaptability under varying climatic and soil conditions, guiding breeders toward more location-specific hybrid development. From an agronomic perspective, innovations in precision irrigation and refined planting configurations have significantly enhanced water use efficiency, especially in arid and semi-arid regions. Research on plant density, nutrient management, and crop rotation has further contributed to yield stability and system resilience. These agronomic practices, when tailored to specific genotypes and environments, ensure sustainable intensification without compromising resource conservation. On the sustainability front, strategies such as reduced-input systems, organic nutrient integration, and climate-resilient hybrids have gained momentum. The adoption of integrated pest management and conservation tillage further promotes sustainable cultivation, reducing the environmental footprint of sweet corn production. By integrating insights from these three dimensions, this review provides a comprehensive roadmap for the future of sweet corn research, merging genetic innovation, agronomic efficiency, and ecological responsibility to achieve resilient and sustainable production systems.



Academic Editor: Hongwei Cai

Received: 26 March 2025

Revised: 12 May 2025

Accepted: 13 May 2025

Published: 21 May 2025

Citation: Sidahmed, H.; Vad, A.; Nagy, J. Advances in Sweet Corn (*Zea mays* L. *saccharata*) Research from 2010 to 2025: Genetics, Agronomy, and Sustainable Production. *Agronomy* **2025**, *15*, 1260. <https://doi.org/10.3390/agronomy15051260>

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Keywords: sweet corn; environmental interaction; sustainability; genotype; agronomic practices; biofortification

1. Introduction

Sweet corn (*Zea mays* L. *saccharata*) is a highly valued crop worldwide, cultivated for its tender kernels consumed as a vegetable, and it is increasingly recognized for its nutritional value and adaptability to various agro-climatic conditions [1]. Unlike field corn, sweet corn possesses a naturally occurring mutation in the sugary (*su*), shrunken 2 (*sh2*), or sugary enhancer (*se*) genes, resulting in high sugar and low starch content in kernels, which enhances its sweetness and eating quality [2]. Global demand for sweet corn has increased steadily over the past two decades due to changing dietary preferences, urbanization, and rising health consciousness, leading to intensified research efforts focused on breeding, agronomy, and sustainability [3].

Research advancements between 2010 and 2025 have focused primarily on three pillars: genetics and breeding, agronomic management, and sustainable production. In genetics and breeding, there has been significant progress in hybrid development, molecular-marker-assisted selection, and the genetic mapping of traits linked to yield, sweetness, kernel quality, and stress tolerance [4]. Next-generation sequencing (NGS) and genome-wide association studies (GWAS) have identified candidate genes related to abiotic stress tolerance, nutrient use efficiency, and resistance to pests and diseases [5]. Additionally, recent work has addressed heterosis and genotype \times environment interaction, particularly in relation to varying sowing dates and climatic conditions [6].

Agronomic research on sweet corn from 2010 to 2025 has emphasized optimizing sowing dates, plant density, irrigation management, and balanced nutrient application to enhance productivity [7]. Studies have shown that precise nitrogen management and planting date adjustments can significantly improve sweet corn yield and quality under changing climate conditions [8]. Moreover, integrated crop management practices, including conservation tillage and organic amendments, are increasingly recognized for their role in soil health and sustainable yield enhancement [9].

Sustainability and environmental stewardship have become central themes in sweet corn production research. The focus has shifted toward climate-resilient hybrids, water-saving technologies, integrated pest management (IPM), and reduced reliance on chemical inputs [10]. Furthermore, efforts to lower the carbon footprint and enhance resource use efficiency through precision agriculture and digital farming tools are gaining momentum globally [11]. Sustainable sweet corn production is increasingly focusing on climate-resilient varieties, reduced chemical inputs, and enhanced resource-use efficiency through precision agriculture [12].

The productivity of sweet corn is increasingly threatened by climate variability, including prolonged droughts and heat stress, which significantly impair physiological processes and yield stability [13].

The limited availability of natural resources such as water and arable land further constrains sustainable cultivation [14]. Incorporating climate-resilient agronomic practices, such as optimized sowing dates and plant densities, has proven effective in mitigating the impact of environmental stress on sweet corn production [15]. These challenges underscore the need for adaptive management practices and resilient cultivars. Understanding genotype-by-environment interactions becomes crucial under such stress-prone conditions [16]. Therefore, research focusing on agronomic optimization and hybrid performance is critical to ensure future food security. A software tool designed for creating and visualizing bibliometric maps enables researchers to explore and analyze large sets of scientific publications effectively [17].

Sweet corn (*Zea mays* L. *saccharata*) production is increasingly threatened by global challenges such as climate change, resource depletion, and environmental degradation. Rising temperatures, erratic rainfall, and frequent extreme weather events disrupt growth

stages and reduce yield stability [18]. Additionally, overreliance on fertilizers and irrigation exacerbates soil degradation and water scarcity, jeopardizing long-term sustainability [19]. As land and water resources become more limited, it is crucial to adopt climate-resilient varieties and resource-efficient agronomic practices. Recent innovations in precision agriculture and breeding strategies offer potential solutions to enhance productivity under stress conditions [20]. Analyses of research trends in sweet corn highlight emerging focus areas in climate resilience and resource efficiency [21]. These insights guide the development of improved cultivars and sustainable management practices to enhance productivity under stress conditions [22]. An integrated approach that combines genetic improvement with sustainable cultivation methods is essential. Addressing these challenges is vital to ensure food security and economic viability in sweet corn production. This review explores such advancements and their role in future-ready sweet corn systems. Visualizing research collaboration through co-authorship networks provides valuable insights into the patterns and dynamics of sustainable agriculture studies [23]. This approach helps identify key contributors, collaborative clusters, and emerging trends in the field, facilitating more effective research partnerships and knowledge sharing.

This review consolidates the major advancements in sweet corn research from 2010 to 2025, covering developments in genetics and breeding, agronomic management, and sustainable production strategies.

Objectives

1. To critically assess and synthesize advancements in the genetic improvement of sweet corn (*Zea mays* L. *saccharata*) from 2010 to 2025, with particular emphasis on hybrid development, trait enhancement (e.g., yield, sweetness, and stress tolerance), and studies on genetic variability.
2. To examine recent innovations in agronomic practices and sustainable production technologies, including optimized sowing dates, plant density, nutrient management, and environmentally friendly cultivation methods, that have been aimed at improving the efficiency, resilience, and sustainability of sweet corn production.
3. To explore the intersection of genetics, agronomy, and sustainability in enhancing sweet corn performance, with a focus on integrated strategies that contribute to both productivity and environmental stewardship.

2. Methodology and Criteria for Article Selection

To ensure a comprehensive and systematic synthesis of the literature, a structured approach was followed in selecting the studies included in this review. The focus was on peer-reviewed publications from 2010 to 2025 that addressed genetic improvement, agronomic innovations, and sustainable production practices specific to sweet corn (*Zea mays* L. *saccharata*).

2.1. Inclusion Criteria

Studies were included based on the following criteria:

- Published between January 2010 and March 2025.
- Focused explicitly on sweet corn, including hybrid development, trait enhancement (e.g., yield, sweetness, stress tolerance), genetic variability, and molecular breeding.
- Investigated agronomic practices such as sowing dates, plant density, nutrient management, and sustainable or environmentally friendly production strategies.
- Articles published in peer-reviewed journals, conference proceedings, and book chapters with relevant scientific contributions.
- Written in English.

2.2. Exclusion Criteria

The following types of studies were excluded:

- Studies focusing exclusively on field or dent maize without specific relevance to sweet corn.
- Publications lacking original data or critical insights, such as news articles, commentaries, and opinion pieces.
- Studies not accessible in full text or outside the scope of the review's thematic objectives.
- Duplicate publications or preliminary abstracts without corresponding full research papers.

3. Genetics

3.1. Historical Overview of Sweet Corn Research

Systematic research into sweet corn genetics and production started to gain momentum in the early 20th century with the development of open-pollinated varieties. However, the release of the first commercial sweet corn hybrids in the 1930s marked a turning point, significantly increasing yield stability and kernel quality [24]. Post World War II, research expanded globally, particularly in Europe and Asia, where sweet corn became increasingly popular for fresh markets and processing industries [25]. Systematic research into sweet corn genetics and production began gaining momentum in the early 20th century with the development of open-pollinated varieties. However, the release of the first commercial sweet corn hybrids in the 1930s represented a major breakthrough, significantly improving yield stability, kernel quality, and crop uniformity [26]. After World War II, sweet corn research expanded globally, particularly in Europe and Asia, where the crop gained popularity for both fresh consumption and processing markets due to growing consumer demand and advancements in breeding technologies [27].

Between 2010 and 2025, sweet corn research has experienced unprecedented progress driven by advances in genomics, biotechnology, and precision agriculture [4]. Researchers have mapped genetic traits associated with sweetness, ear size, kernel depth, and stress tolerance, leading to the development of highly productive hybrids suitable for both tropical and temperate environments [5]. In parallel, agronomic research focused on planting date optimization, plant density, and nutrient management has contributed to the improved productivity and sustainability of sweet corn production systems worldwide [7].

Thus, sweet corn research has evolved from simple selection methods to a sophisticated, interdisciplinary field combining genetics, agronomy, and environmental science to meet the demands of changing climates and market preferences [28].

3.2. Genetic Improvement in Grain Yields

3.2.1. Genetic Improvement of Sweet Corn Hybrids

The genetic improvement of sweet corn hybrids has been central to the crop's yield gains, quality enhancement, and adaptability to diverse environments. Early breeding efforts were limited to conventional crossing and selection, focusing on visual traits and simple quality parameters [29]. However, between 2010 and 2025, sweet corn breeding entered a new era characterized by marker-assisted selection (MAS), genomic selection (GS), and genome-wide association studies (GWAS) [4,5]. Overall, the genetic improvement of sweet corn hybrids from 2010 to 2025 has been transformative, combining classical breeding with cutting-edge genomic tools to meet global production demands, consumer preferences, and environmental challenges [30].

GWAS: genome-wide association study, a study that involves scanning genomes from many different people to find genetic variations associated with a particular disease or trait.

Breeding objectives during this time have focused on improving kernel sweetness, ear uniformity, disease resistance, and tolerance to drought and heat [31]. Molecular markers linked to genes like *sh2*, *su1*, and *se* have made it easier to select for sweetness and shelf-life. Additionally, molecular tools have helped combine multiple disease resistance genes to address common pathogens like northern corn leaf blight and maize dwarf mosaic virus [32]. The findings are outlined in Table 1.

Table 1. Recent applications of molecular markers in sweet corn breeding for quality trait enhancement.

Marker	Target Trait(s)	Genomic Tools Used	Breeding Strategy	Recent Outcomes
<i>sh2</i>	High sugar content, extended freshness	Marker-assisted selection (MAS), QTL mapping	Introgression into elite backgrounds, hybrid development	Development of ultra-sweet cultivars with longer shelf life and improved consumer preference
<i>su1</i>	Creamy texture, moderate sweetness	SNP genotyping, linkage analysis	Used in heirloom and quality-oriented breeding lines	Cultivars with improved eating quality and favorable texture for processing
<i>se1</i>	Enhanced sweetness, improved flavor	Genomic selection (GS), genome-wide association studies (GWAS)	Stacking with <i>su1</i> for enhanced expression	Synergistic effect in new cultivars combining tenderness and high sugar content
Combined (<i>sh2</i> + <i>se1</i> or <i>su1</i> + <i>se1</i>)	Multi-trait enhancement (sweetness, texture, shelf-life)	Pyramiding via MAS and GS	Simultaneous trait targeting hybrid breeding	Superior hybrids with enhanced taste, shelf stability, and consumer appeal

High-throughput genotyping platforms and next-generation sequencing have accelerated genetic diversity studies and the identification of candidate genes associated with yield components and stress tolerance [5]. These genomic data have allowed breeders to predict hybrid performance more accurately and reduce breeding cycles. Hybrid development programs have increasingly incorporated genotype \times environment interaction analysis to ensure stable performance across varying planting dates and climatic conditions [6].

Another notable achievement has been the development of biofortified sweet corn hybrids enriched with vitamins, antioxidants, and carotenoids to meet nutritional demands [33]. Advances in CRISPR/Cas9 technology have also opened new opportunities for targeted genome editing in sweet corn, although this area remains in early-stage research and faces regulatory challenges [34].

The use of doubled haploid technology has further revolutionized sweet corn breeding by enabling the rapid development of homozygous lines for hybrid production [35]. Simultaneously, breeders have focused on expanding the genetic base by incorporating exotic germplasm and landraces, providing novel alleles for quality and stress tolerance traits [36].

Overall, the genetic improvement of sweet corn hybrids from 2010 to 2025 has been transformative, combining classical breeding with cutting-edge genomic tools to meet global production demands, consumer preferences, and environmental challenges [30].

The genetic improvement of sweet corn (*Zea mays* L. *saccharata*) has advanced significantly in recent years, combining classical breeding methods with cutting-edge molecular tools to meet the dual goals of productivity and nutritional enhancement. A key pillar of this progress is the exploitation of heterosis or hybrid vigor, which remains central to hybrid development programs. By crossing genetically diverse inbred lines, breeders have consistently produced F₁ hybrids with superior phenotypic traits, such as improved uniformity, sweetness, early maturity, and environmental adaptability. This approach

enhances not only yield stability but also facilitates broader adaptability across diverse agroecological zones [37]. Heterosis is now being further understood at the molecular level, where insights into gene expression patterns and epistatic interactions help refine parental line selection and hybrid performance prediction.

In parallel, the introduction of CRISPR-Cas9 gene-editing technology has opened new avenues for precision breeding in sweet corn. Unlike traditional transgenic approaches, CRISPR offers a high degree of accuracy, allowing for targeted modifications to specific genes without inserting foreign DNA. This tool is now being used to develop sweet corn varieties with traits such as enhanced sugar metabolism, increased resistance to diseases, and tolerance to abiotic stresses like drought and salinity. For instance, editing genes involved in starch-to-sugar conversion has been shown to improve sweetness while maintaining desirable textural qualities. Additionally, CRISPR is facilitating rapid advances in the development of climate-smart corn by enabling the modification of stress-responsive genes, thus reducing crop vulnerability in changing environments [38]. These technological breakthroughs shorten breeding cycles and enable the development of cultivars tailored to precise environmental and market needs.

Together, heterosis, CRISPR, and biofortification exemplify a synergistic approach to sweet corn improvement that integrates traditional wisdom with next-generation technologies. This integration is not only advancing the genetic potential of sweet corn but also contributing to more resilient, nutritious, and sustainable agricultural systems.

Recent advances in sweet corn breeding have led to the development of hybrid varieties with improved resistance to biotic and abiotic stresses, better nutritional content, and enhanced adaptability. Case studies demonstrate the real-world performance of these hybrids under diverse agro-climatic conditions. For example, the hybrid ‘Sweet Sunshine’ exhibited superior tolerance to high temperatures and common rust (*Puccinia sorghi*), producing yields of up to 12.8 t/ha⁻¹ under semi-arid conditions in southern Pakistan [39]. Similarly, ‘Golden Jubilee’, a popular North American variety, maintained uniform cob quality and stable yields across early and late sowing dates in field trials conducted in the Midwest, United States [40]. These findings underscore the role of targeted hybrid development in addressing location-specific challenges and enhancing sweet corn productivity globally.

3.2.2. Climate Change Impact

The impact of climate change on sweet corn production is increasingly evident through rising temperatures, erratic rainfall, and extreme weather events. Many studies model these impacts using Representative Concentration Pathways (RCPs). For instance, under RCP8.5, which assumes high greenhouse gas emissions, simulations using the DSSAT-CERES-Maize model indicate a potential 10–15% reduction in sweet corn yields by 2050 in lowland tropical areas due to shortened growing periods and increased heat stress [41]. Conversely, regions with cooler climates may see temporary yield improvements under moderate emission scenarios (RCP4.5) due to extended growing seasons [42]. The explicit integration of these climate model parameters allows for more accurate projections and better-informed adaptation strategies in sweet corn cultivation.

3.2.3. Economic Analysis

Economic feasibility remains a key factor in the adoption of improved practices and technologies in sweet corn farming. Cost-benefit analyses reveal significant regional disparities. In the United States, the adoption of precision nitrogen management systems has yielded a benefit–cost ratio (BCR) of 2.8, driven by reduced input costs and increased marketable yields [43]. In contrast, similar interventions in South Asia show a BCR rang-

ing from 1.5 to 1.9, primarily due to limited access to digital tools, variable input costs, and lower output prices [44]. These comparisons highlight the importance of tailored policy support and localized research to promote the equitable and profitable adoption of innovations.

3.3. Technological Innovations in Sweet Corn Research

The integration of genomic tools and marker-assisted selection (MAS) has revolutionized sweet corn breeding from 2010 to 2025, enabling precise and accelerated genetic improvement. Traditional breeding methods, though effective, were time-consuming and dependent on phenotypic evaluations under variable environments. Genomic technologies now allow for the identification of genetic markers closely linked to traits of interest, significantly enhancing selection efficiency and breeding accuracy [45]. Recent genomic innovations in maize have greatly enhanced the efficiency of sweet corn improvement by enabling the rapid identification of loci associated with yield, quality, and stress tolerance traits [46].

These markers have been used in linkage mapping and quantitative trait loci (QTL) analysis to identify genomic regions controlling agronomic and quality traits [47].

Genome-wide association studies (GWASs) have become a cornerstone of modern sweet corn research, leveraging large genomic datasets and diverse populations to detect marker–trait associations with high resolution [5]. GWASs have been pivotal in identifying loci associated with abiotic stress tolerance, nitrogen use efficiency, and kernel quality in sweet corn breeding programs [48]. The application of next-generation sequencing (NGS) technologies, such as genotyping-by-sequencing (GBS), has facilitated high-throughput genotyping and increased the discovery of SNPs in breeding populations [49].

Marker-assisted selection has been widely adopted for the improvement of complex traits in sweet corn. Markers linked to *sh2*, *su1*, *se1*, and other quality-related genes are routinely used for early generation selection, reducing the breeding cycle and ensuring the presence of desired alleles [4]. Moreover, markers associated with resistance to northern corn leaf blight, rust, and root rot pathogens have been successfully integrated into breeding pipelines [32,50].

Genomic selection (GS), an extension of MAS that uses genome-wide marker information to predict breeding values, has also gained traction in recent years. GS has shown promise in improving prediction accuracy for traits with low heritability and for accelerating hybrid development [51]. By combining genomic information with phenotypic data collected across multiple environments, breeders are able to make more informed selections and develop hybrids with superior performance stability [52].

Furthermore, transcriptomic and proteomic analyses have provided deeper insights into gene expression under stress conditions, complementing genomic tools and offering new candidate genes for selection [53]. Bioinformatics platforms and breeding software have streamlined the integration of genomic data with field trials, enhancing decision making and resource efficiency [54].

In conclusion, genomic tools and marker-assisted selection have transformed sweet corn breeding into a precision-driven science. The integration of these technologies continues to drive genetic gains, improve resource use efficiency, and facilitate the development of climate-resilient, high-quality sweet corn hybrids tailored to both fresh market and processing industries [30,55].

3.3.1. Biotechnological Tools and Molecular Approaches in Sweet Corn Improvement

Recent advancements in biotechnology have introduced several tools that significantly aid in the molecular genetics and breeding of sweet corn. These techniques allow

researchers to identify genetic variation, enhance selection efficiency, and accelerate the development of improved hybrids.

Simple Sequence Repeat (SSR) markers are highly polymorphic and conserved DNA sequences used to assess genetic diversity, fingerprint genotypes, and construct linkage maps. According to [56], SSRs remain a valuable resource for molecular breeding due to their high reproducibility and informativeness.

Single Nucleotide Polymorphisms (SNPs), as discussed by [57], are single-base-pair variations widely distributed across the genome. They offer high-resolution mapping and are useful for genome-wide association studies (GWASs), especially in sweet corn kernel trait analysis.

Quantitative trait loci (QTL) mapping is a powerful method to identify genomic regions linked to complex traits. [58] employed QTL mapping to locate regions associated with zeaxanthin content in sweet corn across diverse environments, demonstrating its application in nutritional improvement.

Genomic selection (GS), as reported by [59], utilizes genome-wide marker data to predict the breeding values of individuals. This approach increases selection accuracy and genetic gain, particularly in hybrid performance prediction.

Marker-assisted selection (MAS) is another efficient breeding approach that involves using markers linked to desired traits. Ref. [60] demonstrated its effectiveness in biofortifying sweet corn with beta-carotene through backcross breeding and marker tracking.

Gene expression analysis techniques like quantitative real-time PCR (qPCR) and RNA sequencing (RNA-seq) are widely used to study transcriptional changes. Ref. [61] applied transcriptome analysis and machine learning to uncover crowding-stress-responsive genes in sweet corn.

CRISPR/Cas9 genome editing is a transformative tool for targeted gene modification. Ref. [62] highlighted its role in enhancing climate resilience in maize, including drought and pest resistance through precise genome editing.

Omics approaches, including transcriptomics, proteomics, and metabolomics, offer a systems-level view of biological functions. Ref. [63] used integrated transcriptome and metabolome analyses to explore physiological responses in sweet corn under artificial aging conditions, providing insights into seed vigor and viability.

Together, these biotechnological tools provide a comprehensive and efficient framework for sweet corn improvement by integrating classical breeding with molecular precision. Integrated proteomic and metabolomic analyses have identified key mechanisms underlying drought tolerance in sweet corn, revealing important stress-responsive proteins and metabolites [64]. Similarly, combined transcriptomic and metabolomic profiling has uncovered molecular pathways regulating sugar accumulation in sweet corn kernels, enhancing understanding of quality traits [65].

3.3.2. Genetic Diversity and Germplasm Conservation

Genetic diversity is the cornerstone of any successful breeding program, including sweet corn (*Zea mays* L. *saccharata*). A broad genetic base ensures the availability of alleles that contribute to yield potential, stress tolerance, disease resistance, and kernel quality traits [66]. From 2010 to 2025, there has been a growing recognition of the need to preserve and utilize sweet corn genetic diversity to counter genetic erosion caused by the repeated use of a narrow set of elite lines [67].

Germplasm collections maintained by international organizations, such as the USDA Germplasm Resources Information Network (GRIN) and the International Maize and Wheat Improvement Center (CIMMYT), hold thousands of sweet corn accessions, including landraces, wild relatives, and obsolete cultivars [68]. These collections are invaluable for

identifying new sources of resistance to pests and diseases and for introducing unique quality traits into breeding programs [69].

Advances in molecular characterization techniques have facilitated more efficient germplasm evaluation. High-density SNP genotyping and whole-genome sequencing have been employed to assess genetic diversity in global sweet corn collections, revealing untapped allelic variation and population structures that can be harnessed in breeding [70]. Additionally, genome-wide association studies (GWASs) on diverse germplasm panels have helped identify novel loci associated with agronomic traits, further emphasizing the importance of maintaining a wide genetic pool [48].

Exotic germplasm and wild relatives of maize (*Zea mays* ssp. *parviglumis* and *mexicana*) have also contributed significantly to the genetic improvement of sweet corn by introducing new alleles for stress tolerance and nutritional enrichment [71]. Pre-breeding programs focused on introgressing favorable alleles from exotic germplasm into elite sweet corn backgrounds have gained momentum in recent years [72]. The conservation of sweet corn genetic diversity extends beyond ex-situ collections; the in-situ conservation of landraces maintained by smallholder farmers, particularly in Latin America and Southeast Asia, plays a critical role in preserving genetic variation and adapting to local environmental pressures [73]. Farmer-participatory breeding initiatives have been encouraged to facilitate the exchange of germplasm and promote the conservation of locally adapted sweet corn varieties [74].

Cryopreservation and seed storage technologies have advanced considerably, improving the long-term viability of germplasm collections. Additionally, digital databases and genebank management tools have been developed to facilitate germplasm tracking, evaluation, and distribution to breeders globally [75].

In conclusion, genetic diversity and germplasm conservation efforts are essential for ensuring the sustainability and resilience of sweet corn breeding programs. The continued exploration, characterization, and preservation of sweet corn genetic resources will be pivotal in addressing future challenges posed by climate change and evolving consumer preferences [76].

The integration of digital agriculture into sweet corn production is transforming the way farmers manage their crops, making agriculture more efficient, precise, and sustainable. Digital technologies, such as remote sensing, geographic information systems (GISs), precision farming tools, and data analytics, enable farmers to monitor, control, and optimize various aspects of sweet corn cultivation. These innovations offer valuable insights into crop health, environmental conditions, and operational efficiency, ultimately improving productivity and reducing environmental impact. This section explores the integration of digital agriculture in sweet corn farming and its potential benefits.

3.3.3. Digital Agriculture

Digital agriculture has emerged as a transformative tool in modern sweet corn production, offering precise data-driven decision-making. Drones and field sensors are increasingly used for monitoring crop health, optimizing irrigation, and detecting nutrient deficiencies. For example, a case study in California's Central Valley demonstrated that using drone-mounted multispectral cameras to assess canopy temperature and NDVI (Normalized Difference Vegetation Index) reduced irrigation water usage by 18%, while maintaining optimal yield levels on a 40/ha sweet corn farm [77]. Similarly, in Spain, soil moisture sensors integrated with automated irrigation systems improved water use efficiency by 22% and helped prevent over-irrigation in sweet corn fields [78]. These technologies not only enhance resource efficiency but also support climate-smart agriculture by minimizing water waste and reducing greenhouse gas emissions.

3.3.4. Organic Production

The adoption of organic sweet corn production practices is gaining momentum due to consumer demand for chemical-free food and environmentally sustainable farming. However, transitioning to organic systems involves significant challenges. The economic cost of organic certification ranges from USD 700 to USD 2000 per farm, depending on the region and certifying body [79]. Additionally, during the 2–3 year transition period, yields often decline, while input costs may increase due to the use of approved organic fertilizers and pest control measures [80]. Despite these costs, the market offers a premium price, often 20–40% higher than conventionally grown sweet corn, which can offset initial investments over time [81]. Surveys from the U.S. and Europe show growing consumer acceptance and demand for organic sweet corn, particularly in urban markets [82], indicating strong market potential when certification and supply chains are well managed.

Over time, these premium prices can help recoup initial investments and improve farm profitability, especially when paired with efficient organic management practices [83].

3.3.5. Precision Agriculture Technology

Precision agriculture (PA) refers to the application of technology to manage agricultural practices at a high level of accuracy. In sweet corn farming, precision agriculture utilizes tools like GPS, variable rate technology (VRT), and soil sensors to optimize the application of inputs such as water, fertilizers, and pesticides. By using these technologies, farmers can ensure that inputs are applied only where and when needed, reducing waste and environmental impact while improving crop yields.

For instance, GPS, guided tractors, and machinery allow for precise planting, fertilization, and irrigation, minimizing overlap and under-application in fields. Soil sensors, in combination with real-time data analytics, can provide information on soil moisture and nutrient levels, allowing farmers to adjust irrigation and fertilization schedules to meet the specific needs of their sweet corn crops. This targeted approach to input management can result in a more efficient use of resources, reduced costs, and increased sustainability in sweet corn production [84].

3.3.6. Remote Sensing and Drone Technology

Remote sensing technologies, including satellite imagery and drones, play a crucial role in modern sweet corn farming. These technologies allow farmers to monitor large areas of farmland with high spatial and temporal resolution, providing valuable insights into crop health, growth patterns, and environmental stress factors.

Drones equipped with multispectral and hyperspectral sensors can capture detailed images of sweet corn fields, enabling farmers to assess plant health, detect early signs of diseases or pests, and identify areas of nutrient deficiency. This information helps farmers make informed decisions on where to focus their resources, whether that involves applying pesticides to specific areas or adjusting irrigation practices to address water stress. Remote sensing can also be used to monitor crop growth and development, allowing farmers to track how well their sweet corn crops are progressing throughout the growing season and make timely interventions when needed [85].

3.3.7. Big Data and Data Analytics in Crop Management

The collection and analysis of large volumes of data, known as big data, is revolutionizing decision-making in sweet corn production. Sensors, drones, and other digital technologies generate vast amounts of data that can be analyzed using advanced data analytics tools to gain insights into crop performance, soil health, and environmental conditions.

By leveraging big data, farmers can predict crop yields, optimize resource allocation, and identify trends that would be difficult to discern through traditional observation alone. For example, predictive models can be developed to forecast sweet corn yields based on factors like weather patterns, soil moisture levels, and plant health. These models can also help farmers optimize planting schedules, reduce risks associated with adverse weather, and maximize productivity [86].

In addition to yield predictions, data analytics can be used to optimize irrigation schedules based on real-time weather data and soil moisture readings, minimizing water usage while ensuring crops receive adequate moisture. The ability to analyze vast amounts of data enables farmers to make more informed, evidence-based decisions, ultimately improving the efficiency and profitability of sweet corn farming.

3.4. Genetic Improvement in Environmental Adaptability and Sustainability

3.4.1. Hybrid Performance Across Diverse Environments

The performance of sweet corn hybrids across diverse environments is a critical factor in breeding programs, given the significant genotype \times environment ($G \times E$) interactions that influence yield, quality, and stability [87]. From 2010 to 2025, increasing efforts have been devoted to evaluating hybrid performance under variable climatic conditions, soil types, and management practices to develop resilient and stable cultivars [88].

Multi-environment trials (METs) are the backbone of such evaluations. Through METs, breeders can assess the adaptability and stability of hybrids across different agroecological zones. These trials utilize statistical models such as AMMI (Additive Main effects and Multiplicative Interaction) and GGE (Genotype and Genotype-by-Environment) biplot analyses to identify hybrids with both high performance and broad adaptability [89]. Research has shown that hybrids with stable performance in diverse environments often combine favorable traits such as stress tolerance, efficient nutrient use, and consistent kernel quality [90].

Recent advancements in genomic selection (GS) and phenotyping platforms have allowed breeders to predict hybrid performance more accurately under varying conditions [52]. GS models, when combined with MET data, enhance the ability to select hybrids that not only perform well in optimal conditions but also maintain productivity in suboptimal or stress-prone environments [91]. This is particularly important given the impact of climate change on rainfall variability, temperature fluctuations, and pest pressure.

Studies on sweet corn have revealed that sowing dates, nitrogen management, and planting densities significantly affect hybrid performance across locations [92]. Some hybrids exhibit strong plasticity, adjusting growth patterns in response to environmental signals, while others display static stability with minimal yield fluctuations. Identifying and understanding these hybrid behaviors is essential for recommending hybrids to specific regions and cropping systems [93].

The use of high-throughput phenotyping tools, such as drone-based imaging and remote sensing technologies, has also contributed to the precise measurement of hybrid responses to environmental stressors, including drought and heat stress [94]. Data derived from these technologies, combined with environmental covariates, are increasingly used in predictive modeling to recommend hybrids tailored to specific climatic zones [95].

Collaborative regional trials conducted across North America, Europe, and parts of Asia have emphasized the value of evaluating hybrids in diverse environmental conditions to enhance their commercial viability [96]. Modern breeding programs increasingly incorporate environmental profiling, collecting data on factors such as soil moisture, temperature stress, and nutrient levels to boost the precision of hybrid selection [97].

In summary, evaluating hybrid performance across diverse environments is fundamental for developing sweet corn cultivars with wide adaptability and stability. Continued efforts to integrate genomic prediction, phenotypic data, and environmental analysis will accelerate the development of hybrids that meet productivity and quality standards under changing climatic conditions [98].

3.4.2. Climate Change's Impact on Sweet Corn Production

Climate change is one of the most significant global challenges for agriculture, affecting crop yields, quality, and overall production systems. Sweet corn (*Zea mays* L. *saccharata*) is no exception, as changes in temperature, precipitation patterns, and the frequency of extreme weather events have profound implications for its cultivation. Over the last decade (2010–2025), research has increasingly focused on understanding how climate change impacts sweet corn production and identifying adaptation strategies to mitigate these effects [99].

Rising temperatures are one of the most prominent consequences of climate change, with potential negative effects on sweet corn development. High temperatures, particularly during pollination, can lead to poor kernel formation and reduced yields. Sweet corn is particularly sensitive to heat stress, with temperature extremes above 30 °C causing pollen sterility and kernel abortion. Studies have shown that heat stress during the flowering period can reduce sweet corn yields by up to 30% in certain regions [100]. Additionally, prolonged periods of elevated temperatures may shorten the growing season, limiting the time available for optimal growth and development [101].

Changing precipitation patterns and water availability are also critical factors in sweet corn production. While sweet corn requires significant amounts of water for optimal growth, both droughts and excessive rainfall can cause major problems. Drought stress leads to poor seed germination, reduced growth, and lower yield potential, while excessive rainfall can lead to waterlogging, which restricts root growth and oxygen availability [102]. The increased frequency of extreme weather events, such as storms and flooding, poses a challenge for sweet corn production, especially in regions that experience erratic rainfall patterns or shifts in seasonal timing [103].

The increased occurrence of pests and diseases associated with climate change is another concern for sweet corn growers. Warmer temperatures and altered precipitation regimes provide more favorable conditions for the proliferation of pests such as the corn earworm (*Helicoverpa zea*) and European corn borer (*Ostrinia nubilalis*), which can lead to higher infestations and greater damage to the crop [104]. Similarly, climate change may exacerbate the prevalence of soil-borne diseases like Fusarium and root rot, which thrive under wet and warm conditions [105].

To address these challenges, researchers have focused on developing climate-resilient sweet corn varieties through breeding and genetic modification. These crops are designed to tolerate higher temperatures, drought conditions, and pest pressures, ensuring stable production in the face of climate variability. For example, drought-tolerant hybrids with deeper root systems and improved water use efficiency have been developed to withstand periods of water scarcity, while heat-resistant varieties are being bred to cope with rising temperatures during critical developmental stages [106]. Additionally, the integration of climate-smart agricultural practices such as conservation tillage, agroforestry, and cover cropping has been found to mitigate some of the impacts of climate change by improving soil health and water retention [107].

Moreover, precision agriculture techniques that incorporate weather forecasting, soil moisture sensors, and remote sensing technologies can help optimize resource use and reduce vulnerability to climatic stressors. By providing real-time data, these technologies

allow for more accurate irrigation scheduling, pest and disease monitoring, and early intervention when adverse weather events are anticipated [108].

In conclusion, climate change presents significant challenges for sweet corn production, from altered temperature and precipitation patterns to increased pest and disease pressure. However, through ongoing research and the development of climate-resilient varieties, sustainable farming practices, and precision agriculture, sweet corn production systems can adapt to these changes. Continued innovation and adaptation will be crucial to ensuring the sustainability of sweet corn production in a changing climate [109]. The findings are presented in Figure 1.

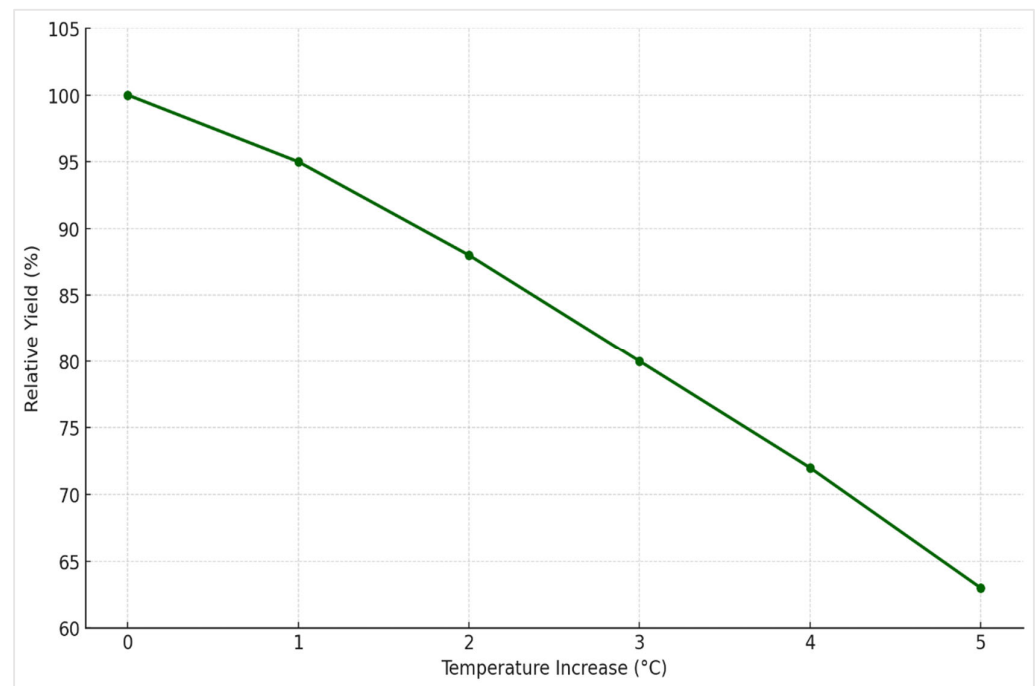


Figure 1. Impact of rising temperatures on sweet corn yield performance. Source: [110].

3.4.3. Abiotic Stress Resilience

Abiotic stressors, such as drought, heat, waterlogging, and salinity, are significant environmental challenges that impact sweet corn (*Zea mays* L. *saccharata*) production worldwide. These stresses can severely reduce yields, lower quality, and limit the geographical regions where sweet corn can be successfully grown. Breeding for abiotic stress tolerance is crucial for enhancing the resilience of sweet corn varieties and ensuring stable production in the face of climate variability and environmental changes. This section explores recent advancements in breeding strategies for improving abiotic stress tolerance in sweet corn with a focus on drought and heat tolerance, waterlogging resistance, and salinity tolerance.

3.4.4. Drought Tolerance

Drought is one of the most common abiotic stress factors affecting sweet corn yield, particularly in regions with limited water availability or those experiencing changing rainfall patterns due to climate change. Drought stress can lead to reduced kernel formation, smaller kernels, and the premature senescence of the plants, significantly impacting overall yield [111]. In response, breeding efforts have focused on developing drought-tolerant sweet corn varieties by selecting traits that improve water use efficiency, enhance root system architecture, and reduce water loss.

One key approach is selecting varieties with deeper and more extensive root systems that can access water from deeper soil layers, allowing the plants to maintain growth and

yield during dry periods [112]. Additionally, the ability to maintain high photosynthetic rates under drought conditions is a valuable trait, as it allows plants to continue producing energy for growth and yield formation even when water is limited. The drought-tolerant (DT) maize lines developed through conventional breeding and genetic modifications have shown promise in improving drought tolerance in sweet corn, with some hybrids exhibiting higher yields under water-limited conditions [113].

3.4.5. Heat Tolerance

Heat stress, particularly during pollination, can reduce fertilization success and result in poor kernel set, leading to yield losses. High temperatures can cause pollen sterility, resulting in incomplete ear formation and lower seed development, significantly reducing yield potential. Breeding for heat tolerance in sweet corn involves selecting heat-resistant genes that allow plants to maintain physiological functions, such as pollination and fertilization, during periods of extreme heat.

One promising area of research involves identifying heat shock proteins and other molecular markers that are associated with heat tolerance in maize. These markers can be used to select heat-tolerant traits in sweet corn hybrids. Additionally, breeding strategies have focused on developing hybrids with improved canopy architecture that can provide shade and reduce heat stress on the ears during high-temperature periods [114]. Recent advances in genomics and gene-editing technologies have accelerated the identification of heat tolerance genes, allowing for the faster development of heat-resistant sweet corn varieties [115].

3.4.6. Waterlogging Resistance

Waterlogging is a form of abiotic stress that occurs when excess water saturates the soil, limiting oxygen availability to plant roots. This can lead to root damage, reduced nutrient uptake, and decreased photosynthetic activity, all of which contribute to lower yields. Waterlogging is particularly problematic in regions prone to heavy rainfall or where irrigation systems lead to excess water.

Breeding for waterlogging resistance involves selecting root traits that allow plants to cope with oxygen deficiency, such as the ability to form aerenchyma (air spaces in the roots that facilitate oxygen diffusion) and enhanced root growth under flooded conditions. Sweet corn varieties with these traits are better equipped to survive in waterlogged soils and can maintain growth and productivity under suboptimal conditions [116]. Additionally, research into genetic loci associated with waterlogging tolerance has enabled the development of molecular markers for selecting waterlogging-resistant traits, facilitating the creation of more resilient sweet corn varieties [117].

3.4.7. Salinity Tolerance

Salinity stress occurs when high salt concentrations in the soil reduce the ability of plants to absorb water, leading to osmotic stress and ion toxicity. This is a significant issue in regions with saline soils or where irrigation with saline water is common. Sweet corn, like many crops, is highly sensitive to salt, and salinity stress can cause stunted growth, chlorosis, and decreased yields.

Breeding for salinity tolerance in sweet corn focuses on identifying genetic variations that allow plants to better tolerate high salt concentrations. These traits include improved ion transport mechanisms, such as the ability to exclude harmful ions (e.g., sodium) from the root system and accumulate beneficial ions (e.g., potassium) for growth and development [118]. Research into the molecular basis of salt tolerance in maize has led to the identification of candidate genes that could be utilized in sweet corn breeding programs to improve salinity resistance. Salinity-tolerant sweet corn varieties are particularly valuable

for areas with saline irrigation water or coastal regions where soil salinization is a growing concern [119].

3.4.8. Genetic Tools for Abiotic Stress Tolerance

The advent of molecular breeding tools, such as genomic selection, marker-assisted selection (MAS), and gene editing (CRISPR-Cas9), has accelerated the development of abiotic-stress-tolerant sweet corn varieties. These tools allow breeders to identify and select stress-tolerant genes more efficiently, speeding up the breeding process and increasing the precision of selection [120]. For example, genomic selection has been used to identify quantitative trait loci (QTL) associated with drought and heat tolerance in maize, which can be applied to sweet corn breeding. Additionally, gene editing technologies are enabling the development of sweet corn hybrids with specific traits, such as improved root architecture or enhanced stress response mechanisms, to combat the effects of abiotic stress [121].

Breeding for abiotic stress tolerance in sweet corn is critical for ensuring that the crop remains productive and resilient in the face of climate change and variable environmental conditions. Advances in breeding techniques, such as marker-assisted selection, genomic selection, and gene editing, have enabled the development of more drought-tolerant, heat-resistant, waterlogging-tolerant, and salinity-resistant sweet corn varieties. These innovations are not only essential for maintaining high yields but also for ensuring the sustainability and profitability of sweet corn production in diverse environmental conditions. Continued research and collaboration between breeders, agronomists, and molecular biologists will be vital for further improving the abiotic stress resilience of sweet corn and securing food production for future generations [122].

3.4.9. Drought and Heat Stress Management

Drought and heat stress are two of the most significant abiotic factors limiting sweet corn (*Zea mays* L. *saccharata*) production globally. These environmental challenges can drastically reduce yields, disrupt crop development, and affect quality. With climate change exacerbating the frequency and severity of such stressors, effective drought and heat stress management strategies are crucial for sustaining sweet corn production in many regions. This section examines key management strategies to mitigate the impacts of drought and heat stress on sweet corn crops, including agronomic practices, irrigation management, and genetic improvements.

Drought stress occurs when water availability is insufficient to meet the crop's demand for normal growth and development. The impacts of drought are particularly pronounced during critical growth stages, such as pollination and grain filling. Sweet corn, like other maize varieties, is highly sensitive to water deficits, which can lead to poor kernel formation, reduced grain size, and overall yield losses. Effective water management is essential for mitigating the effects of drought. Drip irrigation and sprinkler systems are commonly used to optimize water distribution and ensure that sweet corn plants receive consistent moisture, particularly in water-limited environments. Drip irrigation, in particular, is an efficient method for delivering water directly to the root zone, minimizing water wastage and reducing evaporation losses. However, this method requires a well-managed irrigation system and proper scheduling to ensure that water is applied at the right time and in the right amount to prevent water stress during critical growth stages [123].

Another important approach is the use of soil moisture sensors and weather forecasting tools, which can help farmers optimize irrigation schedules based on real-time data. Precision agriculture technologies enable the use of data-driven decisions to avoid over-irrigation and reduce water usage while ensuring crops receive adequate hydration during dry spells [124].

3.4.10. Soil Conservation Practices

In addition to efficient irrigation, soil conservation techniques such as mulching, cover cropping, and reduced tillage can improve water retention and soil moisture availability. Mulching with organic materials helps to reduce surface evaporation and maintain soil moisture levels. Cover crops, such as legumes or grasses, can improve soil structure and increase water infiltration, while also preventing soil erosion during dry periods [125]. These practices are especially beneficial in drought-prone regions where soil health is critical for maintaining long-term water use efficiency.

3.4.11. Drought-Tolerant Varieties

Breeding and selecting drought-tolerant sweet corn varieties is another crucial aspect of drought stress management. Research in drought tolerance has focused on improving water use efficiency, root development, and the ability of plants to continue photosynthesis under water-limited conditions [126]. The development of drought-tolerant hybrids, which exhibit improved resistance to water stress, has helped mitigate yield losses in areas prone to water scarcity.

3.4.12. Optimal Planting Timing

Heat stress, particularly during the reproductive phase of sweet corn, can have severe consequences on pollination and kernel set. High temperatures during pollination lead to pollen sterility, resulting in incomplete kernel formation and reduced ear size. Heat stress also disrupts physiological processes, leading to premature senescence, poor grain filling, and reduced overall yield. One of the most effective ways to manage heat stress is by optimizing planting dates to avoid the hottest periods of the growing season. By adjusting sowing dates, farmers can ensure that critical growth stages, such as pollination, occur during cooler periods of the year. This strategy is particularly effective in regions where temperatures fluctuate and may cause heat stress during the peak summer months [127].

3.4.13. Shade and Canopy Management

Canopy management practices can also reduce the impact of heat stress by providing shade and cooling effects. Techniques such as adjusting planting density to ensure optimal canopy coverage can reduce the exposure of ears to direct sunlight during extreme heat. Additionally, growing taller varieties or increasing plant height through hybrid selection can help shade the ear and reduce temperature stress during the critical pollination phase [128].

3.4.14. Heat-Tolerant Hybrids

Heat tolerance in sweet corn can be improved through the selection and development of heat-resistant hybrids. Breeding programs have identified key genes related to heat stress tolerance, such as those involved in heat shock protein production, which help protect cells from damage caused by high temperatures. Heat-tolerant varieties are designed to maintain reproductive success, even during periods of high temperatures, ensuring better kernel sets and improved yield under heat stress conditions [129]. In addition, genetic improvements in canopy architecture and water use efficiency have contributed to the development of hybrids that can thrive under heat stress without compromising yield.

3.4.15. Integrated Management Strategies

An integrated approach that combines both drought and heat stress management practices is essential for improving sweet corn resilience. Strategies that optimize irrigation, enhance soil moisture retention, and promote early planting can help mitigate the effects of both drought and heat. In regions where both stressors frequently occur, the adoption of water-saving technologies, such as precision irrigation, coupled with the use of drought

and heat-tolerant hybrids, offers a holistic solution for maintaining high productivity under challenging conditions [130].

Drought and heat stress pose significant threats to sweet corn production, but with effective management strategies, their impacts can be mitigated. Water management techniques, soil conservation practices, and the use of drought-tolerant and heat-resistant varieties are key components of an integrated approach to stress management. By adopting these strategies, sweet corn producers can improve yield stability, reduce production risks, and ensure the sustainability of sweet corn farming in the face of climate change. Continued research into breeding for drought and heat tolerance, combined with advancements in irrigation and canopy management, will be essential for further improving sweet corn's resilience to these stresses in the future [131].

3.4.16. Salinity Tolerance in Sweet Corn

Salinity stress is a major abiotic factor that limits crop productivity, especially in regions where saline soils or irrigation with saline water is prevalent. For sweet corn (*Zea mays* L. *saccharata*), salinity can significantly reduce seed germination, growth, yield, and quality. As global water scarcity becomes a greater concern and saline soils expand due to environmental changes, it is essential to develop strategies for improving the salinity tolerance of sweet corn. This section explores the impact of salinity on sweet corn, the mechanisms of salt tolerance, and current breeding efforts aimed at developing salinity-resistant varieties.

3.4.17. Impact of Salinity on Sweet Corn

Salinity negatively affects sweet corn at various stages of growth, particularly during germination, seedling establishment, and grain filling. High concentrations of soluble salts in the soil reduce water availability to the plant, creating an osmotic stress that hampers the uptake of water and nutrients [132]. In addition, excess salts in the root zone can lead to ion toxicity, particularly sodium (Na^+) and chloride (Cl^-), which disrupt cellular functions and interfere with plant metabolism [133].

In the early stages of growth, salt stress can reduce seedling survival and stunt plant growth, leading to poor establishment and delayed development. During the reproductive phase, salinity can affect pollination and kernel development, leading to reduced kernel size, poor grain filling, and significant yield losses. Moreover, salinity stress can also decrease the sugar content and flavor of sweet corn, making it less desirable for fresh consumption [134]. These factors make salinity tolerance a critical trait for maintaining high yields and quality in areas with saline soil or water.

3.4.18. Mechanisms of Salt Tolerance in Sweet Corn

Salt tolerance in sweet corn is a complex trait governed by a combination of physiological, biochemical, and molecular mechanisms. Several adaptive strategies enable plants to survive and maintain growth under saline conditions. One of the key mechanisms of salt tolerance is ion exclusion, which prevents the excessive accumulation of harmful sodium and chloride ions in the plant cells. Salt-tolerant varieties of sweet corn are capable of limiting the uptake of these ions from the soil and preventing their transport to sensitive tissues, such as the leaves and developing kernels. Additionally, when ion uptake is unavoidable, salt-tolerant plants can compartmentalize sodium and chloride ions into vacuoles, isolating them from the cytoplasm where they would otherwise interfere with cellular processes [135].

3.4.19. Osmotic Adjustment

Osmotic adjustment is another important mechanism of salt tolerance. In response to osmotic stress, salt-tolerant plants accumulate compatible solutes such as proline, glycerol, and sugars, which help maintain cellular turgor pressure and protect cell structures from dehydration. This osmotic adjustment allows plants to maintain water uptake and continue metabolic processes, even under conditions of low water availability [136]. Sweet corn varieties that can efficiently accumulate and utilize osmotic regulators tend to exhibit better tolerance to salinity.

3.4.20. Antioxidant Defense Systems

Salinity-induced oxidative stress can damage plant cells by generating reactive oxygen species (ROS), which can lead to cellular injury and death. Salt-tolerant sweet corn varieties have evolved enhanced antioxidant defense systems, including enzymes such as superoxide dismutase (SOD), catalase (CAT), and peroxidase (POD), which scavenge ROS and protect the plant from oxidative damage [137]. These defense mechanisms play a critical role in maintaining plant health and functionality under salinity stress.

3.4.21. Breeding for Salinity Tolerance

Breeding salt-tolerant sweet corn varieties involves the identification and selection of traits that confer resistance to saline conditions. Traditional breeding methods have focused on selecting salt-tolerant genotypes based on phenotypic traits such as growth performance and yield under saline conditions. However, this process can be slow and labor-intensive, especially for traits that are controlled by multiple genes.

With advances in molecular biology, marker-assisted selection (MAS) and genomic selection (GS) have significantly accelerated the breeding of salt-tolerant sweet corn. MAS involves the use of molecular markers linked to salinity tolerance genes, allowing breeders to select individuals with the desired genetic traits more efficiently. Genomic selection, which uses whole-genome data to predict breeding values, is a powerful tool that can help identify genetic regions associated with salinity tolerance and improve selection accuracy [138].

3.4.22. Salinity-Tolerant Hybrids

The development of salt-tolerant hybrids through the crossbreeding of salt-tolerant inbred lines is an important strategy for improving the overall salinity resistance of sweet corn. Hybrids that combine the beneficial traits of both parents, such as better ion exclusion, enhanced osmotic adjustment, and improved antioxidant defense, can exhibit superior performance in saline environments [139]. Recent research has focused on identifying hybrid combinations that show consistent performance across different salinity levels and environmental conditions.

3.4.23. Cultural Practices for Managing Salinity Stress

While breeding for salinity tolerance is essential, cultural practices can also play a significant role in mitigating the effects of salinity on sweet corn. Proper irrigation management is crucial for minimizing salt buildup in the soil. Techniques such as leaching, where excess water is applied to flush salts out of the root zone, can help reduce the salinity concentration in the soil. Additionally, the use of organic amendments, such as compost or mulch, can improve soil structure and enhance water infiltration, reducing the negative effects of salinity stress [140].

The choice of soil amendments can also affect salt tolerance by altering the soil's cation exchange capacity, helping to prevent salt accumulation in the root zone. Moreover,

maintaining proper plant spacing and canopy management can reduce the risk of salt accumulation near the plant roots and ensure better water use efficiency.

Salinity tolerance in sweet corn is a vital trait for ensuring crop productivity in saline environments, particularly with increasing soil salinization and water scarcity challenges. Advances in understanding the physiological, biochemical, and molecular mechanisms of salt tolerance have led to the development of breeding strategies aimed at producing salt-resistant varieties. In combination with proper irrigation management and cultural practices, breeding efforts hold significant promise for improving sweet corn's resilience to salinity stress, thereby ensuring stable yields and quality in areas affected by saline conditions. Continued research into the genetic basis of salinity tolerance and the use of modern breeding tools will be key to developing varieties capable of thriving in saline environments and meeting future food production needs [141].

3.4.24. Cold Stress Adaptation

Cold stress is a significant challenge for sweet corn (*Zea mays* L. *saccharata*) production, particularly in temperate climates where late spring frosts or early autumn cold spells can severely impact crop establishment, growth, and yield. Unlike many crops, sweet corn is highly sensitive to low temperatures, especially during early germination and the seedling stages. As global climate patterns change, the occurrence of cold stress events may become more frequent, requiring the development of cold-tolerant varieties and management strategies to ensure consistent productivity. This section explores the mechanisms of cold tolerance in sweet corn, current breeding efforts to enhance cold stress resistance, and the agronomic practices that can help mitigate cold stress.

Cold stress can have multiple detrimental effects on sweet corn, with the most significant impact occurring during the germination and seedling stages. At temperatures below 10 °C, the physiological processes of sweet corn slow down, leading to reduced seedling vigor, delayed emergence, and poor plant establishment [142]. Extended exposure to low temperatures can also cause direct cellular damage, disrupt membrane integrity, and impair enzyme activities. As a result, the plants are unable to effectively take up nutrients, leading to stunted growth and reduced photosynthetic capacity.

In later stages of growth, particularly during the reproductive phase, cold stress can result in poor pollination and kernel development. Low temperatures can cause pollen sterility, resulting in incomplete fertilization and poor kernel set, which directly impacts yield. Additionally, cold stress can affect the synthesis of sugars in sweet corn, reducing the sweetness and flavor quality of the kernels, which is a key trait for fresh consumption [143].

3.4.25. Mechanisms of Cold Tolerance in Sweet Corn

Cold tolerance in sweet corn is a complex trait involving a range of physiological and biochemical adaptations. These adaptations allow plants to withstand low temperatures and continue growing under unfavorable conditions. Key mechanisms of cold tolerance include the following.

Membrane Stability and Osmotic Regulation

One of the primary responses of plants to cold stress is the stabilization of cellular membranes, which are highly susceptible to damage by low temperatures. Cold-tolerant varieties of sweet corn have been shown to maintain membrane integrity better under low temperatures, preventing the leakage of cell contents and reducing oxidative damage [144]. In addition, cold-tolerant plants can accumulate compatible solutes such as proline, sugars, and betaine, which help maintain osmotic balance and protect cell structures from freezing damage.

Cryoprotective Proteins and Enzymatic Activity

Cold-tolerant sweet corn varieties can produce cryoprotective proteins, which prevent the formation of ice crystals inside plant cells, thus protecting cellular components from freezing. Additionally, the activity of enzymes involved in cellular metabolism is better maintained under cold conditions in tolerant varieties. These enzymes, including those involved in carbohydrate metabolism, continue to function at low temperatures, ensuring that critical metabolic processes are not disrupted during cold stress [145].

Root System Development and Cold Acclimation

Root development is critical for cold tolerance, as it facilitates water and nutrient uptake during cold periods. Cold-tolerant sweet corn varieties often exhibit enhanced root growth, which helps the plant access resources even when surface soil temperatures are low. Cold acclimation is another critical mechanism, where exposure to moderate cold temperatures leads to the production of proteins and other molecules that enhance the plant's ability to tolerate more extreme cold stress [146].

Breeding for Cold Tolerance

Breeding cold-tolerant sweet corn varieties requires the identification of genetic traits associated with cold resistance and the selection of genotypes that exhibit superior performance under low-temperature conditions. Cold tolerance is a polygenic trait, meaning it is controlled by multiple genes, which makes breeding for this trait more challenging. Traditional breeding methods have relied on the selection of cold-tolerant parents based on their performance in cold environments, but this process can be slow and imprecise.

With advancements in genomics, marker-assisted selection (MAS) and genomic selection (GS) are increasingly used to accelerate the breeding of cold-tolerant varieties. MAS involves the use of molecular markers linked to cold tolerance genes, which allows breeders to select individuals with the desired genetic makeup more efficiently. Genomic selection, which uses whole-genome data to predict breeding values, holds great potential for improving selection accuracy and identifying new genetic regions associated with cold tolerance [147].

Agronomic Practices for Mitigating Cold Stress

While breeding cold-tolerant varieties is crucial, agronomic practices can also play an important role in reducing the impact of cold stress. One of the most effective practices is adjusting planting dates to avoid the risk of late frost events. Early planting in areas with a risk of frost can expose sweet corn to cold stress during the early growth stages, leading to poor establishment. By carefully timing planting based on local climate conditions, growers can minimize the chances of exposing young seedlings to harmful cold temperatures [148].

Soil management practices such as using raised beds or mulching can help protect young plants from cold temperatures by improving soil temperature and promoting early seedling development. Raised beds, for instance, warm up faster than flat soil surfaces, allowing the seeds to germinate and grow more quickly. Mulching with organic materials such as straw or compost can also help insulate the soil, reducing the risk of cold stress during early growth stages.

In areas where early frost is a concern, frost protection techniques such as using row covers or windbreaks can provide temporary relief. Row covers act as a barrier that traps heat and creates a microenvironment around the plants, preventing direct exposure to cold air. Windbreaks can reduce the wind chill effect, which can exacerbate cold stress and cause additional damage to the plants [149].

Cold stress remains a significant challenge for sweet corn production, particularly in regions with variable spring and autumn temperatures. Through the combination of breeding for cold tolerance, the development of cold-resistant hybrids, and the adoption of agronomic practices to mitigate cold stress, it is possible to reduce the adverse effects of low temperatures on sweet corn crops. Continued research into the genetic and physiological mechanisms of cold tolerance, as well as advancements in precision agriculture, will be key to ensuring that sweet corn can thrive in increasingly unpredictable climates. By improving cold tolerance, sweet corn production can become more resilient to temperature fluctuations and ensure stable yields and quality for growers and consumers alike [150].

Disease Resistance Breeding

Disease resistance breeding is a crucial aspect of sweet corn production aimed at reducing crop losses and ensuring stable yields. Sweet corn, like other crops, is susceptible to a range of diseases caused by pathogens such as fungi, bacteria, viruses, and nematodes. These diseases can significantly impact both the quantity and quality of the harvest, leading to economic losses for farmers. Therefore, developing sweet corn varieties with improved resistance to these diseases is an essential goal for breeders. This section discusses the strategies and advancements in disease resistance breeding for sweet corn, focusing on both traditional and modern breeding approaches.

Challenges in Disease Resistance for Sweet Corn

Sweet corn faces numerous disease challenges, including leaf blight, rust, corn smut, maize dwarf mosaic virus (MDMV), and Fusarium ear rot. The complexity of these diseases, coupled with the rapid adaptation of pathogens to evolving environmental conditions, makes disease resistance breeding a continuous challenge. Additionally, the polygenic nature of disease resistance, where multiple genes control resistance to a single disease, adds another layer of difficulty to breeding efforts. Furthermore, the interaction between sweet corn plants and pathogens is influenced by environmental conditions, making disease management even more challenging in varying climates [151].

Traditional Breeding for Disease Resistance

Traditional disease resistance breeding methods have relied on selecting plants with natural resistance to specific diseases and then crossing these resistant plants with high-yielding varieties. This process involves screening large populations of sweet corn for disease resistance under controlled conditions, followed by the selection of offspring with the desired resistance traits. Over the years, breeders have successfully developed sweet corn hybrids with improved resistance to several diseases. For example, corn hybrids with resistance to rust and blight have been developed through traditional breeding techniques.

However, traditional breeding often requires extensive field testing and multiple generations to achieve stable disease resistance. Moreover, because sweet corn hybrids are often developed from inbred lines, maintaining genetic diversity while selecting for disease resistance is a delicate balancing act. A common issue in traditional breeding is the lack of durable resistance, as pathogens can evolve quickly, rendering previously resistant cultivars ineffective [152].

Molecular Approaches to Disease Resistance

With the advancement of molecular genetics, breeding strategies for disease resistance have become more efficient and precise. Molecular markers associated with disease resistance genes can be used in marker-assisted selection (MAS) to speed up the breeding process. MAS allows breeders to identify resistant plants at the seedling stage, reducing the time and resources required for field trials. Additionally, genomic tools such as quanti-

tative trait loci (QTL) mapping and genome-wide association studies (GWASs) have been utilized to identify specific regions of the genome associated with resistance to diseases like Fusarium ear rot and rust [153].

Genetic Engineering for Disease Resistance

Genetic engineering is another modern approach being explored to enhance disease resistance in sweet corn. Genetic modifications can introduce resistance genes from other plant species or from wild relatives of maize that are not present in conventional varieties. For example, genetically modified (GM) sweet corn has been developed with resistance to the European corn borer, a major pest that can predispose sweet corn to fungal infections. In addition, GM sweet corn varieties have been engineered for resistance to viral diseases such as maize streak virus (MSV) and MDMV through the introduction of viral resistance genes.

However, the use of genetic engineering in sweet corn has sparked debates regarding consumer acceptance and regulatory approval. Despite these challenges, genetic engineering remains a powerful tool for improving disease resistance in sweet corn, especially for diseases that are difficult to control through conventional methods [154].

Integrated Disease Management

In addition to breeding for disease resistance, integrated disease management (IDM) practices play a key role in managing disease pressures in sweet corn. IDM involves combining genetic resistance with cultural practices, such as crop rotation, proper irrigation, and the use of disease-free seeds. Farmers can also use biological control agents or chemical treatments when necessary to supplement genetic resistance and reduce the incidence of disease outbreaks.

The integration of disease-resistant varieties with these management practices can help reduce the reliance on chemical inputs, which is especially important for sustainable agriculture. By combining breeding efforts with appropriate disease control strategies, sweet corn farmers can reduce the economic impact of diseases while improving long-term productivity [155].

Future Directions in Disease Resistance Breeding

The future of disease resistance breeding in sweet corn lies in the continued integration of cutting-edge technologies. The development of high-throughput sequencing technologies has made it easier to identify and characterize genes involved in disease resistance. In combination with genome editing and bioinformatics tools, breeders will be able to accelerate the identification of disease-resistant traits and introduce them into elite sweet corn varieties more efficiently.

Additionally, research into the microbiome of sweet corn plants and their role in disease resistance is an emerging field. Understanding how beneficial microorganisms in the soil and on the plant surface contribute to disease suppression could open new avenues for breeding and management practices. As these technologies evolve, disease resistance breeding will continue to play a critical role in ensuring the resilience and sustainability of sweet corn production globally.

3.5. Agronomic Management for Yield and Quality

3.5.1. Plant Density Optimization for Sweet Corn

Plant density optimization is a key agronomic practice influencing the yield, ear quality, and profitability of sweet corn (*Zea mays* L. *saccharata*). The ideal plant population varies with hybrid genetics, environmental conditions, and production objectives (fresh market vs. processing) [156]. From 2010 to 2025, research has advanced significantly in

determining optimal plant densities for maximizing productivity and maintaining ear quality under different agro-climatic conditions [157].

Higher plant densities generally increase total biomass and yield potential, but excessive crowding can lead to smaller ears, incomplete kernel filling, and increased competition for nutrients, water, and light [158]. Conversely, low plant densities may result in larger ears but reduce total yield per unit area. Striking a balance between individual plant performance and overall field productivity has been a key focus of modern research [159].

Studies conducted across various environments have shown that sweet corn hybrids with greater leaf erectness, strong root systems, and efficient nutrient use can tolerate higher plant populations without compromising ear quality [160]. Optimal plant density ranges have been reported between 60,000 and 80,000 plants per hectare for fresh market sweet corn, and 75,000 and 95,000 plants per hectare for processing purposes, depending on hybrid and location [161].

Moreover, the interaction between plant density and nitrogen fertilization has been highlighted in several studies. Higher plant densities require precise nitrogen management to prevent nutrient deficiencies and ensure uniform ear development [162]. Split nitrogen applications and the use of slow-release fertilizers have been shown to enhance yield response at higher densities [163].

Recent advances in precision agriculture technologies have enabled variable rate planting and fertilization, allowing farmers to adjust plant populations based on soil fertility zones, expected rainfall, and hybrid characteristics [164]. These technologies have helped optimize planting patterns and reduce yield losses associated with over- or under-population.

Furthermore, plant density optimization also influences disease incidence and pest pressure. Densely planted crops with poor air circulation can be more susceptible to foliar diseases, while appropriate spacing improves airflow and reduces pathogen proliferation [165]. Researchers have also explored the relationship between plant density and weed suppression, showing that higher populations can reduce weed competition through early canopy closure [166]. In conclusion, fine-tuning plant density in sweet corn is critical to optimizing canopy structure, light interception, and nutrient uptake, which collectively influence yield stability and grain quality. Current research advocates for adaptive density management tailored to hybrid characteristics and environmental variability to achieve optimal production outcomes [167].

3.5.2. Sowing Dates and Seasonal Variability

Sowing date is one of the most influential agronomic factors affecting the growth, yield, and quality of sweet corn (*Zea mays* L. *saccharata*), particularly due to its sensitivity to temperature, moisture availability, and photoperiod [168]. The interaction between sowing dates and seasonal variability plays a crucial role in determining the success of sweet corn production, with early, optimal, or delayed sowings producing markedly different outcomes in terms of plant vigor, flowering synchronization, and kernel development [169].

Research between 2010 and 2025 has shown that early sowing can maximize the utilization of available growing degree days, resulting in higher yields and improved kernel quality [170]. However, excessively early sowing in cooler climates risks poor seed germination and seedling establishment due to low soil temperatures [171]. In contrast, late sowing often leads to reduced yields, smaller ears, and increased pest and disease pressure, as plants are exposed to unfavorable conditions during critical growth stages [172].

Optimal sowing windows have been identified for different agro-climatic zones. In temperate regions, the best sowing period for sweet corn generally falls between mid-April and mid-May, while in tropical and subtropical areas, flexibility exists with multiple

planting windows depending on rainfall patterns and irrigation availability [173]. Seasonal variability, including fluctuations in rainfall and temperature extremes, has increased in recent years, making the choice of sowing date more critical than ever [174].

Several studies have used crop simulation models such as DSSAT and APSIM to predict the impact of different sowing dates on sweet corn performance under changing climate scenarios. These models help optimize planting schedules by simulating temperature, rainfall, and soil moisture trends [175]. Furthermore, combining simulation data with long-term climate records has allowed researchers to provide region-specific recommendations to minimize weather-related yield losses [176].

Sowing date also influences phenological stages, with early planting resulting in longer vegetative periods and better ear fill, while late planting shortens the crop duration, negatively impacting yield and quality traits like sugar content and tenderness [177]. In addition, seasonal shifts can alter pest dynamics; delayed sowing has been associated with higher incidences of corn borer and fall armyworm attacks in certain regions [178].

Breeders have responded by developing hybrids with greater plasticity and adaptability to varying planting dates, but careful agronomic planning remains essential. Farmers are increasingly advised to consider not only historical sowing dates, but also real-time weather forecasts and soil temperature monitoring to adjust planting times accordingly [179].

In conclusion, sowing date optimization, combined with an awareness of seasonal variability, is vital for maintaining consistent sweet corn production and quality. Future recommendations will rely more on predictive weather tools, improved crop models, and climate-resilient hybrids tailored for flexible planting schedules [180].

3.5.3. Nitrogen Fertilization Strategies

Nitrogen (N) fertilization is a critical component in sweet corn (*Zea mays* L. *saccharata*) production, directly influencing yield, kernel quality, and plant health. From 2010 to 2025, significant progress has been made in understanding the interaction between nitrogen rates, timing, and forms, contributing to more sustainable and efficient fertilization strategies [181].

The nitrogen requirement of sweet corn is relatively high compared to other vegetable crops, but over-application can lead to nitrate leaching, environmental pollution, and increased production costs [182]. Optimal N rates for sweet corn generally range from 120 to 200 kg ha⁻¹, depending on soil fertility, climatic conditions, hybrid genetics, and planting density [183].

Research has emphasized the importance of split nitrogen applications, where nitrogen is applied in multiple stages (at planting and during early vegetative stages) rather than in a single application. Split applications improve nitrogen use efficiency (NUE) and reduce losses due to volatilization and leaching [184]. Additionally, side-dressing nitrogen at the V6 to V8 growth stages has been shown to align N availability with the plant's peak demand, supporting ear development and kernel filling [185].

Controlled-release fertilizers and nitrification inhibitors have gained popularity in sweet corn production, offering a more consistent nitrogen supply over the growing season and minimizing environmental risks [186]. Moreover, foliar applications of nitrogen during tasseling have been investigated, showing potential benefits in enhancing ear length and kernel depth in nitrogen-deficient soils [187].

Precision agriculture technologies have also played a major role in refining nitrogen management. Tools such as NDVI sensors, remote sensing, and drone-based monitoring help in determining real-time crop nitrogen status and adjusting fertilization rates accordingly [188]. The integration of soil testing, crop modeling, and sensor-based technologies

has facilitated variable rate N application, reduced wastage, and ensured uniform crop development [189].

Furthermore, studies have shown that nitrogen requirements are influenced by sowing date and plant population. Early sowing with higher plant density demands more precise nitrogen management to avoid deficiencies during rapid vegetative growth [190]. Research also indicates that the interaction between nitrogen fertilization and irrigation management is crucial, particularly under drought or water stress conditions, where the proper timing of N application can significantly improve yield outcomes [191].

In conclusion, nitrogen fertilization strategies for sweet corn have evolved toward more site-specific, environmentally friendly, and cost-effective approaches. Future advancements will likely focus on integrating remote sensing, weather forecasting, and machine learning models for nitrogen decision support systems tailored to farm-level conditions [192].

3.5.4. Water Use Efficiency and Irrigation Techniques

Water use efficiency (WUE) and irrigation management are crucial for maximizing sweet corn (*Zea mays* L. *saccharata*) productivity while conserving water resources, especially under climate change scenarios and increasing water scarcity [193]. Sweet corn is highly sensitive to moisture stress during key growth stages, such as tasseling, silking, and grain filling. Inadequate irrigation during these stages can result in reduced ear size, poor kernel fill, and lower overall yield [194].

Between 2010 and 2025, significant advancements have been made in optimizing irrigation strategies and improving WUE for sweet corn. Drip irrigation has been widely adopted due to its ability to deliver water directly to the root zone, reducing evaporation and runoff losses [195]. Studies have demonstrated that drip irrigation combined with fertigation can increase yield by 15–25% and improve WUE by more than 30% compared to traditional flood irrigation methods [196].

Sprinkler irrigation remains another popular technique, especially for large-scale sweet corn production. However, uniformity in application and timing is a key factor in avoiding water stress or oversaturation [197]. Research suggests that deficit irrigation, i.e., supplying water below full crop evapotranspiration needs at non-critical stages, can significantly enhance WUE without compromising yield in areas with limited water availability [198].

The scheduling of irrigation based on crop evapotranspiration (ET_c) calculations, soil moisture sensors, and weather data has gained momentum. Modern sensor-based systems coupled with automated irrigation controllers allow farmers to optimize water use, ensuring that water is applied only when required [199]. Remote sensing technologies, including satellite imagery and UAV (drone)-based monitoring, are increasingly used to detect crop water stress and guide irrigation decisions in real time [200].

In addition to irrigation methods, agronomic practices such as mulching, conservation tillage, and cover cropping have been found to improve soil moisture retention and reduce the need for frequent irrigation [201]. Moreover, breeding efforts have focused on developing sweet corn hybrids with enhanced drought tolerance and better root systems, contributing indirectly to improved WUE [202].

Studies also highlight the importance of irrigation frequency and volume. Frequent shallow irrigations are often less efficient than deep infrequent irrigations that encourage deeper root growth and more efficient water uptake [203]. Additionally, irrigation water quality plays a role in sweet corn production; saline water, if not managed properly, can affect plant growth and soil health [204].

In conclusion, improving water use efficiency in sweet corn production requires an integrated approach, combining advanced irrigation technologies, precise schedul-

ing, water-conserving agronomic practices, and climate-resilient hybrid selection. Future advancements are expected to include AI-driven irrigation systems capable of learning crop-specific water needs based on environmental inputs and growth stages [205].

3.5.5. Weed Management in Sweet Corn Production

Weed competition is one of the major challenges in sweet corn (*Zea mays* L. *saccharata*) production, as weeds can significantly reduce crop yields by competing for light, water, and nutrients. Effective weed management strategies are essential for maintaining high productivity and quality in sweet corn fields. Research from 2010 to 2025 has focused on improving weed control techniques while minimizing environmental impacts and costs associated with herbicide use [206].

Herbicide application is the most common method for weed control in sweet corn, but reliance on chemical control can lead to herbicide resistance, environmental contamination, and negative effects on non-target organisms [207]. As a result, integrated weed management (IWM) strategies that combine cultural, mechanical, and chemical methods have become increasingly popular [208]. Cultural practices, such as crop rotation, cover cropping, and adjusting planting densities, can suppress weed growth by enhancing crop competitiveness and disrupting weed life cycles [209].

Mechanical weed control methods, such as cultivation, mowing, and flaming, have been explored as alternatives to herbicide use. These practices, though labor-intensive, can be effective in early-season weed control, especially in organic sweet corn production systems [210]. Additionally, precision weeding technologies using GPS and machine vision have gained traction, allowing for targeted herbicide applications or mechanical weeding, reducing overall herbicide use, and improving efficiency [211].

In terms of chemical control, pre-emergence and post-emergence herbicides are commonly used to control a wide spectrum of weed species. The choice of herbicide is influenced by weed species, growth stages, and environmental conditions. New formulations and herbicide combinations have been developed to improve efficacy while minimizing crop injury and environmental harm [212]. Furthermore, the timing of herbicide application is critical for maximizing weed control effectiveness and reducing resistance development. Studies have shown that early-season herbicide applications, followed by sequential applications if needed, provide better weed suppression and enhance sweet corn growth [213].

Herbicide resistance management strategies, such as rotating herbicide modes of action, using lower application rates, and combining chemical treatments with non-chemical methods, have been key in preserving herbicide efficacy over time [214]. Research in this area has highlighted the importance of monitoring weed populations for early signs of resistance and adjusting weed management practices accordingly [215].

Finally, breeding has become an important strategy in weed management, with current research focusing on developing sweet corn hybrids that exhibit greater competitiveness against weeds. Characteristics such as faster canopy development, thicker foliage, and allelopathic properties (the release of natural compounds that suppress weed growth) are being investigated to lower weed competition and reduce reliance on herbicides [216]. In conclusion, effective weed management in sweet corn production requires a multifaceted approach, integrating chemical, mechanical, and cultural methods. As herbicide resistance continues to be a concern, the adoption of integrated weed management strategies, precision technologies, and weed-resistant hybrids will be essential for ensuring sustainable and cost-effective production systems in the future [217].

3.5.6. Insect Pest Management and Integrated Pest Management (IPM)

IPM (integrated pest management) is a pest control strategy that uses a combination of methods such as biological control, cultural practices, and chemical methods to manage pests in an environmentally sustainable way.

Insect pests pose a significant threat to sweet corn (*Zea mays* L. *saccharata*) production, affecting yield, quality, and marketability. Effective insect pest management (IPM) strategies are essential for maintaining healthy crops while minimizing environmental and economic impacts. Over the past decade (2010–2025), advances in understanding pest biology, ecology, and control methods have led to the development of integrated pest management (IPM) strategies that emphasize sustainable and cost-effective approaches [218].

The primary insect pests of sweet corn include the European corn borer (*Ostrinia nubilalis*), corn earworm (*Helicoverpa zea*), and rootworms (*Diabrotica* spp.). These pests cause damage to various parts of the plant, including the stalks, ears, and roots, often leading to reduced yields, contamination, and compromised crop quality [219]. Traditional chemical control methods have been widely used but are increasingly being challenged due to concerns about pesticide resistance, environmental contamination, and non-target effects [220].

IPM for sweet corn focuses on combining multiple pest control strategies, including cultural, biological, mechanical, and chemical methods, to reduce reliance on chemical pesticides. Cultural practices such as crop rotation, resistant varieties, and altering planting dates have been effective in reducing pest populations and minimizing pest damage [221]. For example, rotating sweet corn with non-host crops helps break pest life cycles, reducing pest pressure in subsequent seasons [222]. The use of pest-resistant hybrids has also been an important development, particularly in combating pests like the corn borer, with genetically modified (GM) varieties offering resistance to certain pests [223].

Biological control is another key component of IPM. Natural predators and parasitoids, such as Trichogramma wasps (which parasitize corn borers) and predatory beetles, can help reduce pest populations [224]. Insect pathogens like *Bacillus thuringiensis* (Bt) are used as biopesticides to target specific pests, offering a more environmentally friendly alternative to synthetic chemicals [225]. The deployment of beneficial insects and biocontrol agents can significantly reduce the need for chemical interventions and improve pest control efficiency.

Mechanical methods, such as trapping and hand-picking, are useful for monitoring and managing pest populations. Pheromone traps and visual traps are commonly used to monitor the presence and abundance of specific pests, allowing for timely interventions before pest numbers reach economically damaging levels [226]. Additionally, physical barriers like row covers can protect plants from insect pests during critical growth stages [227].

Chemical control remains an important tool in IPM, but is used as a last resort when other methods are insufficient. The focus is on selective insecticides with minimal environmental impact, targeting specific pests at their most vulnerable life stages. Recent research has focused on reducing pesticide use through precision application techniques, which ensure that chemicals are applied only when and where needed, thus minimizing the risk of resistance development and environmental harm [228].

IPM also emphasizes monitoring and decision making based on pest thresholds. The use of scouting, field observation, and pest prediction models helps farmers determine when pest populations are likely to exceed economic thresholds, warranting intervention. Advances in pest modeling and decision support systems, aided by technology such as remote sensing and machine learning, have improved the ability to predict pest outbreaks and optimize control measures [229].

In conclusion, insect pest management in sweet corn production has evolved significantly with the development of integrated pest management strategies. By combining

cultural, biological, mechanical, and chemical control methods, IPM offers a sustainable, effective, and environmentally responsible approach to managing pest populations. Continued research and technological advancements will be crucial in enhancing the efficiency of IPM programs and in combating emerging pest challenges in sweet corn production [230]. The findings are presented in Figure 2.

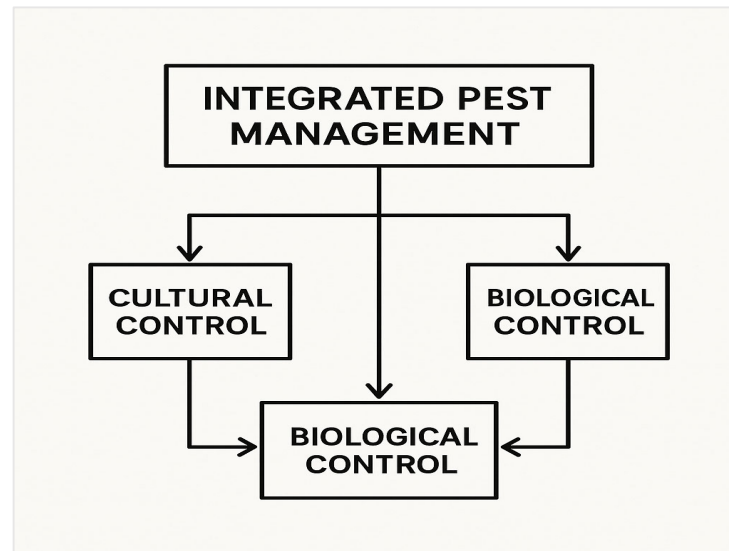


Figure 2. Framework of integrated pest management (IPM) strategies in sweet corn.

3.5.7. Cover Crops and Crop Rotation Benefits

Cover crops and crop rotation play an essential role in sustainable sweet corn (*Zea mays* L. *saccharata*) production by enhancing soil health, improving nutrient cycling, controlling pests, and minimizing the environmental impact of farming practices. In recent years (2010–2025), both practices have gained traction in sweet corn production systems due to their benefits in improving soil structure, water retention, and reducing the dependency on synthetic fertilizers and pesticides [231].

Cover crops, typically grown during fallow periods or between main crops, provide numerous agronomic benefits. They protect the soil from erosion, suppress weeds, improve soil organic matter, and promote beneficial soil microbial activity. Leguminous cover crops, such as clover, vetch, and peas, fix nitrogen in the soil, reducing the need for synthetic nitrogen fertilizers and enhancing the sustainability of sweet corn production [232]. Non-leguminous cover crops, such as rye or oats, provide excellent ground cover, preventing soil erosion, particularly on slopes and fields prone to heavy rainfall [233].

Research has shown that the use of cover crops can reduce soil compaction and increase water infiltration, allowing for better water management in sweet corn fields. This is particularly important in regions where soil structure can degrade due to frequent tillage or the overuse of fertilizers [234]. Furthermore, cover crops can act as a biofumigant, helping to control soil-borne diseases and pests through the release of allelopathic compounds [235].

Crop rotation, the practice of alternating different crops in the same field across seasons, offers multiple benefits to sweet corn production. Rotating sweet corn with non-maize crops, such as soybeans, wheat, or legumes, breaks pest and disease cycles, especially those associated with rootworms, corn borers, and soil pathogens. This practice also reduces the buildup of herbicide-resistant weeds that may become prevalent if the same crop is grown year after year [236]. Additionally, rotation with legumes can help replenish soil nitrogen levels, reducing the need for chemical fertilization [237].

The benefits of crop rotation extend beyond pest and nutrient management. Diversifying crop types in the rotation system can lead to improved soil microbial diversity,

enhancing soil health, and reducing the likelihood of nutrient imbalances. Furthermore, rotating sweet corn with other crops like small grains (e.g., wheat or barley) can provide financial benefits by diversifying income sources and mitigating economic risks associated with market price fluctuations of a single crop [238].

Recent studies have emphasized the importance of integrating cover crops and crop rotation for maximizing sustainability in sweet corn production. For example, planting winter rye as a cover crop followed by rotating sweet corn with soybeans has been shown to improve both soil organic matter and nitrogen levels, thereby boosting sweet corn yields in subsequent seasons. Additionally, integrated practices like these reduce soil erosion and nutrient leaching, contributing to more environmentally responsible farming [239].

In conclusion, the combined use of cover crops and crop rotation offers numerous advantages for sweet corn production, from improving soil health and nutrient management to enhancing pest and disease control. These sustainable practices not only increase the resilience of production systems but also reduce the environmental footprint of farming by decreasing reliance on chemical inputs. Ongoing research is crucial in identifying the most effective cover crops and crop rotation strategies tailored to specific geographic regions and production systems to maximize their potential benefits for sweet corn growers [240].

3.5.8. Mechanical Harvesting and Post-Harvest Handling

Mechanical harvesting and post-harvest handling are critical components of modern sweet corn (*Zea mays* L. *saccharata*) production, especially as demand for efficiency and cost-effectiveness in large-scale operations increases. Over the past decade (2010–2025), advancements in mechanical harvesting technologies and improved post-harvest management practices have enhanced sweet corn production, processing, and quality control, thus ensuring a more sustainable and economically viable system for growers [241].

Mechanical harvesting has become a common practice in commercial sweet corn production, particularly for processing markets. While hand-harvesting is still prevalent in some areas, mechanical harvesters offer significant advantages, including reduced labor costs and faster harvesting times, which are essential for handling large volumes of sweet corn. Modern mechanical harvesters are designed to efficiently harvest both fresh market and processed sweet corn. These machines are equipped with features such as adjustable picking heads, rubber-coated rollers, and automated husking mechanisms that minimize damage to the kernels, which is crucial for maintaining product quality and yield [242].

Recent improvements in mechanical harvesting include the development of precision machinery that reduces ear damage and harvest losses. For example, new systems with variable speed and adjustable settings for different hybrid types have been introduced to optimize ear collection and reduce kernel bruising, which can degrade the quality of both fresh and processed sweet corn. Additionally, the use of GPS technology and automated control systems in harvesters allows for more accurate real-time adjustments based on field conditions, ensuring more efficient harvesting [243].

Post-harvest handling is equally critical for maintaining the quality and marketability of sweet corn after it is harvested. Sweet corn is highly perishable, and improper handling can lead to rapid deterioration in flavor, texture, and nutritional value. Once harvested, sweet corn should be quickly cooled to preserve its freshness. Hydrocooling, which involves immersing the corn in cold water, is a widely used technique for rapidly reducing the temperature of the ears, thereby slowing down respiration and minimizing microbial growth [244]. Additionally, forced-air cooling systems are employed in some packinghouses to speed up the cooling process, especially when large quantities of sweet corn are harvested simultaneously.

For long-term storage and transportation, controlled atmosphere storage is often used to maintain the quality of sweet corn. This technique involves controlling oxygen, carbon dioxide, and humidity levels in storage rooms to slow down the degradation process and extend shelf life. Proper handling during post-harvest storage is crucial to minimize the loss of sweetness and flavor, as the sugar content in sweet corn gradually converts to starch after harvest [245]. For fresh market sweet corn, maintaining the cold chain from the field to the consumer is vital, and vacuum cooling or modified atmosphere packaging (MAP) can help extend shelf life during transportation and retail distribution [246].

Quality control during post-harvest handling is critical to meet market standards. In the processing industry, sweet corn is typically washed, peeled, and blanched before freezing or canning. The blanching process, which involves briefly immersing the corn in hot water or steam, serves to deactivate enzymes that could cause flavor loss and the deterioration of texture during storage. Advanced sorting and grading systems are used to ensure uniformity in size, shape, and appearance, with automated machines often sorting by color and size before packaging [247].

Moreover, organic and sustainable practices are increasingly being adopted in mechanical harvesting and post-harvest handling. Organic sweet corn production, for instance, often requires more delicate handling to avoid contamination with synthetic pesticides, and, as a result, there is growing interest in improving the sustainability of mechanical harvesters and post-harvest systems. This includes using biodegradable packaging materials, minimizing water usage during cooling, and reducing energy consumption in storage systems [248].

In conclusion, mechanical harvesting and efficient post-harvest handling are key to ensuring the quality and profitability of sweet corn production. The continued development of more advanced and precise machinery, along with improved post-harvest technologies and practices, will be essential for meeting the growing global demand for sweet corn while maintaining quality, reducing waste, and improving sustainability. As industry continues to innovate, both harvesting techniques and post-harvest systems will evolve to meet the challenges posed by market demands and environmental considerations [249].

3.6. Sustainable Farming Practices for Sweet Corn

Sustainable farming practices are increasingly essential for maintaining productivity while minimizing environmental impacts, conserving resources, and ensuring long-term soil health. For sweet corn (*Zea mays* L. *saccharata*) production, sustainable agriculture strategies focus on integrating ecological, economic, and social principles to reduce input costs, improve environmental quality, and enhance resilience to climate variability. Over the past decade (2010–2025), a growing body of research has highlighted the potential benefits of adopting sustainable farming practices in sweet corn production [250].

One of the cornerstone practices in sustainable sweet corn farming is conservation tillage, which reduces soil erosion, improves soil structure, and enhances water retention. By minimizing the disturbance of soil through reduced tillage, farmers can help maintain the natural balance of soil organisms, increase organic matter content, and reduce the need for synthetic fertilizers [251]. Reduced tillage also promotes carbon sequestration in the soil, contributing to climate change mitigation by capturing atmospheric CO₂ and storing it in the soil [252].

Another critical aspect of sustainable sweet corn production is integrated pest management (IPM), which employs a combination of cultural, biological, mechanical, and chemical methods to control pest populations with minimal environmental impact. This practice reduces dependence on synthetic pesticides, decreases the risk of pesticide resistance, and fosters biodiversity within the agroecosystem [253]. In sweet corn production, techniques

such as crop rotation, the use of resistant varieties, biological control agents (e.g., parasitoids and predators), and precision pest monitoring has been effective in managing pests while minimizing harm to non-target organisms [254].

Nutrient management is a key practice in sustainable farming, aiming to optimize the use of fertilizers to meet crop needs while reducing nutrient losses to the environment. Precision nutrient management, which involves soil testing and targeted fertilizer application based on crop requirements, can reduce nutrient runoff and improve nutrient-use efficiency. The use of organic fertilizers and compost also helps enhance soil fertility while reducing dependence on chemical inputs [255]. Additionally, incorporating cover crops in the rotation system can reduce the need for synthetic fertilizers by fixing nitrogen in the soil and improving organic matter content [256]. Water use efficiency is another critical component of sustainable sweet corn farming. Climate change, coupled with increasing water scarcity in many agricultural regions, necessitates the implementation of efficient irrigation practices. Techniques such as drip irrigation, which delivers water directly to the plant root zone, and rainwater harvesting systems, which capture and store rainwater for irrigation during dry periods, are increasingly being used to optimize water use in sweet corn production [257]. Additionally, soil moisture sensors and weather-based irrigation scheduling systems help reduce water wastage by providing real-time data on soil moisture levels and adjusting irrigation schedules accordingly [258].

Sustainable sweet corn farming also involves reducing the environmental footprint of production through energy-efficient practices. The use of renewable energy sources, such as solar and wind power, for irrigation systems, greenhouse operations, and farm equipment can significantly reduce the carbon footprint of sweet corn farming. Furthermore, adopting agroforestry practices, such as intercropping sweet corn with trees or shrubs, can help improve biodiversity, provide a habitat for beneficial organisms, and enhance carbon sequestration [259].

Agroecological principles are increasingly being integrated into sweet corn production systems to promote sustainability. These principles include promoting biodiversity, enhancing ecosystem services, and reducing reliance on external inputs. Agroecological practices, such as mixed cropping systems, agroforestry, and maintaining natural habitats alongside crop fields, not only improve ecological resilience but also increase farm profitability by diversifying income sources [260].

In conclusion, sustainable farming practices in sweet corn production aim to balance environmental health, economic viability, and social equity. By incorporating practices such as conservation tillage, integrated pest management, precision nutrient management, efficient water use, and agroecological approaches, sweet corn growers can ensure the long-term sustainability of their farming operations while minimizing environmental impacts. As research continues to explore and refine these practices, the future of sweet corn farming looks promising, with increased productivity, reduced environmental footprints, and enhanced resilience to climate change [261].

3.6.1. Organic Sweet Corn Production Challenges

Organic farming has grown significantly in recent years, driven by consumer demand for healthier and more sustainable food options. Organic sweet corn production, in particular, has seen increasing interest as it provides a marketable crop that meets organic certification standards. However, growing sweet corn organically presents unique challenges that differ from conventional production methods. These challenges arise from the need to balance high-quality yields with sustainable practices while adhering to organic standards that restrict the use of synthetic fertilizers, pesticides, and herbicides. This section

explores the challenges faced by organic sweet corn producers and offers insights into possible solutions.

Weed control is one of the most significant challenges in organic sweet corn production. Unlike conventional methods that rely on synthetic herbicides, organic systems must rely on non-chemical weed management strategies. Common methods include mechanical cultivation, mulching, crop rotation, and the use of organic herbicides. However, these techniques have their limitations and require careful management to be effective.

Mechanical cultivation, while effective at controlling early-season weeds, can damage young sweet corn plants if not performed carefully. Mulching can suppress weeds and maintain soil moisture, but it can also be costly and labor-intensive, especially on large-scale operations. Crop rotation, a core principle of organic farming, can help manage weeds by alternating crops with different growth habits and weed pressures, but it may not always be feasible or efficient for sweet corn monoculture systems. Furthermore, organic herbicides are often less effective than synthetic alternatives, requiring more frequent application and careful timing to manage weeds effectively [262].

In organic systems, pest and disease management is particularly challenging because the use of synthetic pesticides is prohibited. Organic sweet corn producers must rely on biological control, physical barriers, and cultural practices to manage pest populations. Biological control methods, such as introducing natural predators or parasitoids, are effective, but often require careful monitoring and timing to ensure efficacy. For instance, the use of beneficial insects like ladybugs or parasitoid wasps can help control aphid populations, but these insects may not always be present in adequate numbers to suppress pest outbreaks [263].

Additionally, the absence of chemical pesticides makes it difficult to manage common sweet corn pests such as the European corn borer (*Ostrinia nubilalis*) and rootworm larvae (*Diabrotica* spp.), which can cause significant damage to both the plants and the yield. Physical barriers, such as row covers, may help protect against pests in early growth stages, but they are not a complete solution. Cultural practices like proper field sanitation and crop rotation can also reduce pest pressure by interrupting pest life cycles, but they require additional management efforts [264].

Disease management is another major challenge in organic sweet corn production. Fungal diseases, such as northern corn leaf blight (*Exserohilum turcicum*) and gray leaf spot (*Cercospora zea-maydis*), are common problems in organic systems. Without the use of synthetic fungicides, organic farmers must rely on resistant varieties, crop rotation, and cultural practices like proper spacing and field sanitation to reduce disease pressure. However, these methods are not always sufficient, and the risk of yield losses from disease outbreaks remains high in organic systems [265].

Soil fertility is a critical issue in organic sweet corn production. Organic systems must rely on natural sources of nutrients, such as compost, manure, and cover crops, to maintain soil health and fertility. However, the nutrient requirements of sweet corn, which is a high-demand crop, may not always be met by these organic sources alone. Organic fertilizers often have lower nutrient concentrations than synthetic alternatives, requiring larger volumes to meet the crop's needs. Additionally, organic fertilizers release nutrients more slowly, which can sometimes lead to nutrient deficiencies during critical growth stages, such as early-season development or during tasseling and pollination [266].

Cover crops and green manures are often used in organic systems to improve soil fertility and structure. However, the timing of cover crop incorporation can affect the availability of nutrients for sweet corn. If cover crops are not adequately terminated before planting, they can compete with sweet corn for nutrients and water, reducing yields. On

the other hand, if cover crops are not incorporated early enough, they may not contribute enough nutrients to support sweet corn growth [267].

Organic farming practices, while promoting sustainability, can sometimes result in lower yields compared to conventional farming due to the absence of synthetic inputs. Organic sweet corn is particularly sensitive to climatic factors such as temperature, rainfall, and soil moisture. Sweet corn is a warm-season crop that thrives under specific environmental conditions, and deviations from optimal growing conditions can significantly impact yield.

In regions with inconsistent weather patterns or extreme temperature fluctuations, organic sweet corn growers may face challenges in achieving consistent yields. Additionally, organic practices that rely on mechanical cultivation or manual labor are highly dependent on weather conditions, with rain or drought events potentially disrupting the growing season [268].

While organic sweet corn commands a premium price in the market, it also faces higher production costs due to the labor-intensive nature of organic practices and the need for additional management inputs. Organic certification itself can be a significant financial burden for producers, requiring regular inspections and documentation to maintain organic status. Furthermore, the costs associated with weed control, pest and disease management, and soil fertility management in organic systems can be higher than in conventional farming systems, affecting profitability [269].

Despite these challenges, the demand for organic sweet corn continues to rise, driven by consumer preference for pesticide-free and sustainably grown produce. As such, organic sweet corn production can be economically viable for growers who can effectively manage the challenges and take advantage of the premium market prices.

Organic sweet corn production presents a range of challenges, from weed and pest management to soil fertility and climate sensitivity. However, with proper management practices, such as crop rotation, biological pest control, and careful nutrient management, organic sweet corn can be successfully grown. Continued research into organic farming practices, as well as the development of organic pest-resistant varieties and improved soil fertility techniques, will be essential for the future success and sustainability of organic sweet corn production. With the growing consumer demand for organic produce, addressing these challenges will ensure that organic sweet corn remains a viable and profitable option for farmers [270].

3.6.2. Micronutrient Management

Micronutrient management plays a crucial role in optimizing sweet corn growth, yield, and quality. Micronutrients, although required in small amounts, are essential for various physiological processes, including enzyme activation, chlorophyll synthesis, and the regulation of plant metabolism. Deficiencies or imbalances of micronutrients can lead to reduced crop performance, poor grain quality, and increased susceptibility to environmental stresses and diseases. This section explores the importance of micronutrient management in sweet corn production and the strategies used to ensure optimal nutrient uptake for improved crop performance.

The key micronutrients essential for sweet corn growth include iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), boron (B), molybdenum (Mo), and chlorine (Cl). These elements contribute to various physiological and biochemical functions in plants. For example, zinc is crucial for enzyme function and protein synthesis, while iron is involved in chlorophyll production and photosynthesis. Manganese and copper are integral to the functioning of antioxidative systems that help plants cope with oxidative stress. Boron

plays a role in cell wall formation and pollen tube growth, while molybdenum is important for nitrogen fixation and assimilation.

Micronutrient deficiencies in sweet corn can lead to various symptoms, such as the yellowing of leaves, stunted growth, poor kernel formation, and a weakened ability to resist biotic and abiotic stresses. For instance, zinc deficiency can cause leaf chlorosis and reduced grain yield, while boron deficiency is known to result in poor pollination and kernel development. These deficiencies can significantly affect sweet corn yield and quality, making effective micronutrient management crucial for maintaining productivity and sustainability in sweet corn farming [271].

3.6.3. Factors Affecting Micronutrient Availability

The availability of micronutrients in the soil depends on various factors, including soil pH, organic matter content, soil texture, and the presence of other nutrients. In acidic soils, micronutrients such as iron, manganese, and zinc are more available to plants, while in alkaline soils, the availability of these nutrients may be reduced. On the other hand, high levels of certain macronutrients like phosphorus can interfere with the uptake of micronutrients like zinc and iron. Therefore, maintaining balanced soil nutrient levels is essential for optimizing micronutrient availability.

Soil testing and regular nutrient analysis are critical for identifying deficiencies and imbalances in micronutrient levels. Soil pH adjustment, through the application of lime or sulfur, can help optimize micronutrient availability by either increasing or decreasing the solubility of certain elements. Additionally, the use of organic amendments, such as compost or biochar, can enhance micronutrient availability by improving soil structure and increasing microbial activity, which helps release bound nutrients into plant-available forms [272].

3.6.4. Micronutrient Deficiencies and Symptoms in Sweet Corn

Micronutrient deficiencies in sweet corn can lead to characteristic symptoms that can help farmers identify the specific nutrient that is lacking. Zinc deficiency is often marked by interveinal chlorosis, with the youngest leaves showing the most prominent symptoms. Manganese deficiency typically causes chlorosis with brown spots or lesions on older leaves, while iron deficiency leads to the overall yellowing of leaves, particularly in younger leaves. Boron deficiency is often seen in the form of poor pollination and aborted kernels, while copper deficiency may cause stunted growth and leaf curling.

The early identification of these deficiencies is critical for timely intervention and the application of corrective measures. Regular monitoring and visual inspections of sweet corn fields can help identify potential micronutrient issues before they significantly affect yields. In addition, the use of diagnostic tools like tissue analysis can provide valuable insights into micronutrient levels in plant tissues, further aiding in the management of micronutrient status [273].

3.6.5. Micronutrient Fertilization Practices

Micronutrient deficiencies in sweet corn can be addressed through the application of micronutrient fertilizers. There are various ways to supply micronutrients to sweet corn, including soil application, foliar spraying, and fertigation (the application of fertilizers through irrigation). The choice of method depends on the severity of the deficiency, the specific micronutrient needed, and the form in which it is most effectively absorbed by the plant.

1. **Soil Application:** Micronutrient fertilizers can be applied directly to the soil as granules, powders, or chelated forms. These fertilizers are typically incorporated into the

soil before planting or during the growing season. Soil-applied micronutrients are effective in correcting moderate to severe deficiencies, but require proper soil moisture and temperature for optimal nutrient uptake.

2. **Foliar Spraying:** The foliar application of micronutrients involves spraying a solution of micronutrient fertilizers directly onto the plant leaves. This method is particularly useful for correcting micronutrient deficiencies that affect leaf tissue, as it allows for the rapid absorption of nutrients through the leaf surface. Foliar spraying can be performed during the vegetative or reproductive stages, depending on the nutrient required.
3. **Fertigation:** Fertigation is an efficient method of delivering micronutrients to sweet corn through irrigation systems. This technique is especially beneficial in areas with frequent irrigation, as it ensures the consistent and uniform distribution of micronutrients. Fertigation is commonly used for micronutrient management in areas with high water availability or in large-scale commercial farming systems.

It is essential to apply micronutrient fertilizers at the right time and in the correct proportions to avoid toxicity or nutrient imbalances. The excessive application of certain micronutrients, such as boron or copper, can lead to toxicity and damage to the crop, so careful monitoring and adherence to recommended application rates are necessary [274].

3.6.6. Micronutrient Use Efficiency and Sustainability

Improving micronutrient use efficiency (MUE) is crucial for reducing input costs and minimizing environmental impacts associated with the over-application of fertilizers. Strategies to enhance MUE include selecting micronutrient-efficient sweet corn varieties, improving soil health, and adopting precision nutrient management techniques. By using advanced technologies like remote sensing, farmers can monitor nutrient status in real time and apply micronutrients only when and where they are needed, thus reducing waste and improving overall efficiency.

Moreover, the use of organic amendments and the promotion of sustainable agricultural practices, such as crop rotation and reduced tillage, can improve the availability and uptake of micronutrients in sweet corn crops. Sustainable micronutrient management not only improves crop yields but also contributes to the long-term health of the soil ecosystem and the environment.

Effective micronutrient management is vital for optimizing sweet corn growth, improving yield, and ensuring high-quality produce. Understanding the roles of different micronutrients, monitoring soil and plant nutrient status, and using appropriate fertilization techniques can help overcome micronutrient deficiencies and enhance crop productivity. As the demand for more sustainable farming practices increases, improving micronutrient use efficiency will be key to achieving higher yields with fewer environmental impacts. Continued research and the adoption of precision agriculture technologies hold great promise for advancing micronutrient management in sweet corn production.

Micronutrient fertilization is critical for improving sweet corn productivity, quality, and resilience, especially in soils deficient in key elements such as zinc, boron, and iron. Common application methods include soil incorporation, foliar spraying, and fertigation, each selected based on crop growth stage, soil conditions, and deficiency severity. The soil application of chelated or inorganic micronutrients is effective in addressing widespread deficiencies, while foliar spraying provides a rapid response, particularly during sensitive vegetative and reproductive phases [275]. Fertigation offers precise and uniform micronutrient delivery through irrigation systems, enhancing nutrient uptake efficiency under intensive production systems. Improving micronutrient use efficiency (MUE) is essential for reducing input costs and minimizing environmental risks. This can be achieved by

adopting micronutrient-efficient cultivars, enhancing soil health through organic amendments, and implementing precision agriculture tools such as remote sensing and variable rate application technologies [276]. These integrated approaches support environmentally responsible and economically viable farming systems that meet the growing demand for high-quality and nutrient-rich sweet corn.

3.7. Genetic Improvement of Maize Sensory Traits and Nutritional Quality

3.7.1. Sweet Corn Quality Traits

Sweet corn (*Zea mays* L. *saccharata*) is valued not only for its high yield, but also for its distinct eating quality, which is determined by key traits such as sugar content, kernel texture, and flavor. These quality characteristics are influenced by both genetic and environmental factors and are critical in determining the marketability of sweet corn, whether it is for fresh consumption, processing, or direct consumption by consumers. Over the past decade (2010–2025), research has focused on improving the quality of sweet corn by exploring the genetic basis of these traits and developing varieties that meet consumer preferences while maintaining high productivity [277].

3.7.2. Sugars

One of the defining features of sweet corn is its high sugar content, which contributes significantly to its sweetness. The sugars in sweet corn are primarily sucrose, glucose, and fructose, with sucrose being the dominant sugar that gives the crop its characteristic sweet flavor. The concentration of sugars in sweet corn is highly variable and is influenced by both genetic factors and post-harvest conditions. During growth, sugar accumulation is primarily influenced by environmental factors such as temperature, soil fertility, and water availability, with cooler temperatures often leading to higher sugar concentrations. Additionally, the rate of sugar conversion to starch after harvest significantly impacts flavor and sweetness, with sweeter varieties retaining more sugar in the kernels post-harvest [278].

Breeding efforts have focused on developing sweet corn hybrids with higher levels of sugar accumulation and slower sugar-to-starch conversion post-harvest. The development of sugary (su), sugary enhanced (se), and shrunken 2 (sh2) sweet corn varieties has been a key advancement in improving sugar content and maintaining sweetness during storage and processing. These varieties are designed to retain higher sugar levels for longer periods compared to traditional sweet corn varieties, which can rapidly convert sugars into starch after harvest, leading to a decline in sweetness [279]. Additionally, research into the genetic pathways controlling sugar metabolism in sweet corn has advanced the ability to select for higher sugar content through marker-assisted breeding [280].

3.7.3. Texture

Kernel texture is another essential trait in sweet corn quality. The texture of sweet corn kernels is influenced by factors such as the degree of starch gelatinization, cell wall structure, and moisture content. Textural qualities, such as tenderness and crispness, are highly preferred in fresh sweet corn. The texture of the kernels is determined by the balance between the soft sugary endosperm and the firm starchy pericarp, with the texture being influenced by genetic makeup, environmental conditions, and harvest timing. Over-ripe or under-ripe corn can have undesirable textures, with over-ripe kernels becoming hard and starchy, while under-ripe kernels may lack the desired tenderness [281].

In terms of breeding, researchers have focused on varieties that balance tenderness with resistance to over-ripening. The shrunken-2 (sh2) gene, which results in increased sugar content and reduced starch, contributes to a desirable texture by making kernels more tender and less starchy. Additionally, the waxy gene has been explored for its effects on starch composition, leading to modifications in kernel texture that may enhance both

eating quality and shelf life [282]. The proper moisture content at harvest also plays a crucial role in preserving desirable texture, as sweet corn with too much moisture can be prone to decay, while too little moisture can result in tough, unpalatable kernels [283].

3.7.4. Flavor

Flavor is the result of the complex interaction between sugars, amino acids, organic acids, and volatile compounds present in sweet corn. The sweetness of the kernels is complemented by the balance of other flavor compounds, such as phenolic compounds, that contribute to the overall taste. Research into the flavor profile of sweet corn has shown that specific amino acids, such as glutamic acid, and the presence of volatile compounds like aldehydes and alcohols significantly influence the flavor [284]. Consumers often associate the freshness of sweet corn with the absence of off-flavors, which can develop due to improper post-harvest handling, storage conditions, or delays in harvest.

Breeding efforts have targeted improving the flavor of sweet corn by enhancing the concentrations of favorable flavor compounds and reducing the impact of undesirable ones. Moreover, harvest timing is crucial for optimal flavor, as over-ripe corn can lose its sweetness and develop an off flavor due to the conversion of sugars to starch [285]. There is also increasing interest in the role of genetic diversity in sweet corn flavor, with some studies exploring how landrace varieties and wild relatives of maize contribute to the flavor complexity of sweet corn hybrids [286].

In addition, environmental conditions during cultivation play a role in flavor development. Factors such as soil composition, temperature, and water availability influence the synthesis of flavor compounds, with certain growing conditions leading to sweeter and more flavorful corn. Research into the optimal growing conditions for superior flavor profiles is ongoing, with an emphasis on understanding how agroecological practices, such as soil health management and crop rotation, can enhance the flavor of sweet corn [287].

The quality traits of sweet corn sugars, texture, and flavor, are critical factors in determining its market value and consumer acceptance. Advances in breeding and genetic technologies have led to the development of varieties with higher sugar content, improved texture, and better flavor profiles, contributing to more desirable products for both fresh markets and processing. Continued research into these traits will help improve sweet corn varieties that meet consumer demands for sweetness, tenderness, and flavor, while also addressing environmental and production challenges. The development of high-quality sweet corn will remain a focal point of breeding efforts, ensuring that the crop can thrive in diverse climates while maintaining its sensory qualities and marketability [288].

4. Management to Reduce the Environmental and Economic Costs

4.1. Economic Analysis of Sweet Corn Production

Sweet corn (*Zea mays* L. *saccharata*) production is a significant agricultural industry globally, contributing to the economy through both fresh and processed markets. The economic viability of sweet corn production depends on various factors, including yield, input costs, market prices, and regional production practices. As the demand for sweet corn continues to rise, driven by its use in fresh consumption, processing, and as an ingredient in various food products, understanding the economic dynamics of sweet corn production has become increasingly important for farmers, researchers, and policymakers. This section reviews the key economic considerations that influence sweet corn production, including cost structures, profitability, and the economic impact of innovations in production techniques.

4.1.1. Cost Structure and Inputs

The cost of producing sweet corn is influenced by several factors, such as seed costs, labor, land, irrigation, fertilization, pest management, and harvesting. Seed costs are one of the largest fixed costs for sweet corn growers, with hybrid seeds for high-quality varieties typically commanding higher prices due to the advanced genetic traits they offer, such as improved sugar content, disease resistance, and higher yields [289]. Labor costs also represent a significant portion of total production costs, particularly for hand-harvested sweet corn, though these costs can be reduced by utilizing mechanical harvesting equipment, which has become more common in large-scale operations [290].

Fertilization, particularly nitrogen, is another major cost driver in sweet corn production. Optimizing nitrogen application is crucial for maximizing yields and minimizing environmental impacts. Research into more efficient nitrogen fertilization strategies, including the use of slow-release fertilizers and precision agriculture techniques, has helped reduce input costs while maintaining or increasing yield [291]. Additionally, pest management strategies, both chemical and integrated pest management (IPM), contribute to variable production costs. IPM approaches, while often less costly in the long term, may require more initial investment in scouting, biological controls, and monitoring systems [292].

Water use is another crucial input in sweet corn production. In regions where irrigation is necessary, water costs can significantly impact the overall cost structure. Efficient irrigation techniques, such as drip irrigation and sprinkler systems, can help reduce water usage and costs while maintaining crop health. The adoption of water-saving technologies and efficient irrigation management can result in substantial savings and improve the sustainability of production systems [293].

4.1.2. Market Prices and Profitability

The profitability of sweet corn production is heavily influenced by market prices, which can fluctuate depending on supply and demand, weather conditions, and regional competition. Fresh sweet corn typically commands higher prices compared to processed varieties, but it also faces greater risks related to spoilage and quality degradation during harvest and storage. For processed sweet corn, such as frozen or canned products, market prices are often more stable, but the profit margins are generally lower due to processing and storage costs [294].

Price volatility is an ongoing challenge for sweet corn producers, particularly in regions that experience fluctuating weather conditions, such as droughts or excessive rainfall, which can affect yield and quality. In response to this volatility, farmers may diversify their operations by growing sweet corn alongside other crops or by investing in value-added products, such as ready-to-eat corn products or canned sweet corn, to stabilize income and mitigate risk [295].

The cost–benefit analysis of adopting newer technologies, such as precision agriculture tools for monitoring field conditions, soil health, and irrigation needs, has shown that these innovations can improve profitability by increasing yield per acre while reducing input costs. However, the adoption of these technologies may be limited by the initial capital investment required, which can be a barrier for small-scale farmers [296].

4.1.3. Economic Impact of Sweet Corn Innovations

Innovation in sweet corn production has the potential to significantly improve the economic sustainability of the industry. The development of high-yielding, disease-resistant, and drought-tolerant varieties has helped to reduce production risks and increase profitability in diverse environmental conditions. Research into soil health management and organic

farming practices has also opened new markets for sweet corn growers, as consumer demand for organic produce continues to rise [297].

Furthermore, innovations in mechanical harvesting, post-harvest handling, and value-added products have contributed to reducing labor costs and improving shelf life, thereby enhancing profitability in both fresh and processed markets. The adoption of sustainable farming practices, including the use of cover crops and crop rotation, can reduce input costs and improve long-term soil health, benefiting farmers economically by decreasing the need for synthetic fertilizers and pesticides [298].

The economic analysis of sweet corn production reveals that the profitability of this crop is influenced by a complex interplay of input costs, market prices, technological advancements, and government policies. While sweet corn production can be highly profitable, it is also subject to risks related to price volatility, environmental conditions, and input costs. By adopting more efficient production techniques, embracing technological innovations, and diversifying markets, sweet corn producers can improve profitability and ensure the long-term sustainability of the industry. Continued investment in research and development, along with supportive government policies, will be critical for ensuring the economic viability of sweet corn production in the face of evolving challenges and market demands [299]. The findings are presented in Table 2.

Table 2. Comparative analysis of labor, irrigation, and yield in conventional and organic sweet corn production systems.

Parameter	Conventional System	Organic System	Remarks
Labor Requirement (hrs/ha)	120–160	180–220	Organic systems require more manual labor for weed and pest management.
Irrigation Use (mm/season)	350–450	300–400	Organic systems often adopt more water-efficient practices.
Average Yield (tons/ha)	9–12	6–9	Conventional systems generally achieve higher yields due to synthetic inputs.
Labor Cost (USD/ha)	400–600	600–800	Labor is a larger cost component in organic systems.
Irrigation Cost (USD/ha)	250–400	200–350	Efficient irrigation in organic systems can reduce costs.

5. Conclusions

Over the past 15 years, sweet corn research has witnessed remarkable advancements across genetics, agronomy, and sustainability. Genetic improvement, particularly through hybrid development, has significantly enhanced resistance to biotic and abiotic stresses, improved nutritional quality, and increased adaptability to diverse environments. Agronomic innovations, ranging from optimized planting densities and sowing schedules to efficient nitrogen management and irrigation strategies, have collectively contributed to higher yields and better input use efficiency. Simultaneously, the adoption of precision agriculture tools, including remote sensing, GIS-based decision support systems, and variable rate technologies, has enabled site-specific management, reduced environmental impact, and enhanced profitability.

Sustainable production practices have also gained momentum, with emphasis on soil health restoration, conservation tillage, and reduced pesticide use, aligning sweet corn cultivation with the broader goals of climate resilience and environmental stewardship.

To build upon these achievements, future research should focus on leveraging cutting-edge molecular tools like CRISPR/Cas9 for precise gene editing, aimed at improving stress tolerance and quality traits. Additionally, scaling up digital agriculture platforms and

integrating AI-powered analytics will be vital for real-time data-driven decision making and resource optimization. Strengthening interdisciplinary collaborations and promoting farmer-centered innovations will be key to ensuring that sweet corn production systems evolve to be more resilient, productive, and sustainable in the face of global challenges.

Furthermore, initiatives to bridge the gap between research and field application must be reinforced through participatory breeding and adaptive trials. Investment in infrastructure, training, and rural extension services will accelerate technology transfer and empower growers with actionable knowledge. Climate-smart varietal development tailored to specific agroecological zones will enhance regional productivity. Policies promoting environmentally sound practices and innovative incentives should be integrated into national agricultural strategies. Ultimately, a holistic and inclusive approach will be essential to future-proof sweet corn production in a changing global landscape. Biofortification plays a vital role in the genetic improvement of sweet corn by enhancing its nutritional profile. Through targeted increases in provitamin A, zinc, and folate, it supports better health outcomes. This approach adds value to the crop while aligning with global nutrition strategies. Ultimately, it unites agricultural innovation with long-term food security.

Author Contributions: H.S. conducted the literature review, collected and analyzed the data, and drafted the manuscript, including the organization and synthesis of key findings. J.N. provided overall supervision of the research, offering strategic guidance and giving final approval of the manuscript. A.V. served as co-supervisor, providing critical input and ongoing support throughout the study. All authors have read and agreed to the published version of the manuscript.

Funding: Open access funding provided by the University of Debrecen. Project no. TKP2021-NKTA-32 has been implemented with the support provided by the Ministry of Culture and Innovation of Hungary from the National Research, Development and Innovation Fund, financed under the TKP2021-NKTA funding scheme and supported by the EKÖP-24-4 University Research Scholarship Program of the Ministry for Culture and Innovation from the source of the National Research, Development and Innovation Fund.

Data Availability Statement: All data supporting the conclusions of this article are included in this article.

Acknowledgments: We sincerely acknowledge the contributions of the Institute of Land Use, Engineering, and Precision Farming Technology, Debrecen, Hungary, for their valuable support. We are also grateful to the Institute for Agricultural Research and Educational Farm (IAREF), the Farm and Regional Research Institutes of Debrecen (RID), and the Experimental Station of Látókép, University of Debrecen.

Conflicts of Interest: The authors declare that they have no conflicts of interest.

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