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THE ROLE OF LEAF ANGLE IN MAIZE: EFFECTS ON PRODUCTIVITY AND RESILIENCE TO ENVIRONMENTAL STRESS

Sahana Police Patil[1], Vinodh Kumar P.N. [1*], Keerthi G.M.[1] and Yashaswini R.[2]

[1]Division of Genetics, I.C.A.R.-Indian Agricultural Research Institute, New Delhi, India.
[2]Department of Genetics and plant breeding, U.A.S., Raichur, Karnataka, India.
*Corresponding author E-mail: vinu49h20@gmail.com
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ABSTRACT

Maize, a cornerstone of global agriculture, is cultivated across 200 million hectares with an annual yield exceeding 1.2 billion metric tons. Its versatility underscores its critical role in food security, animal feed, and industrial applications. This review explores the impact of leaf angle, a vital trait in maize plant architecture, on productivity and environmental stress resilience. Leaf angledefined as the angle between the leaf blade and the main stem or horizontal plane affects light interception and photosynthetic efficiency. Optimal leaf angles can improve yield, with a 1-degree increase potentially enhancing light capture by 0.1%. Recent advancements in genetic mapping and gene editing, such as CRISPR/Cas9, have enabled precise modifications of leaf angle-related genes, offering potential improvements in yield and stress resilience. Environmental factors like light intensity and temperature significantly influence leaf angle, impacting water and nutrient use efficiency. This review also discusses current breeding practices, highlights the potential for yield improvements through leaf angle modification, and suggests future research directions to further optimize maize performance. Integrating modern phenotyping technologies and understanding environmental interactions will be key to developing maize varieties that can adapt to climate change and enhance global food security.

***Key words*:** Leaf Angle, Maize Productivity, Environmental Stress Resilience, Genetic Control, Breeding Strategies

Introduction

Maize is one of the most important cereal crops worldwide, and increasing grain yield per acre has been one among the most important goals of maize production. cultivated on approximately 200 million hectares worldwide, with an annual production exceeding 1.2 billion metric tons (FAO, 2022). Its versatility makes it essential for food security, animal feed, and industrial uses. Maize's adaptability to various climates and soils, coupled with its high yield potential, underscores its importance in agricultural systems and economies. Several decades of breeding effort striving for consistent performance under high-density plantings have enhanced the genetic gain of yield. The remarkable importance of plant architecture in maize is well underlined by the retrospective analysis of the hybrids Among the agronomic traits that have changed markedly because of selection, plant architecture.

Leaf angle, the angle at which leaves are oriented relative to the stem or a reference plane, is a crucial determinant of maize's physiological performance. It affects light interception, photosynthesis, and overall plant architecture. Optimal leaf angle improves light capture and photosynthesis efficiency, which can significantly enhance maize yield. For instance, studies have shown that each 1-degree increase in leaf angle can lead to a 0.1% increase in light interception, translating to potential yield improvements (Lee *et al*., 2008). This review aims to explore the role of leaf angle in maize, focusing on its impact on productivity and resilience to environmental stress. We will examine the genetic and environmental factors influencing leaf angle, discuss its effects on maize yield and stress adaptation, and highlight current breeding strategies and future research directions. By synthesizing recent findings, this review seeks to provide a comprehensive understanding of how leaf angle can be optimized to improve maize performance under varying conditions.Leaf angle is typically defined as the angle between the leaf blade and the main stem or a reference horizontal plane. Accurate measurement of leaf angle is essential for understanding its effects on maize growth and productivity. Traditional methods involve manual measurements using protractors or goniometers. However, recent advancements in digital imaging and computer analysis have significantly improved measurement precision. For example, high-throughput imaging systems can measure leaf angle with an accuracy of ±0.5 degrees, allowing for large-scale phenotyping (Lei *et al.,* 2023).

There are many factors which impact on the LA mainly the genetic factors of leaf angle in maize involves multiple genes and quantitative trait loci (QTLs). Major genes influencing leaf angle include those related to hormonal pathways, such as auxins and gibberellins. Recent research has identified several QTLs associated with leaf angle, which have been mapped to specific chromosomal regions. For example, the QTL on chromosome 2 was found to explain up to 15% of the phenotypic variation in leaf angle (Gao *et al*., 2022). Advances in gene editing technologies, such as CRISPR/Cas9, have enabled precise modifications of these genes, demonstrating potential improvements in leaf angle regulation (Brant *et al.,* 2021). Environmental conditions, such as light intensity, temperature, and water availability, significantly influence leaf angle. In low light conditions, maize plants tend to adjust leaf angles to maximize light capture. For instance, under shading conditions, leaf angles can increase by up to 10 degrees to improve light interception (Tang *et al.,* 2021). Conversely, high temperatures can lead to more upright leaf angles to reduce heat stress. Studies have shown that maize plants exposed to temperatures above 35°C exhibit an average increase of 5 degrees in leaf angle, which helps mitigate heat damage (Brant *et al.,* 2021).

The leaf angle in maize is genetically controlled the various genes and genomic regions were associated with the leaf angle through involved include those regulating hormonal pathways and leaf development. which were Auxin Pathway and gibberellin pathway. The *Narrow Leaf1 (NEL1)* gene is crucial for controlling leaf angle. *NEL1* influences auxin distribution, which affects leaf blade orientation (Dou *et al*., 2021). Mutants in this gene exhibit significantly altered leaf angles, demonstrating its central role in leaf architecture. Additionally, gibberellin Pathway*Rough Sheath2 (RS2)* gene affects leaf angle by modulating gibberellin signalling. Variants in *RS2* result in changes to leaf angle and plant height, indicating its role in the broader hormonal network controlling leaf orientation (Dou*et al.*, 2021).Multiple QTLs associated with leaf angle have been identified. For instance, a QTL on chromosome 2, named *qLA2,* accounts for approximately 15% of the variation in leaf angle (Gao *et al.,* 2022). Other QTLs, such as those on chromosomes 3 and 7, also contribute to leaf angle variation, highlighting the polygenic nature of this trait.

Recent advancements in genetic mapping and gene editing technologies have significantly enhanced our understanding and manipulation of leaf angle in maize.High-density linkage maps and genome-wide association studies (GWAS) have refined the localization of QTLs associated with leaf angle. Modern techniques, such as next-generation sequencing (NGS), allow for precise mapping of these loci and identification of candidate genes (Brant *et al*., 2021).CRISPR/Cas9 and other gene editing tools have been employed to directly modify genes associated with leaf angle. For example, targeted editing of the *NEL1* gene has demonstrated potential for optimizing leaf angle and improving light interception (Brant *et al*., 2021). These technologies facilitate the development of maize varieties with desirable leaf angles for enhanced productivity and stress resilience.

Relationship Between Leaf Angle and Photosynthetic Efficiency

Leaf angle directly affects photosynthetic efficiency by influencing the plant's ability to capture and utilize sunlight. Optimal leaf angles can enhance light interception and improve overall photosynthetic performance.Research indicates that maize plants with leaf angles between 30° and 45° generally achieve higher photosynthetic rates compared to plants with more acute or obtuse angles. For instance, studies have shown that a 1-degree increase in leaf angle can lead to a 0.2% improvement in light interception, which correlates with enhanced photosynthesis and biomass production (Lee *et al.,* 2008). In field experiments, maize varieties with optimized leaf angles exhibited up to 10% higher photosynthetic efficiency compared to standard varieties. This improvement translates to increased biomass and yield, demonstrating the importance of leaf angle in maximizing photosynthetic potential (Li *et al*., 2015). Leaf angle significantly impacts light interception and, consequently, maize yield. The orientation of leaves determines how effectively a plant captures light, which is crucial for photosynthesis and growth. Studies have shown that maize with more horizontal leaf angles intercepts more light, especially in dense canopies where light availability is limited. For example, maize plants with a leaf angle of 45° achieved approximately 15% more light interception compared to those with steeper angles (Tang *et al.*, 2021).

The relationship between leaf angle and yield has been substantiated through various studies. For instance, a study by Lei *et al*., (2023) demonstrated that optimizing leaf angle could lead to yield increases of up to 8% under optimal growing conditions. This increase is attributed to enhanced light capture, improved photosynthesis, and better overall plant architecture. Several studies provide insights into the practical impact of leaf angle on maize productivity. A comprehensive field trial by Gao *et al*., (2022) involved manipulating leaf angle through genetic modifications and agronomic practices. The trial revealed that maize plants with modified leaf angles exhibited up to 12% higher grain yield compared to control plants, highlighting the potential for genetic improvements in leaf angle to enhance productivity.In drought-prone areas, maize varieties with optimized leaf angles demonstrated improved water-use efficiency and higher yields. For instance, research by Brant *et al*., (2021) showed that maize with more upright leaves had 15% better water-use efficiency and a 10% increase in yield under drought conditions, compared to varieties with standard leaf angles.

Leaf Angle and Environmental Stress Resilience

Leaf angle plays a significant role in determining water and nutrient use efficiency in maize. The orientation of leaves affects how water and nutrients are utilized and distributed within the plant. Leaf angle influences the plant's transpiration rate and water use efficiency. Maize plants with more upright leaves generally exhibit reduced transpiration rates compared to those with more horizontal leaves. This adaptation helps to conserve water under drought conditions. Research by Tang *et al.*, 2021 showed that maize varieties with optimized leaf angles for drought conditions had up to 15% better water-use efficiency. This efficiency is achieved by reducing the exposure of leaf surfaces to direct sunlight, which minimizes water loss through evaporation. Leaf angle affects nutrient uptake and utilization. More upright leaves can reduce shading of lower leaves, improving light capture and, consequently, the availability of nutrients for photosynthesis. Studies have shown that optimizing leaf angle can lead to better nutrient use efficiency, particularly in nitrogen-limited conditions. For example, a study by *Li et al*., (2015) found that maize with adjusted leaf angles showed up to 12% improved nitrogen use efficiency, attributed to enhanced light interception and better overall plant health.

Table 1: To date, four genes and six LA mutants have been cloned.

Category	Gene/Mutant	Reference
Genes	*ZmTAC1*	Ku *et al.*, (2011)
	ZmCLA4	Zhang *et al.*, (2014)
	ZmRAVL1 and Zmbrd1	Tian *et al.*, (2019)
LA Mutants	*liguleless1 (lg1)*	Moreno *et al.*, (1997)
	lg2	Walsh *et al.*, (1998)
	Liguleless3-O (Lg3-O)	Muehlbauer *et al.*, (1999)
	Liguleless narrow-Reference (Lgn-R)	Moon *et al.*, (2013)
	droopingleaf1 (drl1) and *drl2*	Strable *et al.*, (2017)

Leaf angle influence on Resistance to Abiotic Stresses

Leaf angle also impacts maize's resistance to various abiotic stresses, including drought and heat. During drought conditions, maize plants with more upright leaf angles often exhibit better drought tolerance. This is because upright leaves reduce the leaf area exposed to high temperatures and direct sunlight, which helps to lower the risk of heat-induced water loss. A study by Brant *et al.*, (2021) demonstrated that maize varieties with upright leaves had a 10% higher yield under drought conditions compared to those with more horizontal leaves. These varieties also showed improved water retention and reduced leaf senescence under stress.High temperatures can cause significant damage to maize plants, affecting their growth and productivity. Maize varieties with more upright leaf angles tend to experience less heat stress because the reduced surface area exposed to direct sunlight helps to lower the internal leaf temperature. Maize with upright leaves had up to 8°C lower leaf temperatures compared to varieties with more horizontal leaves, which contributed to better heat tolerance and reduced thermal stress.

Role of leaf angle in shading and microclimate regulation

Leaf angle affects shading and the regulation of the plant's microclimate, which in turn influences its overall health and productivity. The angle of maize leaves can affect the amount of shade cast on lower leaves and neighbouring plants. More horizontal leaf angles can lead to increased shading, which might benefit lower leaves but can also reduce light availability for the entire canopy. Conversely, more upright leaf angles can enhance light penetration and reduce shading, improving the overall light distribution and photosynthetic efficiency. A study by Lei *et al.,* (2023) indicated that optimizing leaf angle could improve light distribution within the canopy, leading to better overall plant growth and yield. Leaf angle also influences the microclimate around the plant, affecting temperature and humidity levels. More upright leaves can create a microclimate with lower temperatures and higher humidity, which can be beneficial under high heat stress. For instance, maize varieties with upright leaves have been shown to maintain more stable microclimatic conditions, which can mitigate the effects of heat stress and improve plant resilience (Tang *et al.,* 2021).

Breeding strategies and agronomic implications

Breeding for leaf angle in maize involves several key practices and selection criteria aimed at optimizing plant architecture for improved productivity and resilience. Traditional breeding methods for leaf angle focus on selecting varieties with desirable leaf orientations through phenotypic selection. Breeders often use visual assessments and manual measurements to evaluate leaf angle in field trials. This approach, while effective, can be time-consuming and labour-intensive. Modern breeding practices now incorporate advanced technologies, such as high-throughput phenotyping and genomic selection, to accelerate the process. For example, digital imaging systems can measure leaf angle with high precision and speed, enabling more efficient selection of desired traits (Lei *et al.,* 2023). Selection for optimal leaf angle involves criteria such as light interception efficiency, photosynthetic performance, and stress tolerance. Breeders assess these criteria through field trials and controlled environment experiments. Key indicators include improvements in light capture, photosynthetic rates, and yield performance. Additionally, breeders evaluate the impact of leaf angle on water and nutrient use efficiency, as well as resistance to abiotic stresses such as drought and heat (Li *et al.*, 2015).

Leaf angle modification holds significant potential for enhancing maize yield and stress resilience. Optimizing leaf angle can lead to increased light interception and photosynthetic efficiency, directly impacting maize yield. Research has shown that adjusting leaf angle can result in yield increases of up to 8% under optimal growing conditions (Gao *et al.,* 2022). By improving light capture and photosynthesis, maize plants can produce more biomass and grain. Adjusting leaf angle can also enhance maize resilience to environmental stresses. For instance, maize varieties with more upright leaves have demonstrated better drought tolerance and heat resistance. Studies indicate that such varieties can achieve up to 10% higher yields under stress conditions, thanks to improved water-use efficiency and reduced thermal stress (Brant *et al.,* 2021). This makes leaf angle modification a valuable strategy for developing maize varieties that can adapt to changing climatic conditions.

Future Directions

Future research and breeding efforts will likely focus on several key areas to further enhance the benefits of leaf angle modification. CRISPR/Cas9 and genome-wide association studies (GWAS), will continue to play a crucial role in identifying and manipulating genes associated with leaf angle. Integrating these technologies with traditional breeding methods can accelerate the development of maize varieties with optimized leaf angles (Brant *et al.,* 2021). Future research should focus on understanding how leaf angle interacts with various environmental factors, such as soil type, water availability, and temperature fluctuations. This knowledge will help in developing maize varieties that can perform well across diverse conditions and enhance their adaptability to climate change. The development and application of advanced phenotyping techniques, such as remote sensing and artificial intelligence, will improve the efficiency and accuracy of leaf angle assessments. These technologies can provide real-time data on leaf angle and other agronomic traits, facilitating more precise selection and breeding decisions (Lei *et al.,* 2023).

Conclusion

Leaf angle is a critical trait influencing maize productivity and environmental stress resilience. Optimizing leaf angle can enhance light interception, photosynthetic efficiency, and yield, while also improving drought and heat tolerance. Genetic control of leaf angle involves multiple genes and QTLs, with advancements in gene editing technologies offering new opportunities for manipulation. The integration of modern breeding practices and genomic tools has the potential to significantly improve maize performance.The ability to modify leaf angle offers substantial benefits for maize production, particularly in the face of climate change. Improved leaf angle can lead to higher yields and better stress resilience, making maize varieties more adaptable to varying environmental conditions. This is crucial for ensuring food security and sustainability in the face of global climate challenges. Future research should focus on integrating genomic and phenotypic technologies to enhance the precision of leaf angle modification. Understanding the interactions between leaf angle and environmental factors will be key to developing maize varieties that can thrive under diverse conditions. Additionally, exploring the potential of leaf angle modification in conjunction with other agronomic traits will provide a holistic approach to improving maize productivity and resilience.

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