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Growth and morphological response of imazamox-tolerant sorghum (*Sorghum bicolor* L.) to increasing herbicide doses under field conditions

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Abstract

Sorghum is characterized by high adaptability to abiotic stress; however, its early growth and morphological development may be influenced by herbicide application, even in tolerant hybrids. The present study aimed to evaluate the growth dynamics and morphological response of the imazamox-tolerant sorghum hybrid Sentinel IG to increasing doses of the herbicide Pulsar 40 (imazamox). A three-year field experiment was conducted under rainfed conditions in South Central Bulgaria during the period 2023–2025. Plant height was measured at key phenological stages (4–5 leaf stage, before heading, and at final maturity) to assess the impact of herbicide dose and environmental variability on crop growth. The results demonstrated a consistent dose-dependent reduction in plant height, particularly at the pre-heading and final growth stages. The highest herbicide dose (480 ml da^{-1}) resulted in persistent growth suppression across all experimental years. Interannual differences were observed, reflecting the influence of climatic conditions on growth expression. The study confirms that excessive herbicide doses negatively affect sorghum growth dynamics, even in tolerant hybrids, highlighting the importance of dose optimization for sustainable crop management.

Keywords: Sorghum; Imazamox; Plant height; Growth dynamics; Morphological response

1. Introduction

Sorghum (*Sorghum bicolor* L.) is among the most resilient cereal crops, widely cultivated in semi-arid regions due to its high tolerance to drought and heat stress [1,2]. Despite its adaptability, sorghum exhibits relatively slow early growth, making it sensitive to weed competition during the initial stages of development [3]. Effective weed control is therefore essential to ensure optimal crop establishment and growth.

The introduction of imazamox-tolerant sorghum hybrids has expanded chemical weed control options by enabling the post-emergence use of acetolactate synthase (ALS)-inhibiting herbicides [4]. Although these hybrids can tolerate imazamox application, tolerance does not necessarily imply the absence of growth disturbances, particularly when herbicides are applied at elevated doses or under unfavorable environmental conditions [5,6].

Plant height and growth dynamics are widely used indicators of crop response to both chemical and environmental stress. Changes in height reflect alterations in cell division, elongation, and overall assimilate allocation, making this parameter a reliable measure of sub-lethal herbicide effects [7,8]. Several studies have reported growth suppression in herbicide-tolerant crops when exposed to doses exceeding the recommended rates, especially under rainfed conditions [9].

The objective of the present study was to evaluate the growth and morphological response of imazamox-tolerant sorghum to increasing herbicide doses over three growing seasons, focusing on plant height dynamics at key developmental stages.

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2. Materials and Methods

2.1. Experimental site and plant material

Field experiments were conducted during the 2023, 2024, and 2025 growing seasons at the experimental field of the Agricultural University of Plovdiv, Bulgaria. The experiments were performed under rainfed conditions on alluvial-meadow soil. The imazamox-tolerant sorghum hybrid Sentinel IG was used throughout the study.

2.2. Experimental design and treatments

The experiment was arranged in a randomized block design with four replications. The following treatments were evaluated:

- **A1** – Untreated control (no herbicide)
- **A2** – Farm control (standard agronomic practices, no herbicide)
- **A3** – Pulsar 40 (imazamox) at 120 ml da^{-1}
- **A4** – Pulsar 40 at 240 ml da^{-1}
- **A5** – Pulsar 40 at 480 ml da^{-1}

Herbicide application was performed at the 3–4 leaf stage of sorghum using standard field spraying equipment.

2.3. Growth measurements

Plant height (cm) was measured on randomly selected plants from each plot at the following growth stages:

- 4–5 leaf stage
- Immediately before heading
- Final maturity
- Mean values were calculated for each treatment and year.

2.4. Statistical analysis

The data were processed using descriptive and comparative statistical methods. Growth trends were evaluated by comparing mean plant height values among treatments and across years to identify dose-dependent and interannual effects.

3. Results and Discussion

3.1. Plant height at early growth stages

At the 4–5 leaf stage, differences in plant height among treatments were relatively small but showed a clear tendency toward reduced growth with increasing herbicide dose (Table 1). The untreated and farm control variants consistently exhibited the highest early growth, while plants treated with 480 ml da^{-1} were shorter across all years.

Table 1 Plant height at the 4–5 leaf stage (cm)

Treatment	2023	2024	2025
A1	24.3	26.8	23.2
A2	26.1	25.1	27.8
A3	25.4	24.6	26.5
A4	24.0	23.8	25.1
A5	22.7	22.9	23.8

These results indicate that early growth suppression becomes detectable shortly after herbicide application, even in tolerant hybrids, supporting observations by Knezevic and Datta [9].

3.2. Growth dynamics before heading

Before heading, differences among treatments became more pronounced (Table 2). The highest herbicide dose resulted in significant growth reduction compared to both controls. The farm control consistently produced the tallest plants, while increasing herbicide doses progressively limited plant height.

Table 2 Plant height before heading (cm)

Treatment	2023	2024	2025
A1	45.2	48.9	43.8
A2	61.7	64.3	59.8
A3	58.1	58.8	56.2
A4	53.4	55.2	51.0
A5	50.2	53.5	49.4

The reduction in height before heading suggests that imazamox influences stem elongation and biomass accumulation during the critical vegetative–reproductive transition phase [7].

3.3. Final plant height

At final maturity, growth suppression effects persisted, particularly at the highest herbicide dose (Table 3). Interannual variation was evident, with generally lower final heights recorded in 2025, likely due to reduced precipitation and higher temperatures during the growing season.

Table 3 Final plant height at maturity (cm)

Treatment	2023	2024	2025
A1	62.4	65.1	60.3
A2	70.6	69.2	67.1
A3	66.8	63.9	64.2
A4	63.1	61.0	60.5
A5	59.7	58.1	56.8

Similar growth reductions under elevated herbicide doses have been reported in other ALS-tolerant crops, confirming that tolerance does not fully eliminate morphological sensitivity [5,6].

4. Conclusion

The three-year field study demonstrates that increasing doses of imazamox induce measurable growth suppression in imazamox-tolerant sorghum. Plant height was consistently reduced at higher herbicide doses, particularly before heading and at final maturity. Interannual differences highlight the modifying role of climatic conditions on growth expression. The results emphasize the importance of adhering to recommended herbicide doses to ensure optimal crop growth and sustainable sorghum production.

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