



## Article

# The Impact of Sowing Date and Plant Density on Maize Productivity and Fall Armyworm (*Spodoptera frugiperda*) Infestation Rates Under Abiotic Stress Conditions

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**Abstract:** Two field experiments were conducted at the research farm of the sustainable development center of the New Valley resources in Kharga Oasis, New Valley Governorate, Egypt (25.52° N and 30.61° E) during the growing seasons of 2022 and 2023. To study the effect of both sowing date and plant density on maize productivity, water use efficiency, and fall armyworm infestation rate. The results showed that planting density and time have a significant impact on maize's vulnerability to fall armyworm infestations, as well as its productivity and water-use efficiency over the course of the two growing seasons. The findings indicated that maize productivity peaked when maize was planted on August 15, with a plant density of 150,000 plants/ha, where it recorded 10.21 and 10.26 t/ha during two growing seasons, respectively. The incidence of autumn armyworm was lowest, at a plant density of 50,000 plants/ha and with late planting on August 15, reaching 5.48 % and 3.23% throughout the two growing seasons, respectively. The intermediate density of 100,000 plants/ha with August 15 sowing offers a balanced approach, providing favorable yields (9.17-9.31 t/ha) with moderate infestation (11.67-12.33%) and high WUE (1.68-1.70 kg/m<sup>3</sup>). This combination may represent the most sustainable option for farmers seeking to balance multiple production objectives.

**Key words:** Maize, sowing date, plant density, abiotic stress, armyworm.

## 1. Introduction

By the end of the twenty-first century, the average global surface temperature is predicted to rise by 0.3 to 4.8 C. One of the main issues on the political agenda right now is food security considering global warming. Agricultural output has been severely impacted by climate change, particularly in developing nations. To address the detrimental effects of climate change on crop productivity and guarantee global food security, it is imperative to develop a variety of agronomic management techniques (Xu *et al.*, 2021).

Maize (*Zea mays* L.) is the second most extensively distributed cereal crop in the world, after wheat, and one of the world's three main food crops is maize. Since 1961, maize's yield has increased by 66.9 kg ha<sup>-1</sup> every year (FAO 2016). Global maize production has risen in recent decades, and as a result of climate change, it is predicted to rise even more (Salama, 2019). Since 2001, the world's total production of maize has surpassed that of the three major food crops. As a grain crop grown throughout the summer, it holds a prominent place in Egypt's agricultural landscape. Maize is a field crop and a staple food in Egypt, where it is the country's second-largest cereal crop, and it ranks first in terms of the total area used for summertime grain crop cultivation. Also, maize plays a vital part in Egypt's food security since it is considered a vital source of sustenance for both people and animals. It is cultivated for many purposes, such as human consumption, animal and poultry feed, the manufacturing of starch and cooking oils, and the fermentation industry. Maize is also cultivated for green fodder and silage. In 2022, it was projected that Egypt would produce roughly 7.5 million metric tons of maize (Abdehamid *et al.*, 2024).

According to the Intergovernmental Panel on Climate Change's (IPCC) fifth assessment report, maize yields have been negatively impacted by climate change in several areas. In recent years, the phenomenon has been further confirmed by other investigations. For instance, according to Ramirez & Thornton (2015) climate change will cause a 12–40% decrease in maize production in Africa. One of the biggest challenges to protecting the supply of maize is climate change. Numerous researchers have examined how maize production responds to various management strategies to mitigate the adverse effects of climate change using crop models. It is more effective to use multiple management strategies rather than just one to lessen the detrimental effects of climate change on agricultural productivity. To lessen the effects of future climate change on maize yield, it is imperative to evaluate the potential of various adaptation strategies (Xu *et al.*, 2021).

Temperature, photoperiod, and day length are significant environmental factors influencing maize development and production. The sowing date is the primary factor that influences the temperature and photo period to which the crop is exposed during its growth and development, necessitating precise adjustments (Salama, 2019). According to numerous research delaying planting dates and using longer-season maize varieties can help farmers avoid some production losses. These studies also showed that planting maize at different densities and delaying the sowing date can help farmers deal with the negative effects of climate change (Cuculeanu *et al.*, 1999; Harrison *et al.*, 2011; Ren *et al.*, 2016; Xu *et al.*, 2021). Besides planting date, plant density is of paramount importance in maize cultivation, as maize lacks the ability to branch out and adapt to changes in plant density. It is also well-established that plant density affects maize differently under varying environmental conditions and agricultural practices (Safari *et al.*, 2014; Salama, 2019)

The autumn armyworm (FAW), also known as *Spodoptera frugiperda*, is a polyphagous and lepidopteran pest that damages a wide range of plants. It has been shown to injure over 350 plant species, causing significant losses in agriculture, especially in maize harvests. Since its first recorded occurrence in the United States in 1876, FAW has expanded to Europe, Africa, India, and China. Rapid evolutionary changes and the ability to create several generations in a single mating season have been revealed by this pest (Gichuhi *et al.*, 2020). Since its first recorded incidence in West Africa in 2016, FAW has spread widely over the continent (Goergen *et al.*, 2016). Most Sub-Saharan African countries had recorded FAW (Rwomushana *et al.*, 2018). The pest's presence on maize plants in the Aswan governorate was reported by the Egyptian Ministry of Agriculture in 2019 (Dahi *et al.*, 2020).

As well as several studies have shown that the timing of maize sowing affects the rate and force of establishment and spread of autumn armyworm (FAW) populations within a maize crop. As a result, the time of maize planting can have a big impact on the crop's susceptibility to FAW attack, which in turn affects how severe the infestation becomes later. (Abd El mageed *et al.*, 2022; Olyme *et al.*, 2022).

Therefore, this study aims to examine the impact of different sowing dates and various maize densities on yield, component parameters, and infestation rates of the fall armyworm under abiotic stress conditions at Kharga Oasis, New Valley Governorate, Egypt.

## 2. MATERIALS AND METHODS

### 2.1. Site Description

Field experiments were conducted at research farm of the New Valley Sustainable Resources Development Center, in Kharga Oasis, New Valley Governorate, Egypt, (25.52° N and 30.61° E) during 2022 and 2023 growing seasons. Kharga Oasis has tropical arid climate, with temperatures ranging from a low of 2°C in January to a high of 41°C in August. The highest temperature recorded was 52°C, and the lowest recorded 2°C, and relative humidity is approximately 39%.

**Table (1). Soil Physicochemical properties during the two growing seasons (2022 and 2023)**

Season	Particles (%)			Texture	EC (ppm)	pH	Available aions (meq/l)							
	Sand	Silt	Clay				N	K	Ca	Mg	CO <sub>3</sub>	HCO <sub>3</sub>	Cl <sup>-</sup>	SO <sub>4</sub>
2022	78.5	14.9	6.6	sand	936	8.1	0.84	1.44	1.23	0.78	4.13	6.87	95.9	0.71
2023	80.5	12.6	6.9		922	8.3	0.91	1.57	1.31	0.81	4.37	6.53	93.4	0.67

### 2.2. Experiments design, treatments and layout

A Split-plot experimental design in four-replication was used to study the effect of sowing dates and plant densities on yield, its components, and the incidence of fall armyworm infestation in maize (*Zea mays* L.) cv. HT 2066 (Single cross Yellow Hybrid). Where sowing dates in main plot (three sowing dates studied were 15 July, August 1 and 15, in the growing seasons of 2022 and 2023). and plant densities in sub-plots (three plant densities were 50,000, 100,000, and 150,000 plants/hectare).

The crop was managed, and all agronomic procedures were consistent and applied consistently throughout all treatments in both seasons in accordance with the Ministry of Agriculture's instructions regarding fertilization and irrigation programs. Phosphorus fertilizer (15.5% P<sub>2</sub>O<sub>5</sub>) was added pre-sowing when soil preparation was at a rate of 74.5 kg phosphorus pentoxide/hectare. Nitrogen was added in the form of ammonium nitrate (33.3% nitrogen) at a rate of 234.5 kg nitrogen/hectare, applied in two equal doses: the first two weeks after planting and the second one month after the first application. The seedbeds were prepared by dividing each plot of land (30 m<sup>2</sup>) into 5 rows (60 cm apart and 10 m long), The grains were distributed according to the proposed planting densities and planted in each plot.

### 2.3. Statistical Analysis

To assess the main effects and their interactions, all data were subjected to analysis of variance (ANOVA) at a 5% significance level. To find the significant differences between individual means, the least significant difference (LSD) test was used. For all statistical studies, SPSS version 20 was used.

## 3. RESULTS AND DISCUSSION

### 3.1. Productivity (t/ha)

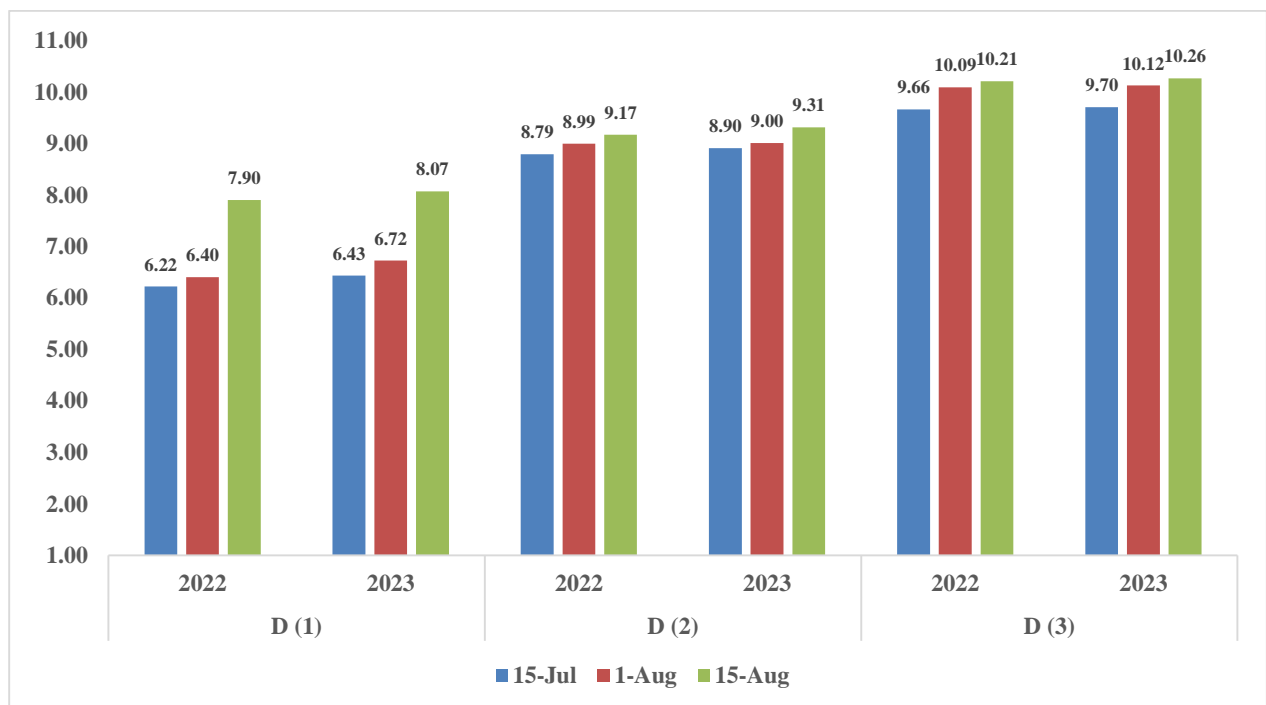
The data presented in Figure 1 demonstrate the impact of sowing date and plant density on maize productivity. The findings indicate that grain yield varied considerably across treatments, ranging from 6.22 t/ha (July 15 sowing at D<sub>1</sub> in 2022) to 10.26 t/ha (August 15 sowing at D<sub>3</sub> in 2023). Statistical

analysis revealed that sowing date, plant density, and their interaction significantly ( $P \leq 0.05$ ) affected grain yield during both growing seasons.

Sowing date exerted a pronounced effect on productivity. Delaying planting from July 15 to August 15 consistently increased grain yield across all density treatments. At the highest density ( $D_3$ ), for instance, mean yield increased from 9.68 t/ha (July 15) to 10.24 t/ha (August 15) across both seasons. This pattern likely reflects the synchronization of critical reproductive stages with more favorable thermal conditions. In the Kharga Oasis environment, where summer temperatures regularly exceed  $41^\circ\text{C}$ , early sown crops experience heat stress during flowering and grain filling, which can impair pollination and reduce kernel set. Later sowing shifts these sensitive phases to periods of declining temperatures, thereby extending the grain-filling duration and enhancing dry matter accumulation. These findings align with [Salama \(2019\)](#) and [Xu \*et al.\* \(2021\)](#), who reported similar benefits from adjusted sowing dates under thermal stress conditions.

Plant density also significantly influenced yield. Increasing population from 50,000 to 150,000 plants/ha progressively improved grain yield across all sowing dates. For the August 15 sowing in 2023, yield increased from 8.07 t/ha at  $D_1$  to 9.31 t/ha at  $D_2$ , reaching 10.26 t/ha at  $D_3$ . This response suggests that under the conditions tested, the yield advantage conferred by higher ear number per unit area outweighed the negative effects of intensified inter-plant competition. The hybrid HT 2066 appears well-adapted to moderate-to-high planting densities, particularly when coupled with optimal sowing timing. Similar density responses have been documented by [Safari \*et al.\* \(2014\)](#) and [Ren \*et al.\* \(2016\)](#), though they emphasized that such relationships are highly environment specific.

The interaction between sowing date and density proved particularly important. The combination of August 15 sowing with  $D_3$  produced the highest absolute yields (10.21-10.26 t/ha), representing the optimal management package for productivity maximization under the prevailing conditions. Conversely, July 15 sowing at  $D_1$  consistently yielded poorest (6.22-6.43 t/ha), underscoring the importance of integrated management decisions.



**Fig. (1).** Effect of sowing date and plant density on maize productivity (t/ha) during the two growing seasons (2022 and 2023)

### 3.2. 100-kernel weight (g)

Hundred-kernel weight, an indicator of grain-filling efficiency, generally paralleled yield trends though with some noteworthy deviations. Later sowing dates produced heavier kernels across most density treatments. At D<sub>3</sub> in 2023, kernel weight increased from 31.87 g (July 15) to 33.02 g (August 15), suggesting improved assimilate partitioning under more favorable post-anthesis conditions (Fig. 2).

The density effect on kernel weight was less straightforward. While D<sub>3</sub> produced the highest kernel weights under late sowing (32.67-33.02 g), this pattern was less consistent under early sowing, where D<sub>2</sub> occasionally matched or exceeded D<sub>3</sub>. This interaction implies that under heat-stressed conditions (July 15), excessive plant densities may exacerbate competition for resources during grain filling, partially offsetting the population advantage. The capacity of D<sub>3</sub> to achieve maximum kernel weight only under late sowing reinforces the conclusion that August 15 provides superior conditions for hybrid HT 2066 to express its yield potential (Fig. 2).

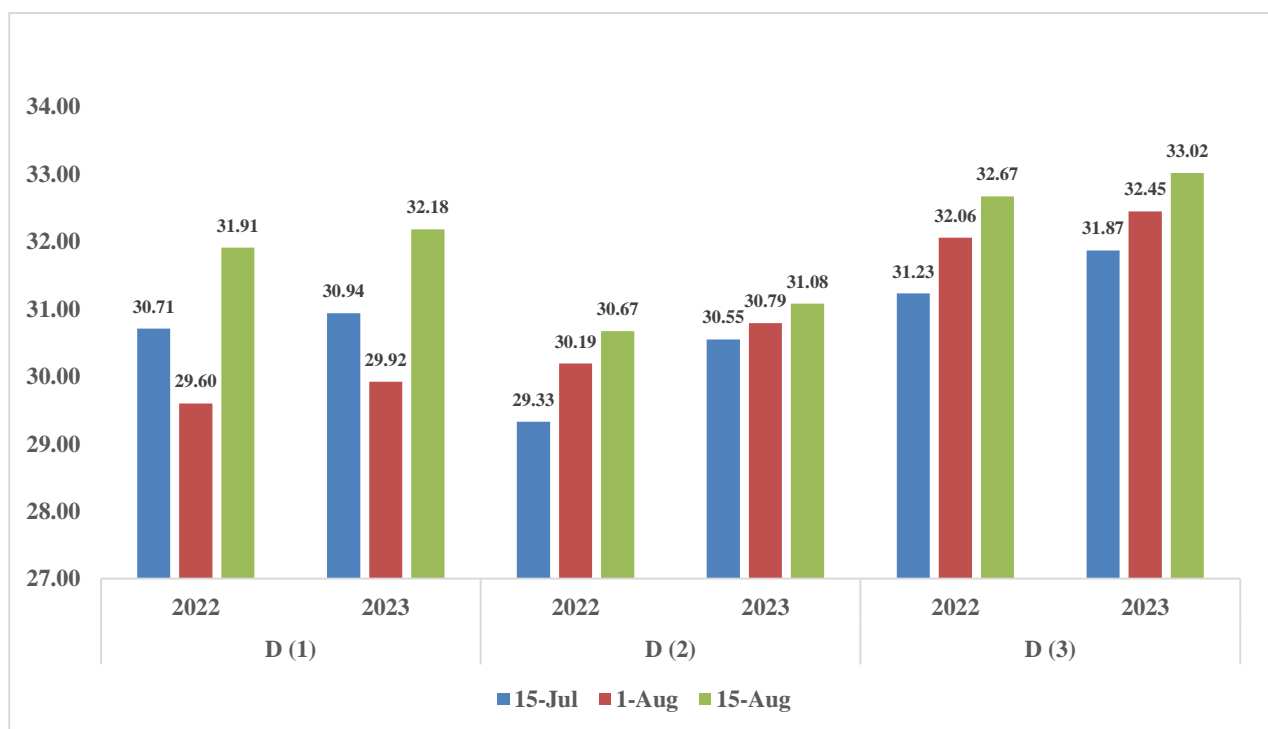


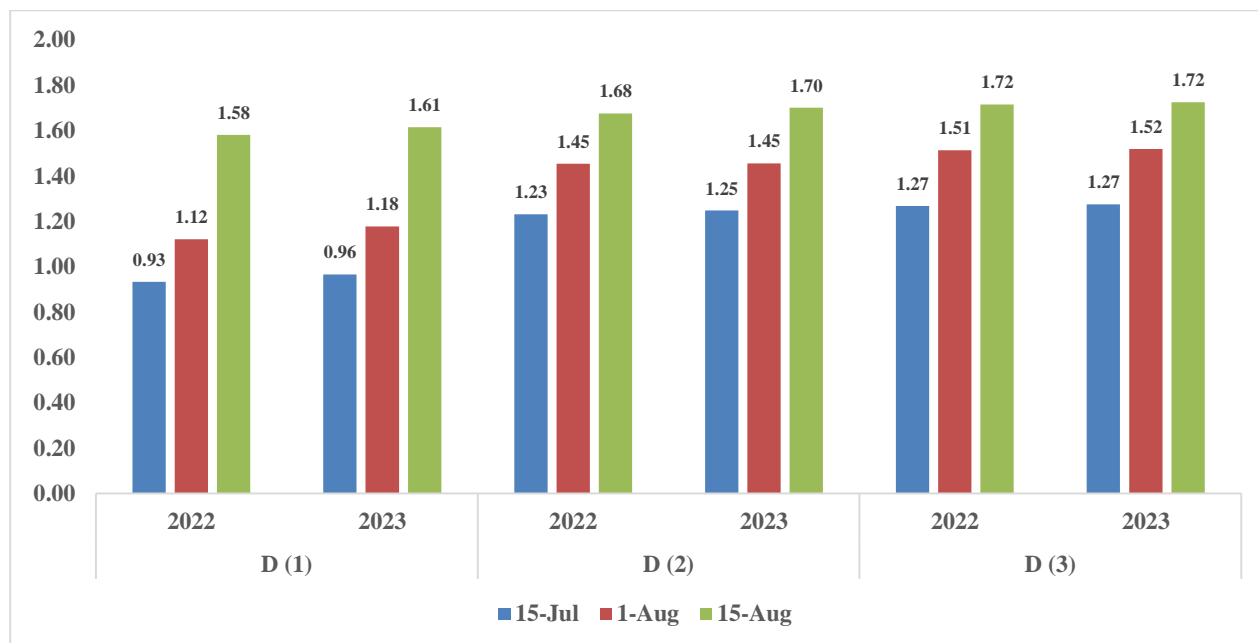
Fig. (2). Effect of sowing date and plant density on 100 grains weight (g) of maize during the two growing seasons (2022 and 2023)

### 3.3. Water Use Efficiency (WUE - kg/m<sup>3</sup>)

The data shown in Figure 3 illustrate the effects of sowing date and plant density on water use efficiency. Data demonstrated that water use efficiency followed patterns similar to grain yield, with both factors exerting significant influence. Late sowing consistently enhanced WUE across all densities. At D<sub>3</sub>, WUE increased from 1.27 kg/m<sup>3</sup> (July 15) to 1.72 kg/m<sup>3</sup> (August 15) in 2023 an improvement of approximately 35%.

Higher plant densities also improved WUE, particularly under late sowing. At the August 15 planting in 2023, WUE rose from 1.61 kg/m<sup>3</sup> at D<sub>1</sub> to 1.72 kg/m<sup>3</sup> at D<sub>3</sub>. This enhancement likely reflects two mechanisms. First, denser canopies achieve more rapid ground cover, reducing evaporative water loss from the surface of the soil and shifting the water balance toward productive transpiration. Second, later sowing aligns crop water demand with periods of lower atmospheric evaporative demand (reduced vapor pressure deficit), increasing transpiration efficiency.

The highest WUE values were achieved with the August 15 sowing at D<sub>3</sub> (1.72 kg/m<sup>3</sup> in both seasons), mirroring the yield optimum. In arid environments like the New Valley Governorate, where water represents the primary production constraint, this efficiency improvement carries particular significance. Optimizing both factors simultaneously enhances not only absolute productivity but also the productivity of each unit of water consumed—a critical consideration for sustainable agricultural development in desert regions.



**Fig. (3).** Effect of sowing date and plant density on water use efficiency (WUE) of maize (kg/m<sup>3</sup>) during the two growing seasons (2022 and 2023)

### 3.4. Fall Armyworm Infestation (%)

According to data in follow figure (4) fall armyworm (FAW) infestation responded dramatically to both experimental factors, with implications for integrated pest management strategies.

Sowing date profoundly influenced infestation levels. Early sowing (July 15) consistently produced the highest infestation rates, while late sowing (August 15) dramatically reduced pest pressure. At D<sub>1</sub>, infestation dropped from 16.67% (July 15) to 5.48% (August 15) in 2022, and from 14.33% to 3.23% in 2023, representing a 67-77% reduction achieved simply through planting date adjustment. This phenomenon likely reflects phenological asynchrony between the crop and pest populations. Early planted maize coincides with peak FAW moth emergence and population buildup, creating substantial inoculum pressure. Late-planted crops escape this peak, as their vulnerable early growth stages do not align with major periods of adult activity. These results strongly corroborate findings by **Abd El mageed et al. (2022)** and **Olyme et al. (2022)**.

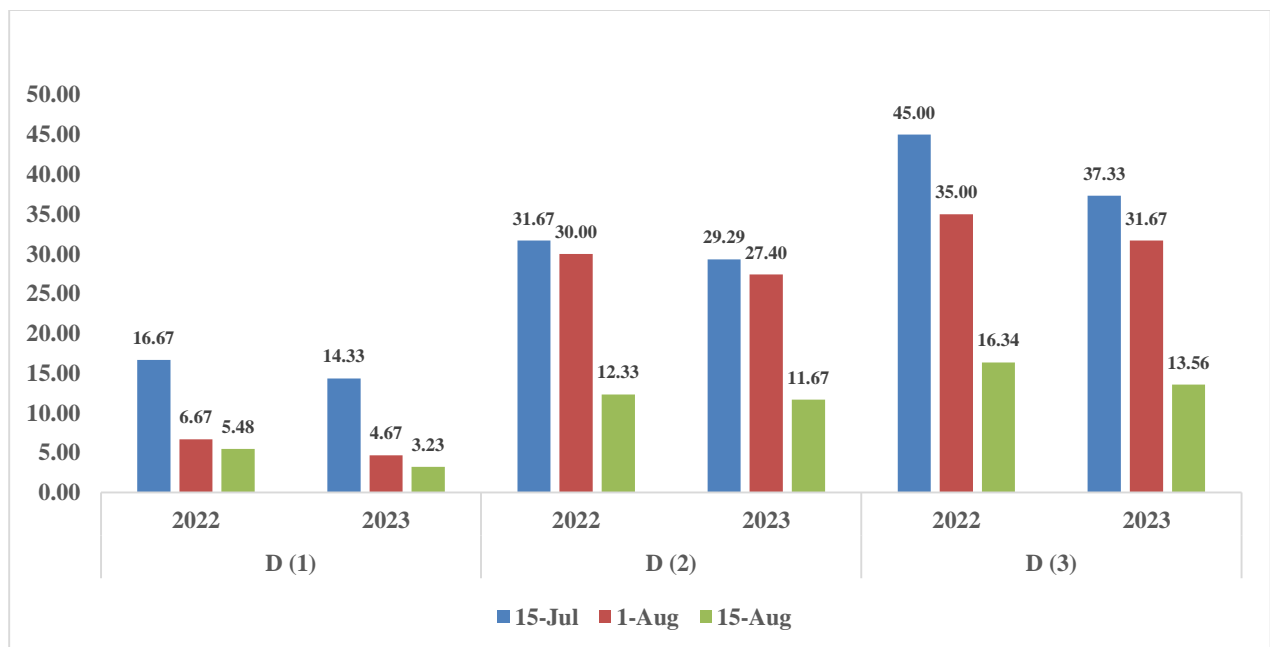
Plant density exhibited a strong positive association with infestation. Higher densities consistently supported greater pest populations. At August 15, 2023, infestation increased progressively from 3.23% at D<sub>1</sub> to 11.67% at D<sub>2</sub>, reaching 13.56% at D<sub>3</sub>. This relationship likely reflects microclimatic modification within denser canopies, which:

- Create more humid conditions favoring larval survival.
- Provide physical protection from natural enemies and environmental extremes.

- May stress host plants through intensified competition, potentially altering their defensive capacity.
- Facilitate larval movement between adjacent plants.

The interaction between factors proved particularly striking. The combination of early sowing (July 15) with high density (D<sub>3</sub>) produced the most severe infestations (45.00% in 2022; 37.33% in 2023)—levels that would almost certainly necessitate intensive insecticide intervention. Conversely, late sowing (August 15) with low density (D<sub>1</sub>) minimized infestation (3.23-5.48%), demonstrates effective cultural suppression.

This interaction presents a clear management trade-off. The yield-maximizing treatment (August 15 + D<sub>3</sub>) resulted in moderate infestation (13.56-16.34%), while the pest-minimizing treatment (August 15 + D<sub>1</sub>) incurred substantial yield penalty (7.90-8.07 t/ha). The intermediate density (D<sub>2</sub>) combined with late sowing may offer the most practical compromise, providing respectable yields (9.17-9.31 t/ha) with moderate infestation levels (11.67-12.33%).



**Fig. (4).** Effect of sowing date and plant density on the percentage of armyworm infestation on maize (%) during the two growing seasons (2022 and 2023)

#### 4. Conclusion

The results demonstrate that both sowing date and plant density significantly influence maize productivity, water use efficiency, and fall-armyworm infestation under the arid conditions of the New Valley Governorate. The principal findings can be summarized as follows:

- For yield maximization, the combination of August 15 sowing with 150,000 plants/ha produced the highest grain yields (10.21-10.26 t/ha) and greatest water use efficiency (1.72 kg/m<sup>3</sup>). This package is appropriate when productivity is the primary objective and pest monitoring and management capacity exist to address moderate FAW pressure (13-16% infestation).

- For pest suppression, the combination of August 15 sowing with 50,000 plants/ha minimized FAW infestation (3.23-5.48%) through effective cultural control, though with substantial yield reduction (7.90-8.07 t/ha).
- The intermediate density of 100,000 plants/ha with August 15 sowing offers a balanced approach, providing favorable yields (9.17-9.31 t/ha) with moderate infestation (11.67-12.33%) and high WUE (1.68-1.70 kg/m<sup>3</sup>). This combination may represent the most sustainable option for farmers seeking to balance multiple production objectives.
- Early sowing (July 15) should be avoided, as it consistently produced lower yields, reduced WUE, and dramatically elevated FAW infestation—reaching 45% at high densities.

These findings provide location-specific guidance for developing adaptive maize production strategies in Egypt's desert frontier areas, contributing to food security objectives under the constraints of climate change and emerging biotic threats.

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