Agrotechniques in Industrial Crops

Journal Homepage: https://atic.razi.ac.ir

Exploring the Impact of Nitrogen and Water Superabsorbent on Agronomic Performance and Nitrogen Uptake in Pumpkin (*Cucurbita pepo*)

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ARTICLE INFO

Original paper

Article history:
Received: x Month 202x
Revised: x Month 202x
Accepted: x Month 202x

Keywords:
Nitrogen
Pumpkin
Superabsorbent

ABSTRACT

This study investigated the effects of nitrogen fertilization and moisture superabsorbent on yield, yield components, seed nitrogen content, and various biological traits of field pumpkin (*Cucurbita pepo*) over two consecutive cropping seasons in Kermanshah, Iran. The experiment was conducted using a split-plot design in a randomized complete block design with three replications. The main factor was the moisture superabsorbent at four levels: 0 (control), 40, 80, and 160 kg ha^{-1}, while nitrogen fertilization at 0, 50, 100, and 150 kg ha^{-1} was the sub-factor. The results indicated that all measured traits, except fruit number, were significantly affected by the treatments. Yield exhibited an increasing trend across all nitrogen levels, though the difference between 100 and 150 kg ha^{-1} nitrogen levels was not statistically significant. Furthermore, the application of moisture superabsorbent had a positive impact on all traits, with higher application rates leading to greater improvements. In conclusion, the study underscores the synergistic effect of nitrogen fertilization and moisture superabsorbent in improving field pumpkin productivity, highlighting their potential for enhancing agricultural practices in water-deficient regions.

DOI: 10.22126/ATIC.2025.11239.1170

1. Introduction

Medicinal plants have been highly valued for their therapeutic properties for centuries. With growing concerns over the side effects of synthetic drugs, interest in natural alternatives is on the rise, resulting in a renewed focus on the use of medicinal plants (Zeng *et al.*, 2023). Among these, the field pumpkin (*Cucurbita pepo* L.) holds notable medicinal significance, particularly in developed countries, where its seed oil is extensively utilized in both traditional and modern medical practices (Peričin *et al*., 2008).

In agriculture, one effective strategy for improving water conservation is the application of superabsorbent materials to soil (Oladosu *et al*., 2022). These materials have been shown to enhance soil moisture retention and nutrient availability, thereby reducing the risk of water and nutrient deficiencies in plants (Efeoğlu *et al*., 2009) and potentially boosting plant performance in arid and semi-arid regions. Nitrogen is a vital nutrient that significantly impacts both the quantity and quality of medicinal plant yields (Maclean *et al*., 2017). For field pumpkin, optimal fresh fruit weight averages 2.61 kg, with a 1000-seed weight of 160.36 g. Maximum fruit and seed yields of 127.00 and 1.51 tons per hectare, respectively, have been observed with a nitrogen application of 200 kg per hectare (Zhao *et al*., 2019).

Research indicates that the highest fruit yields are achieved with 75 kg of nitrogen applied as ammonium nitrate. However, increasing the nitrogen level to 150 kg per hectare results in reduced yields, while further increments to 225 and 300 kg per hectare show negligible or no additional improvement in fruit production over a two-year period (Zhao *et al*., 2019; Hui *et al*., 2021). This decline in yield is attributed to excessive vegetative growth, where nutrients are primarily absorbed by young leaves for photosynthesis. This inhibits the conversion of vegetative buds into reproductive structures, thereby reducing fruit development. Interestingly, Shi et al. (2019) reported a decrease in fruit yield with higher nitrogen levels,

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whereas Truzzi et al. (2022) found that nitrogen supplementation can improve both yield and water-use efficiency. Similarly, Lalnunthari et al. (2019) observed that increasing nitrogen application up to 180 kg per hectare could enhance grain yield in field pumpkin. Generally, the effectiveness of nitrogen fertilizer is highest at lower application rates but diminishes as nitrogen levels increase (Huang *et al*., 2019).

The application of superabsorbents in soil enhances moisture retention and nutrient uptake, promoting improved plant growth and yield, particularly under drought-stress conditions (Islam *et al*., 2011). Research indicates that combining super absorbents with balanced chemical fertilizers (determined through soil testing) and bio-fertilizers yields the best crop performance. These polymers effectively absorb and retain irrigation water, minimize water loss through deep percolation, and improve water use efficiency. Their benefits have been demonstrated in various crops, such as corn under drought conditions, and in ornamental plants like chrysanthemums, where both growth and quality were significantly improved (Jahan *et al*., 2017).

This study focuses on addressing water scarcity and optimizing nitrogen fertilizer use to improve the yield of field pumpkin, a medicinal and industrial crop known for its nutritional and therapeutic value. Given its economic and industrial significance, enhancing field pumpkin yield is crucial. The research examines the combined effects of moisture super absorbents, which enhance soil water retention, and nitrogen fertilizers on crop performance over two growing seasons. The goal is to develop efficient, sustainable agricultural strategies that minimize water and chemical usage while maximizing yields in arid and semi-arid regions.

2. Materials and methods

To evaluate the effects of nitrogen fertilizer and moisture superabsorbent on the yield and yield components of pumpkin (*Cucurbita pepo* L.) this experiment was carried out. Seedlings over two consecutive crop years were cultivated in a research field located in the west of Kermanshah, Iran. The geographical coordinates of the research site are approximately 36° 33' to 36° 34' North latitude and 45° 24' to 48° 30' East longitude.

2.1. Experimental design

The experiment was conducted as a split-plot design in randomized complete block design (RCBD) with three replications. The main factor was four levels of moisture superabsorbent 0 (control), 40, 80, and 160 kg ha^{-1}), and the sub-factor was four nitrogen levels (0, 50, 100, and 150 kg ha^{-1}) on urea fertilizer. This arrangement allowed for the assessment of both main and interaction effects of the measured parameters.

2.2. Field preparation and planting

Field preparation was done in early June and included comprehensive agronomic practices and the application of moisture superabsorbent to improve soil moisture retention capabilities. The following seeds were manually sown in bulk. The specific planting configuration was as follows: planting lines measured 5 meters in length, with a seed spacing of 40 cm and a row 2 meters apart. A one-meter corridor was maintained between main plots and blocks to minimize treatment interference and facilitate management and harvesting activities. To ensure optimal plant density and growth, seedlings were manually thinned at the 4-leaf stage. Weed control was managed manually throughout the growing season.

2.3. Measured traits

The measured traits included fresh and dry weight of fruits, leaves dry weight, stem dry weight, fruit number per plant, grain weight, grain number per fruit and seed nitrogen percentage.

2.4. Statistical analysis

Statistical analysis of the collected data was performed using SPSS which is widely used for agricultural research. A significance level of 5% ($p<0.05$) was considered statistically. When significant differences were identified, means were compared using Duncan's multiple range test (DMRT). Additionally, the interaction effects between nitrogen and moisture superabsorbent levels were thoroughly analyzed to gain insights into their combined impact on the yield components.

3. Results and discussion

3.1. Analysis of variance

The analysis of variance (ANOVA) for the first year (Table 1) shows significant effects of both moisture superabsorbent and nitrogen levels on several measured traits. Superabsorbent treatments had a significant impact on grain number per fruit, grain weight, stem dry weight, leaf dry weight, fruit dry weight, and fruit fresh weight at the 1% probability level, but no significant effect was observed on grain nitrogen content or fruit number per plant (Safavi *et al*., 2016). Nitrogen treatments also showed highly significant effects on most traits, except for fruit number per plant and grain nitrogen content, highlighting the critical role of nitrogen in improving plant biomass and yield components (Khalili and Nejatzadeh, 2021).

Additionally, the interaction between nitrogen and superabsorbent (N × S) was significant for all traits except grain nitrogen content and fruit number per plant, indicating a synergistic relationship between these two factors. The coefficient of variation (CV) ranged from 7.84% to 21.21%, reflecting moderate to high variability among different traits, with the highest variability observed in fruit number per plant (Zeng *et al*., 2023).

Table 1. Analysis of variance of the first year

Source of Variations	Fruit fresh weight	Fruit dry weight	Leaf dry weight	Stem dry weight	Fruit number per plant	Grain weight	Grain number per fruit	Grain nitrogen percentage
Replication	1.44	43719.56	20379.34	5876.15	0.06	599.91	1907.65	0.015
Superabsorbent	3.119*	197776.2**	560859.438**	351883.319**	2.243ns	516592.477**	43906.743**	0.227ns
Error 1	0.56	44015	8215.46	4513.91	0.7	551.91	8072.87	0.0001
Nitrogen	5.288*	323448.746**	2696.619**	38015.64**	1.632ns	48246.026**	86032.576**	1.1**
N × S	8.249*	106970.921**	7752.652**	2064.321**	4.706ns	12355.43**	122577.428**	0.1**
Error 2	1.40	3868.96	1810.12	771.67	1.04	2110.92	8262.84	0.01
CV (%)	21.11	7.84	13.19	10.43	21.21	13.91	13.18	13.91

ns, *, and ** are non-significant and significant at the probability levels 0.05 and 0.01, respectively.

The analysis of variance (ANOVA) for the first year (Table 1) revealed significant effects of both moisture superabsorbent and nitrogen levels on several measured traits. Superabsorbent treatments significantly influenced grain number per fruit, grain weight, stem dry weight, leaf dry weight, fruit dry weight, and fruit fresh weight at the 1% probability level. However, no significant effects were observed on grain nitrogen percentage or fruit number per plant (Safavi *et al*., 2016).

Nitrogen treatments also had highly significant effects on most traits, except for fruit number per plant and grain nitrogen percentage, indicating nitrogen's essential role in improving plant biomass and yield components (Khalili and Nejatzadeh, 2021). Furthermore, the interaction between nitrogen and superabsorbent (N × S) was significant for all traits except grain nitrogen percentage and fruit number per plant, suggesting a synergistic effect between these two factors. The coefficient of variation (CV) values ranged from 7.84% to 21.21%, reflecting moderate to high variability across traits, with the highest variability observed in fruit number per plant (Zeng *et al*., 2023).

The ANOVA results for the second year (Table 2) showed similar trends. Moisture superabsorbent significantly affected most traits at the 1% probability level, including grain number per fruit, grain weight, stem dry weight, leaf dry weight, fruit dry weight, and fruit fresh weight. Nitrogen treatments also significantly influenced these traits, except for fruit number per plant and grain nitrogen percentage. The interaction between nitrogen and superabsorbent remained significant for all traits except grain nitrogen percentage and fruit number per plant, mirroring the findings of the first year.

Superabsorbent polymers (SAP) and modified natural polymer hydrogels are increasingly being used in various fields, including agriculture, healthcare textiles, wastewater treatment, drug delivery, tissue engineering, and civil engineering. However, comprehensive reviews on this class of innovative polymers are limited. A detailed review of the applications of SAPs would greatly benefit researchers, industry professionals, and those in medical, healthcare, and agricultural sectors (Venkatachalam and Kaliappa, 2021).

These findings indicate that combining nitrogen fertilizer with moisture superabsorbent consistently enhances yield-related traits. The CV values in the second year were slightly lower for some traits, particularly grain nitrogen percentage (5.91%), indicating improved consistency in the second year's results. Overall, the second-year data confirmed the positive effects of both nitrogen and superabsorbent on field pumpkin yield and biomass production (Rico *et al*., 2020). Gallardo et al. (2011) evaluated the VegSyst model for muskmelon to simulate crop growth, nitrogen uptake, and evapotranspiration, further highlighting the potential of integrated approaches to optimize crop performance.

Table 2. Analysis of variance of the second year

Source of Variations	Fruit fresh weight	Fruit dry weight	Leaf dry weight	Stem dry weight	Fruit number per plant	Grain weight	Grain number per fruit	Grain nitrogen percentage
Replication	0.35	38835.31	43564.67	6379.32	0.02	1276.67	6953.52	0.02
Superabsorbent	2.95*	324820.43**	672431.87**	432652.45**	3.18*	4570.91**	69348.02**	0.42**
Error 1	0.45	14327.42	7535.57	7516.65	0.4	457.61	8072.87	0.001
Nitrogen	6.21*	2278620.34**	3494.78**	42194.61**	2.24*	12445.05**	86032.57**	1.15**
N × S	9.27*	82276.38**	8645.95**	2473.48**	4.26**	3095.67**	122577.42**	0.001**
Error 2	0.87	5880.29	20.14	892.79	0.98	3654.67	8377.52	0.01
CV (%)	18.08	6.37	15.32	12.34	20.24	14.34	12.56	11.57

ns, *, and ** are non-significant and significant at the probability levels 0.05 and 0.01, respectively.

3.2. Fruit fresh weight

The findings reveal that the application of superabsorbent polymers and nitrogen, both individually and in combination, significantly influenced fresh fruit weight over the two-year experimental period. The highest average fresh fruit weight (1776 g) was recorded with the application of 120 kg ha^{-1} of superabsorbent combined with 150 kg ha^{-1} of nitrogen, representing a remarkable 57% increase compared to the control. This improvement highlights the synergistic effects of enhanced moisture retention from the superabsorbent and increased nitrogen availability, which together promote vigorous vegetative growth and contribute to higher fresh fruit yields (Gallardo *et al*., 2011; Venkatachalam and Kaliappa, 2021). No significant difference in fresh fruit weight was observed when lower superabsorbent rates (40 and 80 kg ha^{-1}) were combined with nitrogen levels of 100 and 150 kg ha^{-1}, suggesting that exceeding certain input thresholds may not result in additional gains in fruit weight. The increase in fresh fruit weight at higher nitrogen and superabsorbent levels can be attributed to improved moisture retention and nutrient availability, particularly nitrogen, which is essential for vegetative growth and fruit biomass accumulation (Fig. 1). These findings align with previous studies, such as those by Huang et al. (2019) and Bannayan et al. (2011), which also reported increased fruit weight in field pumpkin with higher nitrogen applications.

3.3. Fruit dry weight

The findings indicate that fruit dry weight was significantly affected by the application of superabsorbent polymers, nitrogen, and their combination. The highest average dry weight (8.283 g) was observed with 120 kg ha^{-1} of superabsorbent and 150 kg ha^{-1} of nitrogen, resulting in a 73% increase compared to the control. This trend suggests that as nitrogen levels increased alongside varying superabsorbent applications, fruit dry weight also significantly increased. In contrast, no significant differences in dry weight were observed among the control, 40, and 80 kg ha^{-1} superabsorbent treatments when combined with 50, 100, or 150 kg ha^{-1} of nitrogen (Fig. 2) (Rico *et al*., 2020). These results align with previous studies by Lalnunthari et al. (2019) and Zheng et al. (2023), which also found that higher nitrogen levels in field pumpkin positively influenced fresh weight and overall fruit biomass.

3.4. Leaf dry weight

The findings show that the application of superabsorbent polymers, nitrogen, and their combination significantly impacted leaf dry weight. The highest leaf dry weight recorded (329.2 g) occurred with the combined application of 120 kg ha^{-1} superabsorbent and 150 kg ha^{-1} nitrogen (N), representing an approximately 91% increase compared to the control. This increase in leaf dry weight corresponds with rising levels of both superabsorbent and nitrogen, likely resulting from enhanced overall plant biomass due to improved nitrogen availability and moisture retention (Fig. 3). These results are consistent with earlier studies by Hui et al. (2021) and Naderi et al. (2017), which also observed similar increases in leaf biomass under comparable conditions.

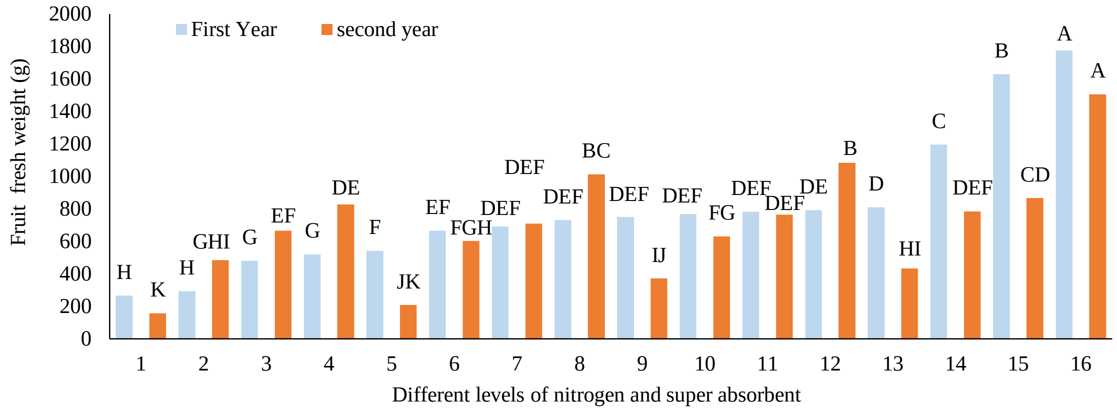

Figure 1. Mean comparison of fruit fresh weight. Means followed by the same letters in each column are not significantly different at 5% (by DMRT). 1: Nitrogen 0 + Super Adsorbent 0; 2: Nitrogen 0 + Super Adsorbent 50; 3: Nitrogen 0 + Super Adsorbent 100; 4: Nitrogen 0 + Super Adsorbent 150; 5: Nitrogen 40 + Super Adsorbent 0; 6: Nitrogen 40 + Super Adsorbent 50; 7: Nitrogen 40 + Super Adsorbent 100; 8: Nitrogen 40 + Super Adsorbent 150; 9: Nitrogen 80 + Super Adsorbent 0; 10: Nitrogen 80 + Super Adsorbent 50; 11: Nitrogen 80 + Super Adsorbent 100; 12: Nitrogen 80 + Super Adsorbent 150; 13: Nitrogen 120 + Super Adsorbent 0; 14: Nitrogen 120 + Super Adsorbent 50; 15: Nitrogen 120 + Super Adsorbent 100; 16: Nitrogen 120 + Super Adsorbent 150.

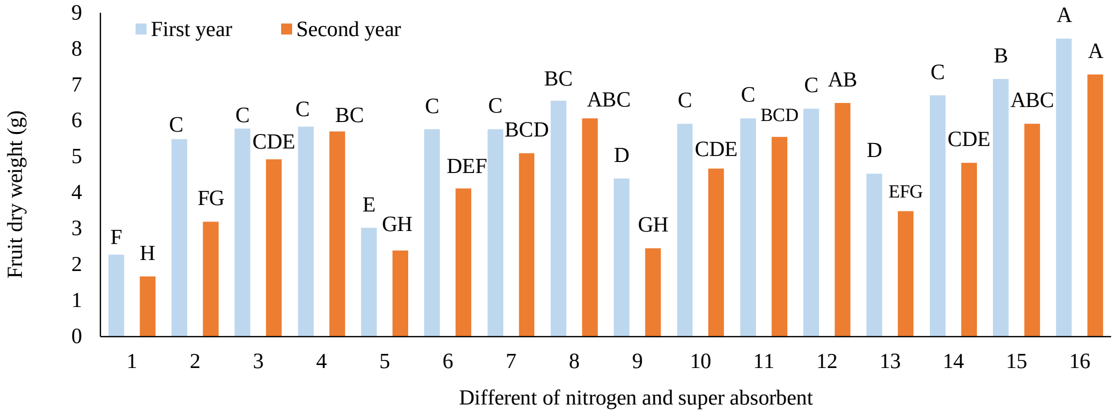

Figure 2. Mean comparison of fruit dry weight. Means followed by the same letters in each column are not significantly different at 5% (by DMRT). 1: Nitrogen 0 + Super Adsorbent 0; 2: Nitrogen 0 + Super Adsorbent 50; 3: Nitrogen 0 + Super Adsorbent 100; 4: Nitrogen 0 + Super Adsorbent 150; 5: Nitrogen 40 + Super Adsorbent 0; 6: Nitrogen 40 + Super Adsorbent 50; 7: Nitrogen 40 + Super Adsorbent 100; 8: Nitrogen 40 + Super Adsorbent 150; 9: Nitrogen 80 + Super Adsorbent 0; 10: Nitrogen 80 + Super Adsorbent 50; 11: Nitrogen 80 + Super Adsorbent 100; 12: Nitrogen 80 + Super Adsorbent 150; 13: Nitrogen 120 + Super Adsorbent 0; 14: Nitrogen 120 + Super Adsorbent 50; 15: Nitrogen 120 + Super Adsorbent 100; 16: Nitrogen 120 + Super Adsorbent 150.

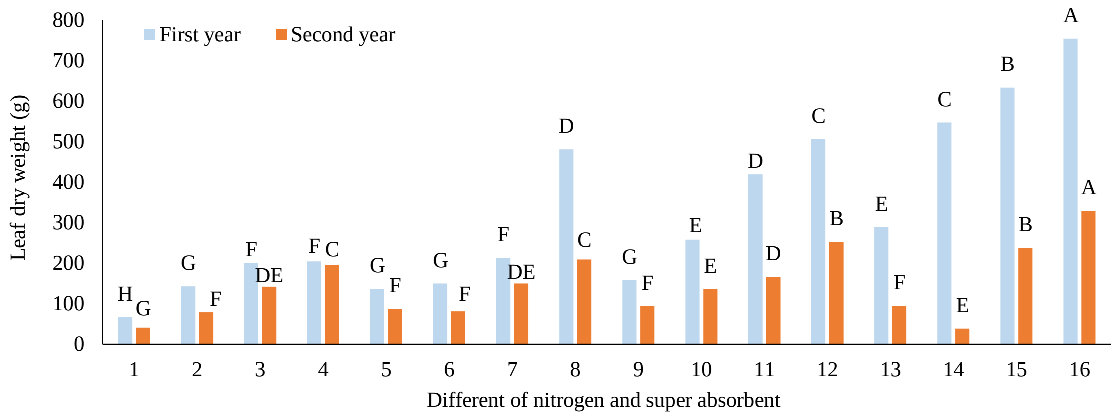

Figure 3. Mean comparison of leaf dry weight. Means followed by the same letters in each column are not significantly different at 5% (by DMRT). 1: Nitrogen 0 + Super Adsorbent 0; 2: Nitrogen 0 + Super Adsorbent 50; 3: Nitrogen 0 + Super Adsorbent 100; 4: Nitrogen 0 + Super Adsorbent 150; 5: Nitrogen 40 + Super Adsorbent 0; 6: Nitrogen 40 + Super Adsorbent 50; 7: Nitrogen 40 + Super Adsorbent 100; 8: Nitrogen 40 + Super Adsorbent 150; 9: Nitrogen 80 + Super Adsorbent 0; 10: Nitrogen 80 + Super Adsorbent 50; 11: Nitrogen 80 + Super Adsorbent 100; 12: Nitrogen 80 + Super Adsorbent 150; 13: Nitrogen 120 + Super Adsorbent 0; 14: Nitrogen 120 + Super Adsorbent 50; 15: Nitrogen 120 + Super Adsorbent 100; 16: Nitrogen 120 + Super Adsorbent 150.

3.5. Stem dry weight

The study revealed that the application of superabsorbent polymers, nitrogen (N), and their combined use significantly affected stem dry weight across the two-year experimental period. The highest stem dry weight (595.5 g) was observed with the combined treatment of 120 kg ha^{-1} superabsorbent and 150 kg ha^{-1} nitrogen. Favorable environmental conditions further contributed to this notable increase in stem dry biomass under these treatments (Fig. 4). Similar approaches were reported for biomass responses to nitrogen and superabsorbent treatments in plant studies (Jahan *et al*., 2017; Malik *et al*., 2022).

3.6. Fruit number per plant

In the first year of the experiment, neither the main effects of superabsorbent nor nitrogen on fruit count per plant were statistically significant. However, in the second year, both the main effects and their interaction became significant. The highest average fruit count (6.7) was recorded with the application of 150 kg ha^{-1} nitrogen (N) combined with 120 kg ha^{-1} superabsorbent, although no significant differences were observed among the 50, 100, and 150 kg ha^{-1} nitrogen treatments.

The control group consistently yielded the lowest fruit count. Furthermore, across the different superabsorbent levels, no notable differences were found between the 100 and 150 kg ha^{-1} nitrogen treatments in both years. The minimal impact of nitrogen levels and superabsorbent on fruit count per plant suggests that this trait is primarily genetically determined and shows limited responsiveness to environmental factors (Fig. 5). These findings are consistent with those of Jahan et al. (2017) and Ashraf et al. (2021), who reported similar results.

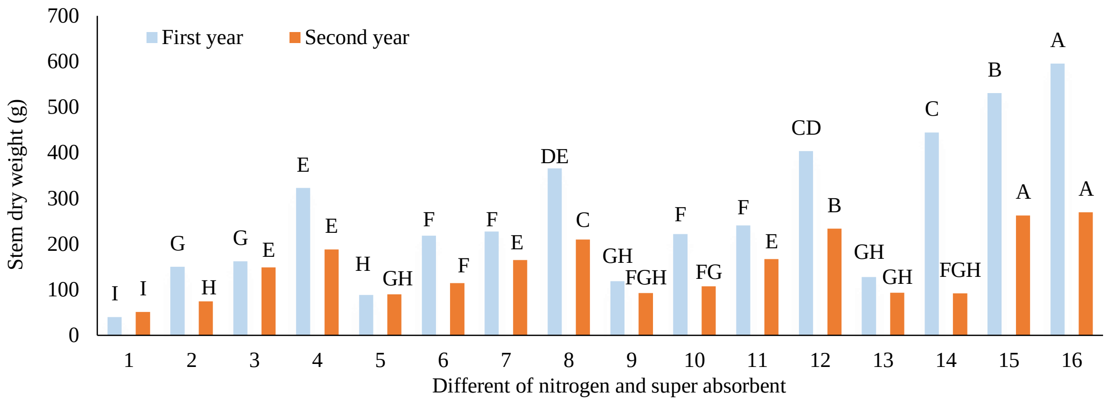

Figure 4. Mean comparison of stem dry weight. Means followed by the same letters in each column are not significantly different at 5% (by DMRT). 1: Nitrogen 0 + Super Adsorbent 0; 2: Nitrogen 0 + Super Adsorbent 50; 3: Nitrogen 0 + Super Adsorbent 100; 4: Nitrogen 0 + Super Adsorbent 150; 5: Nitrogen 40 + Super Adsorbent 0; 6: Nitrogen 40 + Super Adsorbent 50; 7: Nitrogen 40 + Super Adsorbent 100; 8: Nitrogen 40 + Super Adsorbent 150; 9: Nitrogen 80 + Super Adsorbent 0; 10: Nitrogen 80 + Super Adsorbent 50; 11: Nitrogen 80 + Super Adsorbent 100; 12: Nitrogen 80 + Super Adsorbent 150; 13: Nitrogen 120 + Super Adsorbent 0; 14: Nitrogen 120 + Super Adsorbent 50; 15: Nitrogen 120 + Super Adsorbent 100; 16: Nitrogen 120 + Super Adsorbent 150.

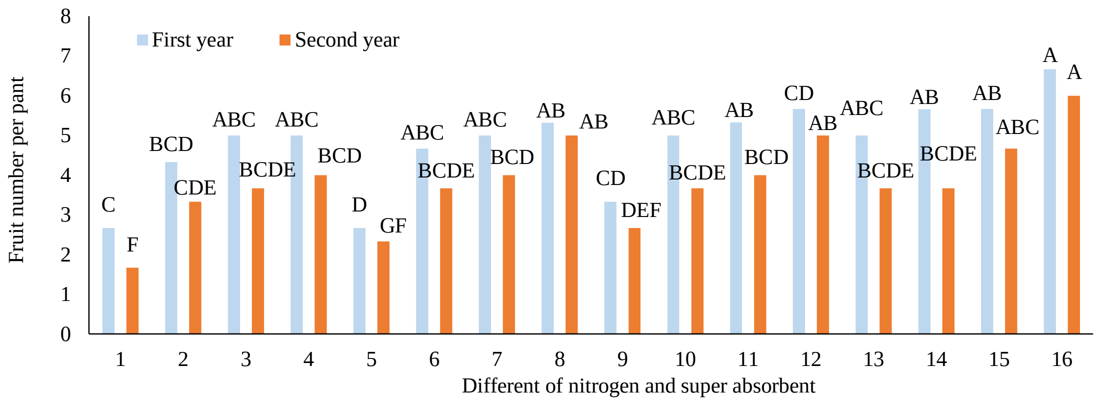

Figure 5. Mean comparison of fruit number per plant. Means followed by the same letters in each column are not significantly different at 5% (by DMRT). 1: Nitrogen 0 + Super Adsorbent 0; 2: Nitrogen 0 + Super Adsorbent 50; 3: Nitrogen 0 + Super Adsorbent 100; 4: Nitrogen 0 + Super Adsorbent 150; 5: Nitrogen 40 + Super Adsorbent 0; 6: Nitrogen 40 + Super Adsorbent 50; 7: Nitrogen 40 + Super Adsorbent 100; 8: Nitrogen 40 + Super Adsorbent 150; 9: Nitrogen 80 + Super Adsorbent 0; 10: Nitrogen 80 + Super Adsorbent 50; 11: Nitrogen 80 + Super Adsorbent 100; 12: Nitrogen 80 + Super Adsorbent 150; 13: Nitrogen 120 + Super Adsorbent 0; 14: Nitrogen 120 + Super Adsorbent 50; 15: Nitrogen 120 + Super Adsorbent 100; 16: Nitrogen 120 + Super Adsorbent 150.

3.7. Grain weight

The results indicated that superabsorbent polymers, nitrogen (N), and their combined application significantly affected grain weight over the two-year study period. The highest grain weight (791.2 g) was observed with the combined application of 150 kg ha^{-1} nitrogen and 120 kg ha^{-1} superabsorbent, while the control group recorded the lowest values. This increase in grain weight can be attributed to improved seed storage capacity, facilitated by the higher nitrogen levels and moisture availability from the superabsorbent (Fig. 6). These findings align with previous studies by Safavi et al. (2016), and Esmaeili and Danaeifar (2023), which reported similar results in pumpkin research.

3.8. Grain number per plant

The application of superabsorbent polymers, nitrogen (N), and their interaction significantly affected the number of grains per plant over both years of the study. Mean comparisons revealed that the highest grain number per plant (1153) was achieved with the combined treatment of 150 kg ha^{-1} nitrogen and 120 kg ha^{-1} superabsorbent each year (Fig. 7). These findings are consistent with reports from several researchers (Chen *et al*., 2019).

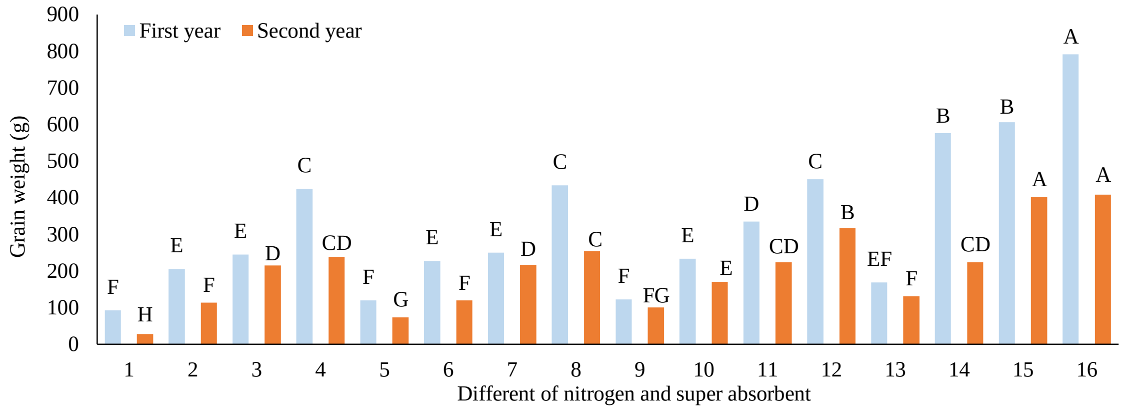

Figure 6. Mean comparison of grain weight. Means followed by the same letters in each column are not significantly different at 5% (by DMRT). 1: Nitrogen 0 + Super Adsorbent 0; 2: Nitrogen 0 + Super Adsorbent 50; 3: Nitrogen 0 + Super Adsorbent 100; 4: Nitrogen 0 + Super Adsorbent 150; 5: Nitrogen 40 + Super Adsorbent 0; 6: Nitrogen 40 + Super Adsorbent 50; 7: Nitrogen 40 + Super Adsorbent 100; 8: Nitrogen 40 + Super Adsorbent 150; 9: Nitrogen 80 + Super Adsorbent 0; 10: Nitrogen 80 + Super Adsorbent 50; 11: Nitrogen 80 + Super Adsorbent 100; 12: Nitrogen 80 + Super Adsorbent 150; 13: Nitrogen 120 + Super Adsorbent 0; 14: Nitrogen 120 + Super Adsorbent 50; 15: Nitrogen 120 + Super Adsorbent 100; 16: Nitrogen 120 + Super Adsorbent 150.

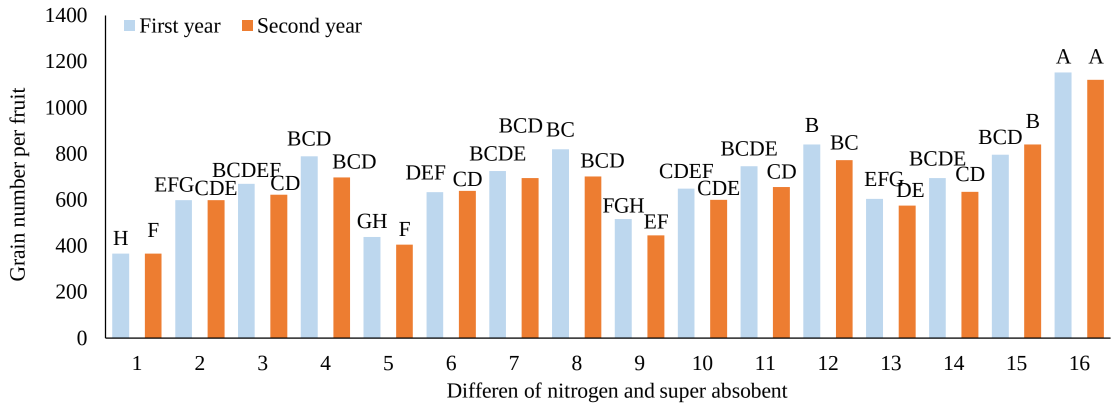

Figure 7. Mean comparison of grain number per plant. Means followed by the same letters in each column are not significantly different at 5% (by DMRT). 1: Nitrogen 0 + Super Adsorbent 0; 2: Nitrogen 0 + Super Adsorbent 50; 3: Nitrogen 0 + Super Adsorbent 100; 4: Nitrogen 0 + Super Adsorbent 150; 5: Nitrogen 40 + Super Adsorbent 0; 6: Nitrogen 40 + Super Adsorbent 50; 7: Nitrogen 40 + Super Adsorbent 100; 8: Nitrogen 40 + Super Adsorbent 150; 9: Nitrogen 80 + Super Adsorbent 0; 10: Nitrogen 80 + Super Adsorbent 50; 11: Nitrogen 80 + Super Adsorbent 100; 12: Nitrogen 80 + Super Adsorbent 150; 13: Nitrogen 120 + Super Adsorbent 0; 14: Nitrogen 120 + Super Adsorbent 50; 15: Nitrogen 120 + Super Adsorbent 100; 16: Nitrogen 120 + Super Adsorbent 150.

3.9. Grain nitrogen content

The results indicated that the application of superabsorbent and nitrogen significantly affected the nitrogen content (76.15) in the grains. Mean comparison analysis revealed that the highest nitrogen percentage in the grains was observed with the combined treatment of 150 kg ha^{-1} nitrogen and 120 kg ha^{-1} superabsorbent, while the control treatment showed the lowest nitrogen percentage. This increase in nitrogen concentration is likely due to higher nitrogen uptake, with part of it being absorbed and stored in the seeds, thereby enhancing the nitrogen content in the grains (Fig. 8). These findings are consistent with those reported by Khalili and Nejatzadeh (2021) and Li et al. (2022).

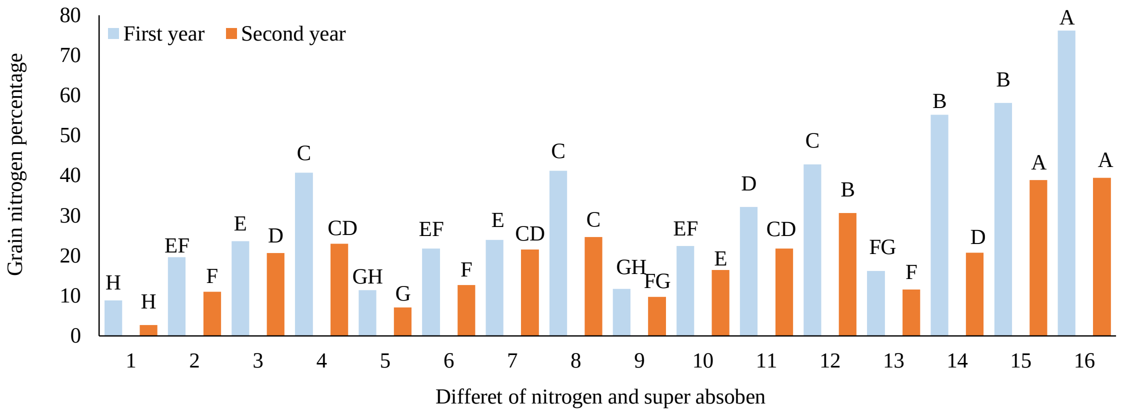

Figure 8. Mean comparison of grain nitrogen content. Means followed by the same letters in each column are not significantly different at 5% (by DMRT). 1: Nitrogen 0 + Super Adsorbent 0; 2: Nitrogen 0 + Super Adsorbent 50; 3: Nitrogen 0 + Super Adsorbent 100; 4: Nitrogen 0 + Super Adsorbent 150; 5: Nitrogen 40 + Super Adsorbent 0; 6: Nitrogen 40 + Super Adsorbent 50; 7: Nitrogen 40 + Super Adsorbent 100; 8: Nitrogen 40 + Super Adsorbent 150; 9: Nitrogen 80 + Super Adsorbent 0; 10: Nitrogen 80 + Super Adsorbent 50; 11: Nitrogen 80 + Super Adsorbent 100; 12: Nitrogen 80 + Super Adsorbent 150; 13: Nitrogen 120 + Super Adsorbent 0; 14: Nitrogen 120 + Super Adsorbent 50; 15: Nitrogen 120 + Super Adsorbent 100; 16: Nitrogen 120 + Super Adsorbent 150.

4. Conclusion

The findings of this study demonstrated that the application of superabsorbent materials and nitrogen (N) significantly influenced various seed production and quality characteristics in medicinal crops, such as field pumpkin. Specifically, the optimal combination of 150 kg ha^{-1} nitrogen and 120 kg ha^{-1} superabsorbent resulted in the highest seed weight, fruit number, and nitrogen percentage in the grains.

The increased use of nitrogen and superabsorbent materials contributed to improved moisture retention and provided the necessary nitrogen for plant growth, which, in turn, enhanced fruit weight and seed quality. Moreover, the positive impact of superabsorbent materials on soil moisture retention is particularly significant in arid and semi-arid regions, underscoring their potential to optimize water and nitrogen management for sustainable agriculture.

Therefore, it is recommended that farmers and producers incorporate these materials into their nutrient management strategies to improve the yield and quality of medicinal crops. These results can serve as a scientific guideline for enhancing cultivation practices and strengthening the quality of medicinal products worldwide.

Conflict of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics approval and consent to participate

No humans or animals were used in the present research. The authors have adhered to ethical standards, including avoiding plagiarism, data fabrication, and double publication.

Consent for publications

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and material

The datasets used and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' contributions

MJ: Investigation, Methodology, Data curation, Formal analysis, Visualization, Validation, Software, Writing – original draft. MJ: Investigation, Methodology, Data curation, Formal analysis, Visualization, Validation, Software, Writing – original draft. KHG: Supervision, Funding administration, Writing – review & editing.

Informed consent

The authors declare not to use any patients in this research.

Funding/Support

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. All research activities and the writing of this manuscript were independently conducted by the authors without any financial support. Additionally, none of the authors have any financial conflicts of interest that could have influenced the outcomes of this research.

Acknowledgement

We would like to express our gratitude to the Agricultural and Natural Resources Research and Education Center (AREEO) of Kermanshah Province for providing the necessary facilities.

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HOW TO CITE THIS ARTICLE

Amjadian M., Jahan M., Hajmohammadnia Ghalibaf K. 202x. Exploring the Impact of Nitrogen and Water Superabsorbent on Agronomic Performance and Nitrogen Uptake in Pumpkin (*Cucurbita pepo*). *Agrotechniques in Industrial Crops* x(x): xx-xx. 10.22126/ATIC.2025.11239.1170