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The Effect of Planting Date and Different Amounts of Nitrogen and Phosphorus Chemical Fertilizers on Biochemical Traits and Seed Yield of Lallemantia (*Lallemantia iberica*)

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ABSTRACT

This study investigated the effects of planting date and nitrogen-phosphorus fertilizer levels on the physiological, morphological, and biochemical traits of *Lallemantia iberica* (Balango) at a medicinal plant farm in Azna County, Lorestan Province, Iran. The experiment utilized a two-factor factorial design within a randomized complete block design (RCBD) with three replications. The factors included two planting dates (Autumn: November 1; Spring: March 1) and three fertilizer levels (Control: no fertilizer; 50%: 50 kg ha^{-1}; 100%: 100 kg ha^{-1}). Key findings from the variance analysis revealed that the interaction between planting date and fertilizer levels significantly influenced protein and nitrogen yield, total carbohydrate content, mucilage percentage, thousand-grain weight, and seed yield at the 1% probability level. Phosphorus yield was affected by planting date at the 5% level and by fertilizer amount at the 1% level. Spring planting with full fertilizer (100 kg ha^{-1}) resulted in the highest grain nitrogen yield (1.92%), mucilage percentage (7.66%), and thousand-grain weight (2 g). Autumn planting with half fertilizer (50 kg ha^{-1}) achieved the highest grain protein content (9.85%), total carbohydrate content (80.18 ppm), and seed yield (1065.06 kg ha^{-1}). Autumn planting with full fertilizer led to the highest grain phosphorus content (7.07 ppm). The interaction between autumn planting and half-fertilizer also produced a high mucilage percentage (7.4%) and thousand-grain weight (1.97 g). Generally, it is recommended to apply 50% of the fertilizer during the autumn planting season to optimize the cultivation of the Balango plant in the desired area, as it balances yield and biochemical quality while conserving resources. This study provides valuable insights for optimizing cultivation practices to enhance the productivity and quality of this medicinal plant.

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1. Introduction

Plants belonging to the mint family (Lamiaceae) are known to be one of the largest plant families. The majority of species in this family have herbaceous vegetation with sturdy stems, and they tend to thrive in dry and barren habitats (Haas *et al*., 2024). These plants can be classified as terrestrial plants, specifically xerophytes (Paravar *et al*., 2021). The presence of effective ingredients in medicinal plants makes their use important, and controlling the amount of water on the root surface can contribute to enhancing the quality and quantity of effective substances in medicinal plants (Ahmadian *et al*., 2011). Balango (Lallemantia) is a one-year herbaceous plant from the mint family, and its seeds contain oil. There are four species of this plant, namely *L. iberica*, *L. canescens*, *L. peltata*, and *L. royleana*. In Iran, the cultivation of *L. iberica* and *L. royleana* species is more popular (Paravar *et al*., 2022). Balango seeds contain approximately 20 to 28% oil, consisting of linolenic, linoleic, stearic, oleic, and palmitic fatty acids (Paravar *et al*., 2023). Balango oil has multiple uses, including the prevention of colon cancer, breast cancer, liver disorders, kidney diseases, and digestive pains. It has also been found effective in

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treating kidney and bladder stones, healing wounds, and relieving coughs caused by colds, according to observations in traditional medicine (Bano *et al*., 2024). Environmental factors, like temperature during growth and seed formation on the maternal plant, have the potential to impact the quality of seeds (Nguyen *et al*., 2021). Moreover, delays in planting, as well as disruptions in seed formation, growth, and ripening processes, can significantly alter the plant's developmental trajectory. Under limited water availability, soil nutrient deficiency, and reduced moisture retention, the plant's physiological efficiency is markedly reduced, leading to a decline in seed production. This reduction is attributed to the insufficient availability of essential nutrients, limited moisture accessibility, and exposure to elevated temperatures. Consequently, seed vigor is directly and indirectly compromised by a combination of abiotic stresses, such as drought and heat, as well as biotic factors, including pests and diseases, which collectively impair the plant's overall productivity and resilience (Bouremani *et al*., 2023). Changes in seed quality on the mother plant depend on various factors. These factors include cultivars, the intensity and duration of environmental conditions, the stage of seed maturation and growth, harvest time, and the cumulative impact of these factors (Li *et al*., 2017).

Climatic changes can significantly impact the production and potency of medicinal plants. To ensure maximum performance, it is essential to select the appropriate planting date and provide optimal nutrition for producing vigorous soybean seeds (Farahani *et al*., 2011). On the other hand, the optimal planting time in plants is crucial and is a significant factor in achieving maximum potential yield in canola seed production and dry matter accumulation (Begna and Angadi, 2016).

In a study conducted by Waliullah et al. (2021), it was emphasized that the determination of the planting date is crucial in order to identify the most suitable time for planting particular genotypes or varieties of plants to prevailing environmental conditions during planting promotes the survival and growth of seedlings of black cumin, thereby resulting in enhanced production. By planting at the optimal time, a solid groundwork is established for the seeds, making them better equipped to adapt to the surrounding environment and ultimately increasing the overall crop yield. According to Ahmadi and Maleki Farahani (2021), the planting date had a significant impact on the yield of Balango seeds. Specifically, delaying the planting date to April, in comparison to planting in March, resulted in plants with lower altitude and less dry matter production. In the study on the effects of planting date, the report by Karimi Jalilehvandi et al. (2017) found that the optimal planting date significantly affected the duration of seed filling, the increase in weight of thousand seeds, and the dry matter yield of *Lallemantia* plants.

Nitrogen and phosphorus are crucial elements in the vital functions of plants. Nitrogen plays an essential role in the synthesis of chlorophyll, amino acids, nucleic acids, and plant enzymes. Meanwhile, phosphorus promotes stem growth and strength. Additionally, phosphorus aids in root growth, fruit formation, seed development, and the structure of DNA and RNA, as it forms bonds with phosphorus. Furthermore, the concentration of phosphorus in the root contributes to establishing a balance of low-use elements in the leaf (Farahani *et al*., 2011). In another study, Kozera et al. (2013) reported that the use of nitrogen and phosphorus chemical fertilizers significantly increased seed yield in European black cumin. According to the study conducted by Yimam et al. (2015), the treatment of 60 kg of nitrogen fertilizer and 40 kg of phosphorus fertilizer per hectare resulted in higher yields of black cumin compared to the control treatment.

Despite extensive research on agronomic practices for conventional crops, there remains a significant knowledge gap regarding optimal cultivation protocols for medicinal plants, particularly Dreagon head or Balango. Existing studies have largely overlooked the interactive effects of planting dates and reduced fertilizer application on both yield components and medicinal quality traits in this species. Furthermore, there is insufficient data on how seasonal growth periods influence nutrient use efficiency and secondary metabolite production in semi-arid regions like western Iran. This study addresses these critical gaps through a comprehensive investigation with important scientific and practical implications. The research provides novel insights into Balango's physiological responses to nutrient management while establishing evidence-based recommendations for sustainable cultivation. From a scientific perspective, this work advances understanding of medicinal plant physiology under different growing conditions. Practically, it delivers actionable guidelines for optimizing both productivity and medicinal quality in Balango cultivation. The results establish a valuable framework that could be adapted for other underutilized medicinal species in similar agroecological zones, while promoting sustainable agricultural practices in semi-arid regions. Future research should explore long-term soil health impacts and economic viability of the proposed cultivation system.

2. Materials and methods

This experiment was conducted in the Japleq region of Azna County, Lorestan Province, Iran during the 2018-2019 growing season. The experimental site was located at an altitude of 1870 meters above sea level. The average temperature and precipitation during the growth period are presented in Table 1, while the physical and chemical properties of the soil are detailed in Table 2.

Table 1. Average temperature and precipitation during the year 2018-2019

Weather condition	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Temperature	24.5	20	14	1	9	15	21	24	29
Monthly rainfall (ml)	25	32	80	48	27	25	35	30	18

Table 2. Characteristics of farm soil in the depth of 0 to 30 cm of farm soil

Fe	Zn	P	EC ($ds.m^{-1}$)	pH	Organic matter	N	Sand	Silt	Clay
($mg\ kg^{-1}$)					(%)				
2.4	0.92	8.6	3.1	7.3	0.29	0.05	50	25	25

The experiment utilized a two-factor factorial design within a randomized complete block design (RCBD) with three replications. The factors included two planting dates (Autumn: November 1; Spring: March 1) and three fertilizer levels (Control: no fertilizer; 50%: 50 kg ha^{-1}; 100%: 100 kg ha^{-1}). Additionally, three levels of phosphorus fertilizer were applied: no fertilizer, 50% fertilizer (70 kg ha^{-1} P_2O_5), and 100% fertilizer (140 kg ha^{-1} P_2O_5). The fertilizers used in this study, namely nitrogen (urea) and triple superphosphate (TSP), were procured from Green Biotech Company (Zist Fanavar Sabz in Persian). Land preparation for autumn planting was completed on October 30, 2018, while spring planting was carried out on March 1, 2019. Balango seeds, obtained from Pakanbazr Seed Co. in Isfahan, Iran, were sown on the specified dates. The seeds were planted in two rows at a depth of three centimeters, with a row spacing of 30 centimeters. Urea fertilizer was applied in two stages: the first application was during planting, and the second was at the eight-leaf stage. Phosphorus fertilizer (P_2O_5) was applied at the time of seed sowing.

Thinning was performed between May 20 and May 25, 2019, by increasing the spacing between plant stems to remove excess plants. After the completion of the plant growth cycle, sampling was conducted at specific intervals to measure the desired traits. During the flowering stage, 30 plants at the same developmental stage were selected for sampling. From the beginning of flowering until seed maturation, sampling was carried out at seven-day intervals, with five plants sampled from each plot at each interval. Sampling was performed on the main stem of each plant. At the end of the experiment, the following traits were measured from the harvested seeds.

2.1. Measurement of nitrogen content and protein percentage

The protein concentration was determined using a dry ashing digestion method followed by nitrogen quantification via the Kjeldahl method (Chapman and Pratt, 1962). Briefly, 1 g of plant material was ashed in an electric furnace, and the resulting ash was dissolved in 10 mL of hydrochloric acid (Equation 1). The nitrogen content was then measured using the Kjeldahl method, which serves as a basis for calculating protein concentration (Equation 2).

(1) $\%Protein = N \times 6.25$

(2) $\%N = 1.4008 \times 0.1 \times (Vs - Vb) / m$

Where N represents the nitrogen content; V_s is the volume of acid (usually 0.1 N HCl or H_2SO_4) consumed during sample titration (in mL), and V_b is the volume of acid consumed during blank titration (in mL), which corrects for any nitrogen contamination arising from reagents or solvents. The value 0.1 refers to the normality of the acid used, and should be adjusted accordingly if a different normality is applied. The constant 1.4008 is derived from the atomic weight of nitrogen (14.008 g mol^{-1}) and relevant unit conversions, based on the expression (100×14.008)/1000, which accounts for conversions to percentage and from milliliters to liters. Finally, m denotes the mass of the sample, expressed in grams (g).

2.2. Phosphorus measurement

Ash deposition was performed following the method described by Wilson (1983) as follows: First, the crucible was placed in an oven set at 110°C for 4 hours. Afterward, weigh the crucible. Then, two grams of the dried plant sample were placed inside the crucible .The crucible is placed inside the electric furnace for three hours at a temperature of 600°C. At the end, the crucible is weighed, and the amount of ash is determined by calculating the difference in weight of the crucibles. Then, ten milliliters of 2N HCl were added to each crucible and placed on the heater to be digested by boiling (temperature 30-40°C). The crucible's contents were filtered through a piece of filter paper and then adjusted to a volume of 100 cc using a laboratory flask. Finally, the obtained extract was used to measure mineral elements.

2.3. Measurement of total carbohydrate content

First, 0.2 grams of the green tissue of the plant, along with 10 cc of distilled water, were placed in closed test tubes heated for 15 minutes in a water bath at 100°C. After cooling, 1 cc of the samples was taken and 1 cc of 5% phenol and 5 cc of 98% sulfuric acid were added to it. Finally, the total carbohydrate was read using a 160-VU spectrophotometer at a wavelength of 488 nm (Ahmadian and Norzad, 2014).

2.4. Mucilage percentage measurement

First, 1.5 mL of hydrochloric acid (HCl) was added to 50 mL of distilled water, and the volume was adjusted to a total of 180 mL. Next, 10 mL of the prepared acid solution was mixed with one gram of seeds from each treatment. The mixture was heated on a hot plate until the solution turned brown. The brown solution was then separated from the seeds using filter paper. After filtration, the seeds from each treatment were washed with five milliliters of boiling water, and the resulting wash solution was combined with the original filtrate. Subsequently, 60 mL of 96% ethyl alcohol was added to the combined solution, and the mixture was shaken thoroughly. The solution was then refrigerated for five hours to allow the mucilage to settle at the bottom of the container. To determine the mucilage content, the supernatant was carefully discarded, and the settled mucilage was transferred to a pre-weighed container. The mucilage was dried in an oven at 50°C for 12 hours. The mucilage content was calculated by measuring the difference in weight before and after drying, as described by Quintero-García et al. (2021).

2.5. Measuring the weight of a thousand grains

To determine the weight of thousand grains, 1000 grains were counted with a seed counter and measured to one thousandth with an accurate digital scale.

2.6. Statistical analysis

The data obtained were analyzed using SAS (V 9.1) software. For the analysis of averages, Duncan's test was utilized at a significance level of 5%. The graphs were drawn using Microsoft Excel software.

3. Results and discussion

3.1. Seed protein percentage

The results showed that the effect of fertilizer amount and the interaction effect of planting date and fertilizer amount on protein levels were significant at the 1% probability level (Table 3). The highest seed protein (9.85%) was associated with 50% fertilizer in autumn planting. The lowest protein content was observed in the autumn and spring planting dates without fertilizer. There was no statistically significant difference between these two treatments (Fig. 1).

In a research, Ahmadi and Maleki Farahani (2021) reported that compared to control plots without fertilization, nitrogen uptake and use efficiencies were significantly higher in fertilized plots for all tested sowing dates (autumn/spring) in both *L. iberica* and *Lallemantia royleana* varieties. Complex compounds are related to simpler chemical compounds in the plant. Yousefpoor and Yadavi (2014) stated that the fertilizer levels significantly affected the protein percentage of the sunflower plant and increased the quantitative and qualitative yield of the plant.

Ravan et al. (2015) stated that the planting date significantly affected the protein percentage. The highest seed protein percentage was obtained in spring planting with a value of 8.29% and the interactions of both factors had no significant effect on seed protein. Sepehri and Shahabazi (2018) reported that the effect of planting date, fertilizer and the interaction effect of planting date and fertilizer on seed protein was significant at the probability level of 1%. Heydarzade et al. (2022) in investigating the effects of planting date with four planting dates (May 22, June 5, June 19, July 2), revealed that the first planting date can be compared to other planting dates and is better.

Table 3. Analysis of variance the effects of planting date and amount of nitrogen and phosphorus chemical fertilizers on physiological and biochemical traits in *Lallemantia iberica*

S.O.V	df	Protein	N	P	Total Carbohydrate
Planting date (P)	1	0.0307^{ns}	0.626*	5.413*	14.11^{ns}
Fertilizer (F)	2	8.60**	0.190^{ns}	14.63**	170.01^{ns}
P × F	2	37.83**	1.404**	2.021^{ns}	1280.09**
Error	12	0.930	0.116	0.580	85.78
C.V. (%)	-	14.21	29	15.58	15.80

ns,* and ** indicating not significant, and significant at 5 and 1% probability levels, respectively.

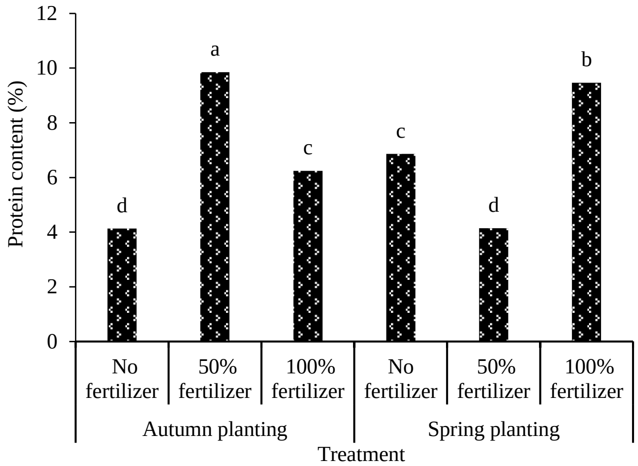

Figure 1. The effects of planting date and the amount of nitrogen and phosphorus fertilizers on seed protein percentage. Means with the same letter are not significantly different according to Duncan's test at P = 0.05.

The planting date had a significant effect on nitrogen yield, with a 5% probability level. Additionally, the results indicated a significant interaction between planting date and fertilizer amounts on seed nitrogen yield, at a 1% probability level (Table 3). The highest seed nitrogen percentage, at 1.92%, was observed in the 100% fertilizer treatment during the spring planting date, which consisted of 50 kg ha^{-1} N and 70 kg ha^{-1} (P_2O_5). On the other hand, the control treatment, which did not involve any fertilizer application and took place during autumn, had the lowest seed nitrogen percentage at 0.66% (Fig. 2). Also, the results of this research showed that the 50% fertilizer treatment for the spring planting date (0.79%) with (100 kg ha^{-1} nitrogen + 140 kg ha^{-1} P_2O_5) is statistically lower than the 50% fertilizer treatment for the autumn season. The results of this research showed that there was no significant difference in seed nitrogen levels between the treatment without fertilizer in the autumn planting date and the 50% fertilizer treatment in the spring planting date. Also, the results of this research showed that the treatment of 100% fertilizer on the spring planting date with the highest treatment was almost at the same statistical level, with the difference that the spring planting date achieved this result with twice the consumption of fertilizer (Fig. 2).

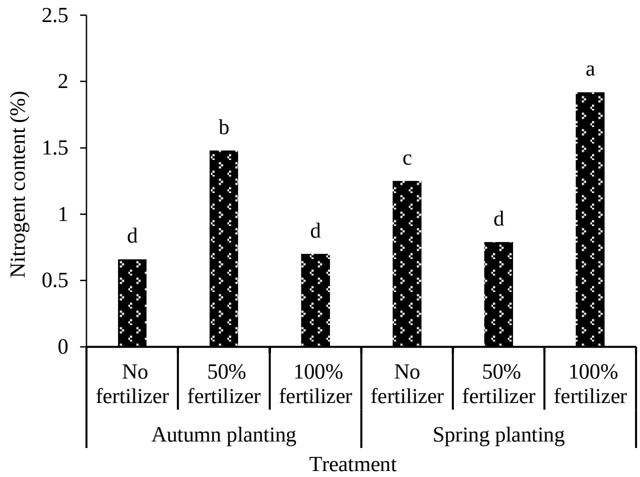

Figure 2. The effects of planting date and the amount of nitrogen and phosphorus fertilizers on seed nitrogen percentage. Means with the same letter are not significantly different according to Duncan's test at P = 0.05.

The results of this research were in contrast with the results of Karimi Jalilehvandi et al. (2017) and Maleki Farahani et al. (2019), who reported that the autumn planting date had higher nitrogen efficiency. The reason for this discrepancy can be explained by the climatic conditions of the cultivated area where Balango was tested. Temperature stress during the greening, establishment, and survival stages of the seedling, as well as the four-leaf and six-leaf stages, may have contributed to the observed changes in the plant during its reproductive growth. As a result, the plant did not have optimal conditions to store sufficient nitrogen in its seeds. Among the other factors contributing to seed nitrogen deficiency in autumn planting with complete fertilizer treatment, amount of winter rainfall in the tested area. This rainfall drains the soil nitrogen, along with the rainwater, from the surface soils of the cultivation area. The highest amount of seed nitrogen was associated with the complete fertilizer treatment on the spring planting date. This may be attributed to the decrease in rainfall during this season compared to winter, resulting in less washing and nitrogen release from the surface soils. In the case of the 50% fertilizer treatment on the autumn planting date, one possible explanation for the increase in nitrogen is that the plants had their maximum ability to utilize the required fertilizer (Koocheki *et al*., 2012).

Alijani et al. (2011) conducted a study on the medicinal plant German chamomile (*Matricaria recutita* L). Their findings revealed that the application of nitrogen fertilizer had a significant impact on both grain yield and the length of the seed filling period. The findings of the aforementioned research on German chamomile indicate that the consistent presence of nutrients, such as phosphorus, which is crucial for the plant's reproductive processes, can positively impact the plant's overall performance. According to Moosavi et al. (2014), when nitrogen consumption increased from zero to 140 kg ha^{-1}, there was a 50.51% increase in all traits, including nitrogen yield in the plant. Additionally, increasing phosphorus consumption increased the chlorophyll index, the number of pods per square meter, and the number of seeds per pod. It also led to a decrease in seed porosity and an increase in seed nitrogen. Increasing phosphorus consumption from zero to 120 kg ha^{-1} resulted in a 24.24% increase in plant yield. Moreover, the interaction between planting date and nitrogen caused a significant increase in the number of pods per square meter and nitrogen percentage. Rezayat et al. (2023) found that the application of higher nitrogen levels resulted in increased yields of rapeseed and white chickpeas.

These findings are consistent with a previous study conducted by Soleimani (2008), which demonstrated that increased nitrogen levels promote seed nitrogen accumulation and prolong the seed filling period, while reducing the filling rate of sunflower seeds. Several recent studies have examined the complex effects of nitrogen fertilization on medicinal plants, yielding important but sometimes contradictory findings. Xing et al. (2023) demonstrated that nitrogen application enhanced both the content of bioactive compounds and seed quality in *Salvia officinalis*, suggesting potential benefits for medicinal value. However, Cun et al. (2023) reported a more nuanced relationship, where while nitrogen increased overall biomass production, it simultaneously reduced root biomass and saponin content - key parameters for medicinal quality. These contrasting results highlight the species-specific nature of plant responses to nitrogen fertilization and underscore the importance of optimizing application rates to balance vegetative growth with secondary metabolite production. The differential effects observed between aerial and underground plant parts particularly emphasize the need for comprehensive evaluation of fertilization impacts on all plant organs when developing cultivation protocols for medicinal species. These findings collectively suggest that while nitrogen plays a crucial role in enhancing plant growth and certain bioactive compounds, excessive application may negatively affect specific medicinal components, necessitating careful management of fertilization regimes based on the target plant parts and desired phytochemical profiles.

3.2. Seed phosphorus

The results of variance analysis showed significant differences in planting date at a 5% probability level and fertilizer amount at a 1% probability level. However, there were no significant results found for the interaction effects of planting date and fertilizer amount on seed phosphorus traits (Table 3). The mean comparison of the data revealed that the highest grain phosphorus content, measured at 7.07 ppm, was observed in the treatment involving complete fertilizer application (100 kg ha^{-1} N + 140 kg ha^{-1} P_2O_5) on the autumn planting date. This treatment significantly enhanced the grain phosphorus yield, demonstrating a positive impact on the trait. In contrast, the lowest grain phosphorus content, recorded at 3.26 ppm, was associated with the 50% fertilizer treatment (50 kg ha^{-1} N + 70 kg ha^{-1} P_2O_5) on the autumn planting date. This treatment exhibited a 116.87% increase in performance compared to the lowest-performing treatment (Fig. 3). The control treatment (no fertilizer) on the autumn planting date resulted in a grain phosphorus yield of 5.96 ppm, representing a 116.8% increase compared to the 50% fertilizer treatment on the same planting date and all treatments on the spring planting date. Conversely, during the spring planting date, the complete fertilizer treatment achieved the highest grain phosphorus yield (5.82 ppm), showing a 78.52% increase compared to the lowest-performing treatment. Notably, the control treatment (no fertilizer) and the 50% fertilizer treatment on the spring planting date were statistically similar, with no significant difference observed between them (Fig. 3).

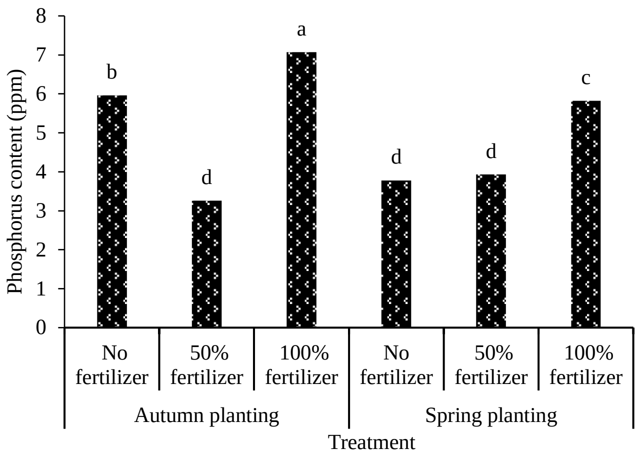

Figure 3. The effects of planting date and the amount of nitrogen and phosphorus chemical fertilizers on seed phosphorus. Means with the same letter are not significantly different according to Duncan's test at P = 0.05.

Given the critical role of phosphorus in providing energy for seedling metabolism and growth, the observed increase in seed germination may be attributed to the improved solubility and availability of soil phosphorus during the growth and developmental stages of the Balango plant. This ultimately results in an increased allocation of phosphorus to the reproductive organs of the Balango plant. The findings of this study align with the results of previous research.

A study by Fanaei et al. (2013) found that increasing phosphorus application from 0 to 150 kg ha^{-1} had a positive effect on Indian mustard (*Brassica juncea* L.). Sharma et al. (2014) similarly found that increasing phosphorus application enhanced dry matter production in fenugreek plants, with positive effects noted at rates up to 40 kg ha^{-1}. This ultimately results in an increased allocation of phosphorus to the reproductive organs of the Balango plant. The findings of this study align with the results of previous research.

3.3. Total carbohydrate content

The results of this research about the effects of planting date and fertilizer amounts on total carbohydrate were not significant, but the interaction results of planting date and fertilizer amounts on total carbohydrate were significant at the 1% probability level (Table 3). The results of the data analysis indicated that the 50% fertilizer treatment on the autumn planting date, with an application rate of 50 kg ha^{-1} N + 70 kg ha^{-1} P_2O_5, yielded the highest total carbohydrate content (80.18 ppm). In contrast, the 100% fertilizer treatment on the autumn planting date resulted in the lowest total carbohydrate content (45.18 ppm). A significant difference in carbohydrate levels was observed between these two treatments. For the spring planting date, the 50% fertilizer treatment recorded a carbohydrate level of 48 ppm, while the full fertilizer treatment on the autumn planting date showed a slightly lower level of 45.18 ppm. However, no significant difference in total carbohydrate content was observed between these two treatments, indicating that they were statistically similar (Fig. 4). In the control treatments (no fertilizer), no significant difference was found between the spring planting date (53.86 ppm) and the autumn planting date (53.66 ppm).

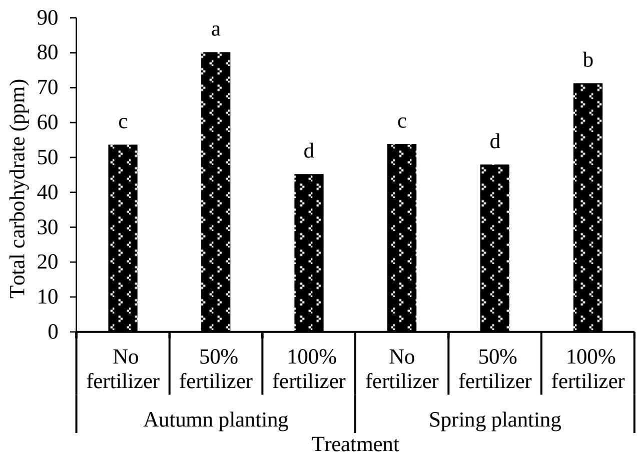

Figure 4. The effects of planting date and the amount of nitrogen and phosphorus chemical fertilizers on total carbohydrate. Means with the same letter are not significantly different according to the Duncan's test at P = 0.05.

The highest total carbohydrate content represented a 49.42% increase compared to the lowest level. The increase in soluble carbohydrates can be attributed to stress factors, such as exposure to cold air in the experimental area, which may have prompted the plant to increase its internal osmotic pressure as a physiological response. This allows the plant to effectively absorb the necessary nutrients and water from the soil. Enhancing nitrate reductase activity significantly increases the synthesis of nitrogen-containing compounds, which in turn facilitate the production of enzymes that mediate phloem-based sugar transport to sink organs during photosynthesis (Li *et al.*, 2024). This process allows for the consumption and storage of ATP. Consequently, the plant absorbs more substances from the soil and experiences greater nutritional effects, particularly in stressful conditions such as cold weather. In such conditions, nitrogen and phosphorus fertilizers can release elements more easily and rapidly. Therefore, it is crucial to prioritize the production of sugars, soluble carbohydrates, and other essential compounds to effectively prevent any negative effects during plant growth and reproduction. Maintaining high levels of soluble carbohydrates can enhance a plant's resilience to environmental stresses, thereby improving its overall productivity and reproductive success (Su *et al.*, 2024).

3.4. Percentage of seed mucilage

The results of the variance analysis revealed that both the amount of fertilizer and the interaction between planting date and fertilizer amounts significantly affected seed mucilage at the 1% probability level. However, the impact of planting date on the percentage of mucilage was not significant (Table 4).

Table 4. Analysis of Variance of the effects of planting date and nitrogen amount and phosphorus chemical fertilizers on physiological and biochemical traits in *Lallemantia iberica*

S.O.V	df	Seed mucilage	Thousand grains weight	Seed Yield
Planting date (P)	1	0.002^{ns}	0.038^{ns}	20007.33^{ns}
Fertilizer (F)	2	4.60^{**}	0.177^{*}	194273.27^{**}
P × F	2	3.74^{**}	0.352^{**}	62609.5^{**}
Error	12	0.371	0.0285	16367.4
C.V. (%)	-	9.74	10.24	17.42

ns, * and ** indicating not significant, and significant at 5 and 1 % probability levels, respectively.

The results of the interaction between planting date and fertilizer amount showed that the highest percentage of mucilage (7.66%) was related to the complete fertilizer treatment during the spring planting date (100 kg ha^{-1} N + 140 kg ha^{-1} P_2O_5). On the other hand, the lowest amount (5.13 %) was observed in the control treatment (without fertilizer) during the autumn planting date. The highest percentage of mucilage was observed in the 50% fertilizer treatment, the autumn planting date (7.4%), which consisted of 50 kg ha^{-1} N + 70 kg ha^{-1} P_2O_5. This treatment did not show a significant difference compared to the highest treatment (Fig. 5). Furthermore, when comparing average data, the results indicated that the 50% fertilizer treatment during the autumn planting date resulted in a 49.31% increase compared to the lowest treatment. However, this increase was not significantly different from the maximum yield of seed mucilage. The results of this research on the effects of autumn planting date on mucilage percentage were consistent with the findings of a previous study (Ahmadi and Maleki Farahani, 2021). The earlier study reported that the percentage of Balango seed mucilage was mainly influenced by genetic factors. The results of this research on the use of nitrogen and phosphorus fertilizers align with the findings of Kiani et al. (2014). They found that increasing the amount of chemical fertilizer enhances nutrient levels, thereby improving photosynthesis. Additionally, their research showed that greater contributions of materials in the reservoirs lead to increased production of plant seed mucilage. Cun et al. (2023) confirmed the positive effects of nitrogen and phosphorus on the physiological and biochemical characteristics of plants, including the percentage of mucilage in confirmed.

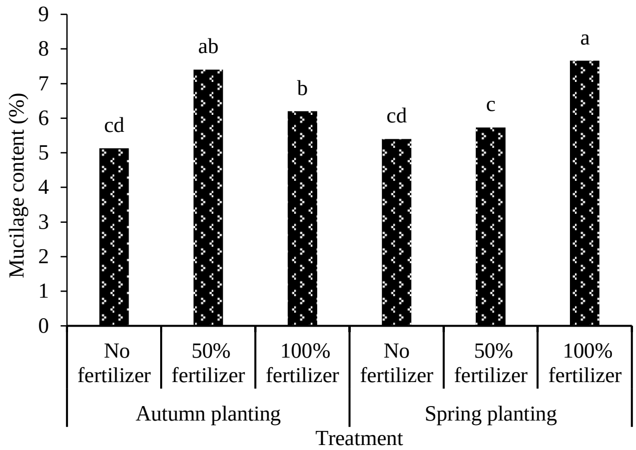

Figure 5. The effects of planting date and the amount of nitrogen and phosphorus chemical fertilizers on mucilage percentage. Means with the same letter are not significantly different according to Duncan's test at P = 0.05.

3.5. Thousand grains weight

The results indicate that the planting date did not have a significant impact on the weight of thousand grains. However, the fertilizer had a significant effect, as did the interaction between the planting date and the amount of fertilizer. These results were significant at 1% probability level (Table 4). The mean comparison of data revealed that the treatment with 100% fertilizer application during spring planting (100 kg ha^{-1} N + 140 kg ha^{-1} P_2O_5) resulted in the highest thousand-grain weight, measuring 2 grams. This result was not significantly different from the treatment where only 50% of the amount of fertilizer was applied during autumn planting (1.97 g, 50 kg ha^{-1} N + 70 kg ha^{-1} P_2O_5) (Fig. 6). The lowest amount of this trait (1.4 g) was observed in the control treatment (without fertilizer) for the autumn planting date. The results indicate that the maximum weight of one thousand grains increased by 42.85% compared to the lowest treatment (Fig. 5). No significant difference was observed between the control treatment (without fertilizer) in the amount of (1.4 g) and the treatment receiving complete fertilizer in the amount of (1.43 g) the autumn planting date in terms of the thousand grains weight.

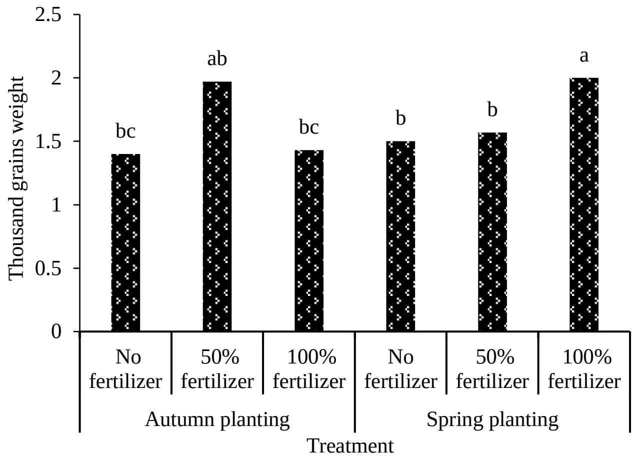

Figure 6. The effects of planting date and the amount of nitrogen and phosphorus chemical fertilizers on thousand-grain weight. Means with the same letter are not significantly different according to Duncan's test at P = 0.05.

The results of the research conducted by Karimi Jalilehvandi et al. (2017) on the Balango plant were consistent with the present study. The research reported that the thousand-grain weight trait in *Lallemantia* plant was directly affected by the flow of photosynthetic materials after pollination. According to a study conducted by Rahmani et al. (2012), it was found that when rapeseed was planted in the autumn, the flowering phase occurred earlier, and the duration of both flowering and seed filling was longer.

3.6. Seed yield

The results of this research on the effect of planting date on seed yield were not significant, but the results of fertilizer amounts and the mutual effects of planting date and fertilizer amounts on seed yield were significant at the 1% probability level (Table 4). The results of the data showed that the treatment of 50% fertilizer at the autumn planting date with 50 kg ha^{-1} of pure nitrogen + 70 kg ha^{-1} (P_2O_5) had the highest seed yield (1065.06 kg ha^{-1}). On the other hand, the treatment without fertilizer had the lowest amount (659.69 kg ha^{-1}) in the autumn planting date. The results showed that the treatment of 100% fertilizer of the spring planting date with 100 kg ha^{-1} of pure nitrogen + 140 kg ha^{-1} (P_2O_5) showed a significant difference in the grain yield levels with (1059.6 kg ha^{-1}) with the highest treatment, while compared to the 50% fertilizer treatment, the plant had twice the amount of fertilizer consumed, while the results were the same with the 50% fertilizer treatment. Also, the results showed that the treatments without fertilizer in both autumn and spring planting dates, as well as the 50% fertilizer treatment in the spring planting date, were statistically at the same level, and no significant difference was observed in the grain yield levels in these three treatments. The overall results of this research showed that the treatment of 50% fertilizer on the autumn planting date showed an increase of 61.44% compared to the lowest level (Fig. 7).

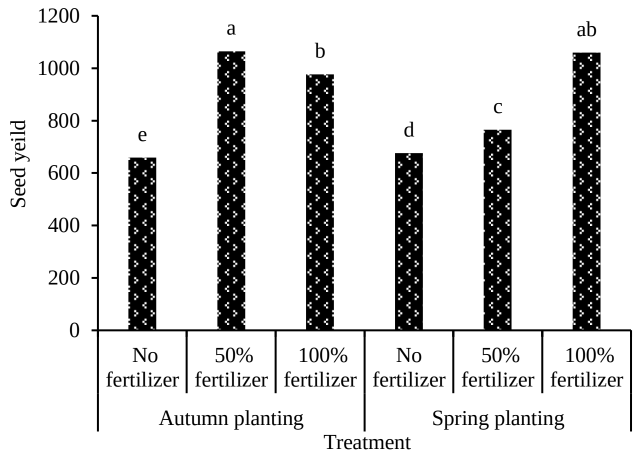

Figure 7. The effects of planting date and the amount of nitrogen and phosphorus fertilizers on seed yield. Means with the same letter are not significantly different according to Duncan's test at P = 0.05.

The positive and significant effect of increasing nitrogen and phosphorus means that with an increase in the amount of nitrogen and phosphorus consumed, a greater share of photosynthetic materials is allocated to the *Lallemantia* plant, and in the conditions of sufficient plant access to nitrogen fertilizer, due to the increase in the durability of the leaf surface and the speed of transfer. Photosynthetic materials from the source (vegetative part) to the destination of the seeds. More photosynthetic materials were transferred to the seeds and increased the yield as a result of increasing the harvest index in *Lallemantia* plant. Also, in the conditions of plant root access to sufficient phosphorus, due to the positive effect of phosphorus on the reproductive part and yield components, it caused a significant increase in grain yield in the plant. The plants in the autumn planting date had more height and yield components than the spring planting date, which ultimately led to a greater increase in grain yield in *Lallemantia* plant. According to the soil test investigated in this research, with pH = 7.3 and the availability of molybdenum and manganese in alkaline soils as well as nitrogen, with an effect on the growth and development of vegetative organs through the synthesis of proteins, expansion of the leaf surface and durability. They have photosynthesizing organs, which can play an effective role in increasing the seed yield in the plant. In late planting, due to the short height of the plants and the shorter distance from planting to flowering, as well as the lower efficiency of the plant in allocating dry matter to the seeds, we encountered a decrease in seed yield in the plant. Also, the results of this research showed that according to the climatic conditions of the discussed area, the autumn cultivation treatments that benefited from 50% fertilizer had more grain yield, as a result, we encountered an increase in the yield of the whole plant. In this research, the provision of better physiological conditions of the plant due to the absorption of nutrients and the creation of favorable environmental conditions in order to obtain sufficient nutrients due to the application of nitrogen and phosphorus fertilizers has increased the grain yield. In a research, Daneshmand et al. (2008) in investigating the effects of seed protein of two canola varieties and its relationship with seed oil yield and seed protein yield stated that the increase in nitrogen consumption increased the amount of seed protein by (25.19%) and there was a positive and significant correlation between consumption nitrogen and increased seed yield and seed protein were found in rapeseed.

Alijani et al. (2011) the constant presence of phosphorus plays a key role in the reproductive process of the plant and causes an increase in the yield of the German chamomile plant. Donohue et al. (2012) stated that ripening temperature affects the germination of the next generation through the effect on phytochromes. Also, high light intensity, continuous light, the benefits of the plant from nitrate and phosphate increase the percentage of germination, resulting in a higher number of seeds produced by in the plant and ultimately, an increase in seed yield.

In a previous study, Moosavi et al. (2020) reported that the delay in planting caused a decrease in pod length, chlorophyll index, thousand grain weight and finally seed yield (47.35%) in fenugreek plant. Farhoudi and Khodarahmpour (2018) in the study of the effect of planting date and nitrogen consumption reported that on both planting dates, the use of 150 kg ha^{-1} of nitrogen fertilizer increased the yield of fennel seeds per square meter compared to lower levels of nitrogen, and the highest seed dry weight in the history planting on November 15 and consumption of 150 kg ha^{-1} of nitrogen was achieved at the rate of 81.2 grams per square meter. In research, Al-Kahtani et al. (2017) stated that increasing the application of phosphorus caused an increase in grain yield in alfalfa (*Medicago sativa*) plants. The results of this research are similar to those reported by Moosavi et al. (2020) regarding yield and components of fenugreek yield in the middle region, which stated that the delay in planting has resulted in a decrease in seed yield.

4. Conclusion

In general, the results of this research showed that the use of nitrogen and phosphorus chemical fertilizers increased all the traits investigated in this research. The highest seed protein is related to the treatment 50% fertilizer, the date of autumn planting, the highest yield of seed nitrogen is related to the treatment of 100% fertilizer, the date of spring planting, the highest yield of phosphorus is related to the treatment of full fertilizer, in the autumn planting date, the highest total carbohydrate yield is related to 50% fertilizer, the date of planting In autumn, the most characteristics of seed mucilage percentage and thousand grains weight were related to full fertilizer treatment in spring planting date, but no significant difference was observed with 50% fertilizer treatment in autumn planting date. And the highest seed yield was related to the treatment of 50% fertilizer at the autumn planting date.

The geographical and climatic conditions of the region, coupled with extended vegetative and reproductive growth periods, suggest that *Lallemantia* achieves optimal performance, particularly in seed formation and filling, with reduced fertilizer inputs (50%) during autumn planting. This approach not only enhances agronomic efficiency but also aligns with sustainable agricultural practices by minimizing environmental impacts on soil and ecosystems. In conclusion, this study provides a foundation for eco-friendly cultivation practices for Lallemantia, advocating for precision in fertilizer management to reconcile productivity with ecological preservation. Future work should expand these findings to diverse cultivars and regions to refine universal guidelines.

Conflict of interests

All authors declare no conflict of interest.

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

All authors read and approved the final manuscript for publication.

Availability of data and material

All the data are embedded in the manuscript.

Authors' contributions

All authors had an equal role in study design, work, statistical analysis and manuscript writing.

Informed consent

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

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