

Flowering capacity and yield of garlic genotypes under different planting seasons and vernalization periods

Capacidade de floração e rendimento de genótipos de alho em diferentes épocas de plantio e períodos de vernalização

Capacidad de floración y rendimiento de genotipos de ajo en diferentes épocas de plantación y períodos de vernalización

Orlando Gonçalves Brito

Doctor in Crop Production

Institution: Universidade Federal dos Vales do Jequitinhonha e Mucuri

Address: Diamantina – Minas Gerais, Brazil

Email: orlandocefe@yahoo.com.br

Antônio Jorge Viegas Taula

Master in Phytotechnology

Institution: Universidade Federal de Lavras

Address: Lavras – Minas Gerais, Brazil

Email: antonio.taula@gmail.com

Valter Carvalho de Andrade Júnior

Doctor in Phytotechnology

Institution: Universidade Federal de Lavras

Address: Lavras – Minas Gerais, Brazil

Email: valter.andrade@ufla.br

Francisco Vilela Resende

Doctor in Phytotechnology

Institution: Universidade Federal de Lavras

Address: Lavras – Minas Gerais, Brazil

Email: francisco.resende@embrapa.br

Ariana Lemes da Costa

Doctor in Phytotechnology

Institution: Universidade Federal de Lavras

Address: Lavras – Minas Gerais, Brazil

Email: arianalemesdacosta@gmail.com

André Boscolo Nogueira Gama

Doctor in Phytotechnology

Institution: Universidade Federal de Lavras

Address: Lavras – Minas Gerais, Brazil

Email: andre.bng91@gmail.com

ABSTRACT

Garlic flowering is agronomically important because it ensures seed production, which is necessary for the reproduction of the species and the generation of new plants. Therefore, the objective of this study was to evaluate the agronomic performance and flowering capacity of garlic genotypes subjected to different vernalization periods and planting dates in southern Minas Gerais, Brazil. The study was conducted at the Department of Agriculture of the Federal University of Lavras, in Lavras, MG, Brazil. The treatments consisted of four garlic genotypes (DDR 6024, RAL 159, RAL 75, and RAL 751) subjected to three vernalization periods (40, 50, and 60 days) and two planting dates (March 15 and April 15, 2019). The following parameters were evaluated: emergence, emergence speed index, mortality, total number of bulbs, number of marketable bulbs, total bulb yield, marketable bulb yield, flowering percentage, and floral scape length and diameter. The experimental genotypes did not differ in bulb production. Regarding flowering percentage, only genotype RAL 159 was inferior to the others when planted on the first planting date (March 15). For bulb production, the second planting date (April 15) was better than the first. All genotypes showed similar flowering performance, except for genotype DDR 6024, which had lower flowering on the second planting date. The 50-day vernalization period was superior to the others for bulb production. For flowering percentage, the 50- and 60-day vernalization periods were more favorable. The treatments that promoted greater flowering also resulted in higher total and marketable bulb yields.

Keywords: *Allium sativum* L., cooling., gene \times environment interaction, seeds, flower.

RESUMO

A floração do alho é agronomicamente importante porque garante a produção de sementes, necessária para a reprodução da espécie e a geração de novas plantas. Portanto, o objetivo deste estudo foi avaliar o desempenho agrônomo e a capacidade de florescimento de genótipos de alho submetidos a diferentes períodos de vernalização e datas de plantio no sul de Minas Gerais, Brasil. O estudo foi conduzido no Departamento de Agricultura da Universidade Federal de Lavras, em Lavras, MG, Brasil. Os tratamentos consistiram em quatro genótipos de alho (DDR 6024, RAL 159, RAL 75 e RAL 751) submetidos a três períodos de vernalização (40, 50 e 60 dias) e duas datas de plantio (15 de março e 15 de abril de 2019). Os seguintes parâmetros foram avaliados: emergência, índice de velocidade de emergência, mortalidade, número total de bulbos, número de bulbos comercializáveis, rendimento total de bulbos, rendimento de bulbos comercializáveis, porcentagem de floração e comprimento e diâmetro do escapo floral. Os genótipos experimentais não diferiram na produção de bulbos. Com relação à porcentagem de floração, apenas o genótipo RAL 159 foi inferior aos demais quando plantado na primeira data de plantio (15 de março). Para a produção de bulbos, a segunda data de plantio (15 de abril) foi melhor do que a primeira. Todos os genótipos apresentaram desempenho de floração semelhante, exceto o genótipo DDR 6024, que teve floração menor na segunda data de plantio. O período de vernalização de 50 dias foi superior aos demais para a produção de bulbos. Para a porcentagem de floração, os períodos de vernalização de 50 e 60 dias foram mais favoráveis. Os tratamentos que promoveram maior floração também resultaram em maior produção de bulbos totais e comercializáveis.

Palavras-chave: *Allium sativum* L., resfriamento, interação gene \times ambiente, sementes, flor.

RESUMEN

La floración del ajo tiene importancia agronómica porque asegura la producción de semillas, necesaria para la reproducción de la especie y la generación de nuevas plantas. Por lo tanto, el objetivo de este estudio fue evaluar el desempeño agronómico y la capacidad de floración de genotipos de ajo sometidos a diferentes períodos de vernalización y fechas de plantación en el sur de Minas Gerais, Brasil. El estudio se realizó en el Departamento de Agricultura de la Universidad Federal de Lavras, en Lavras, MG, Brasil. Los tratamientos consistieron en cuatro genotipos de ajo (DDR 6024, RAL 159, RAL 75 y RAL 751) sometidos a tres períodos de vernalización (40, 50 y 60 días) y dos fechas de plantación (15 de marzo y 15 de abril de 2019). Se evaluaron los siguientes parámetros: emergencia, índice de velocidad de emergencia, mortalidad, número total de bulbos, número de bulbos comercializables, rendimiento total de bulbos, rendimiento de bulbos comercializables, porcentaje de floración y longitud y diámetro del escapo floral. Los genotipos experimentales no difirieron en la producción de bulbos. En cuanto al porcentaje de floración, sólo el genotipo RAL 159 fue inferior a los demás cuando se plantó en la primera fecha de plantación (15 de marzo). Para la producción de bulbos, la segunda fecha de plantación (15 de abril) fue mejor que la primera. Todos los genotipos mostraron un rendimiento similar en floración, excepto el genotipo DDR 6024, que tuvo una floración inferior en la segunda fecha de plantación. El periodo de vernalización de 50 días fue superior a los demás para la producción de bulbos. Para el porcentaje de floración, los periodos de vernalización de 50 y 60 días fueron más favorables. Los tratamientos que promovieron una mayor floración también resultaron en mayores rendimientos totales y comercializables de bulbos.

Palabras clave: *Allium sativum* L., enfriamiento, interacción gen \times ambiente, semillas, floración.

1 INTRODUCTION

Garlic (*Allium sativum* L.) is one of the main vegetables grown and consumed worldwide. Despite its relevance, garlic still has several production limitations because its leaf and bulb production are strongly limited by regional climatic conditions, especially temperature and photoperiod (Wu *et al.*, 2016; Lopes *et al.*, 2016; Atif *et al.*, 2019). In Brazil, these limitations are especially relevant to the cultivars of the group called “noble garlic”. Despite its greater acceptance and commercial value, this group has higher climatic requirements for its cultivation when compared to common garlic. Noble garlic cultivars have a longer cycle and require a photoperiod of at least 13 hours and milder temperatures (Lopes *et al.*, 2016; Azmi *et al.*, 2022).

The cultivation of noble garlic in Brazil was restricted to South Brazil for a long time. However, the use of seed bulb vernalization allowed its cultivation to expand to other regions with warmer climates and lower photoperiods, such as to the Southeast and Central-West regions of the country and to Bahia state (Embrapa, 2020). Vernalization alleviates the climatic

requirements of noble garlic by cooling the cloves to 3 to 5 °C for 40 to 65 days in a cold chamber with a relative humidity of 65 to 70% (Resende *et al.*, 2011; Azmi *et al.*, 2022). This generalized protocol is typically recommended for the different regions that produce noble garlic in Brazil. Despite the importance of the technique for the cultivation of noble garlic, few studies have been conducted to identify the most suitable vernalization periods of garlic for different regions of the country (Luz *et al.*, 2023).

According to Wu *et al.*, (2015, 2016), vernalization can enable the cultivation of garlic in regions where the climatic conditions do not favor bulb formation, in addition to stimulating flowering and affecting morphophysiology. Even if vernalization allows planting in areas unfavorable to garlic bulb formation, incorrect temperatures and periods to which the cloves may be subjected in this process can cause undesirable morphological and cycle changes, resulting in a low-quality product (Lopes *et al.*, 2016).

Another point to be considered is that the existing garlic cultivars differ in terms of growth temperature and photoperiod, which allows flexibility in the growing seasons (Atif *et al.*, 2019; Azmi *et al.*, 2022). Thus, it is possible that, depending on the genotype, the minimum vernalization period required for optimal bulb formation may vary by the planting season adopted (Sedoguchi *et al.*, 2002; Luz *et al.*, 2023), but there are few studies on such relationships in garlic.

In addition to bulb production, the study of the effect of these factors on garlic flowering is relevant to the genetic improvement of the crop. Because it is a sterile plant with exclusively vegetative propagation (Kaur & Dhall, 2017; Taula *et al.*, 2021), viruses frequently accumulate in crop propagules, resulting in significant yield declines during cloning (Velásquez-Valle *et al.*, 2017; Sopha *et al.*, 2024). One way to minimize the effects of viruses on garlic is to use virus-free cloves, which allow the recovery of the vigor and yield (Marodin *et al.*, 2019). However, the use of these cloves significantly increases production costs. Another option is the development of new clones with high yield and tolerance to viruses. This would require the development of genetic variability in the crop from the production of viable botanical seeds. It would be necessary to select genotypes with high flowering capacity and associate them with techniques and conditions that maximize this capacity, such as the growing season and the vernalization period, which may allow the recombination of genotypes of interest in the future.

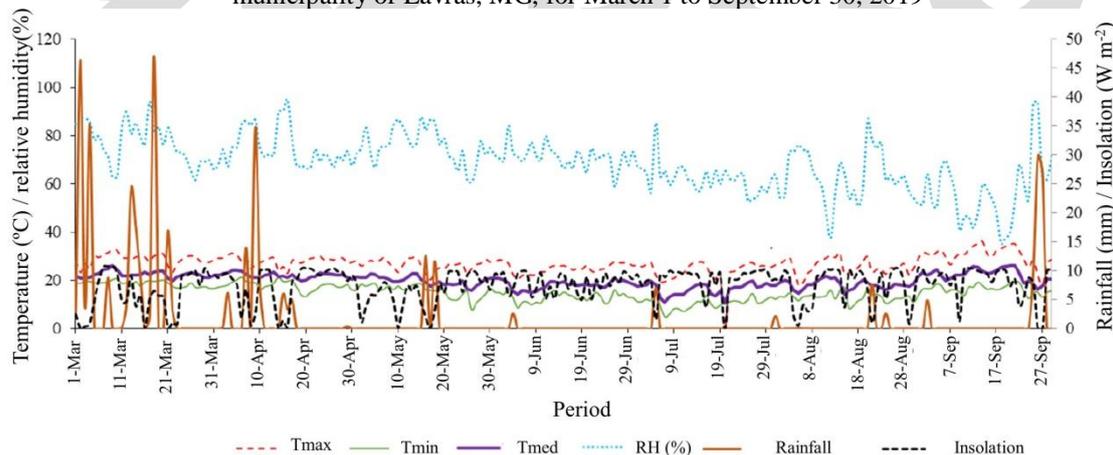
In this sense, studies related to the identification of the most appropriate vernalization periods and their interactions with different growing seasons may guide farming technological

strategies that favor the expansion of garlic growing in Brazil, in addition to providing information for the genetic improvement of the crop. The objective of this study was to evaluate the flowering capacity and yield of garlic genotypes subjected to different vernalization periods and grown in different planting seasons in southern Minas Gerais state (MG), Brazil.

2 MATERIALS AND METHODS

The experiment was set up at the experimental site of the Olericulture Sector of the Department of Agriculture of the Federal University of Lavras, located in Lavras (21°13'20.54" south latitude, 44°58'7.99" west longitude, and 910 m altitude), southern MG, Brazil. The soil of the experimental site was classified as a typical dystroferic red latosol (Embrapa 2013), with a clayey texture, with 33% sand, 18% silt, and 49% clay. The climate in Lavras is the Cwa type: subtropical temperate (mesothermal) with dry winters and rainy summers, characterized by a dry season from April to September and a rainy season from October to March (Köppen, 1948). Fig. 1 shows the weather data from the study period.

Figure 1 Maximum, mean, and minimum temperatures, relative humidity, rainfall, and insolation in the municipality of Lavras, MG, for March 1 to September 30, 2019



Source: Authors (2025)

The experiment followed a 4×3×2 factorial design, with four garlic genotypes (DDR 6024, RAL 159, RAL 75, and RAL 751), three vernalization periods (40, 50, and 60 days), and two planting seasons (15 March and April 15, 2019). The DDR 6024, RAL 159, RAL 75, and RAL 751 genotypes were provided by EMBRAPA-CNPQ. A randomized block design was used,

with four replicates, totaling 96 experimental units. Each experimental unit had an area of 1.5 m² (1 m wide × 1.5 m long), with four single rows and with a spacing between rows of 20 cm and between plants of 10 cm, and each row had 15 plants (60 plants per plot).

Plowing and harrowing were performed for soil management, followed by raising the beds. Fertilization and liming were performed based on soil analysis following the recommendations proposed for the crop (CFSEMG, 1999). Topdressing fertilizations were performed in two applications, one at 30 days and another at 60 days after planting the garlic, using urea and potassium chloride as sources.

A microsprinkler irrigation system was adopted, with a flow rate of 27 L h⁻¹ per microsprinkler and 200 kPa pressure; the amount of water applied was estimated according to the crop evapotranspiration. Weed control was performed whenever necessary for the plants to always remain on clean soil, manually between plants and using a hoe between the beds. For disease management, sprayings were performed whenever necessary, for example, when purple blotch was seen, in addition to controlling pests such as thrips and mites with recommended insecticides.

Water stress was applied to the crop by suspending irrigation at 30 days after planting (DAP) in both planting seasons. In the first planting season, water stress was started on May 22 and ended on June 6. In the second planting season, water stress lasted from June 4 and 19. The stress was applied for 15 days to favor bulb formation.

Plant emergence was evaluated from 10 to 30 DAP. These data were used to determine the calculate speed index (Maguire, 1962) and plant mortality (%), which equaled the ratio between the number of harvested and emerged plants.

The flowering percentage was determined from frequent observations of the area, considering all living plants in the plot that produced a floral scape. In these plants, the floral scape length and diameter were also evaluated in 10 plants in the plot (when possible).

Bulbs were harvested at 165 DAP, when the plants showed signs of maturation, characterized by yellowing and dryness of 2/3 of the shoots, and respecting the crop cycle of each accession. The harvested plants were cured under the sun for 21 days in a shed. Next, the plants were stored for 10 days in a shaded, dry, ventilated place for evaluation of bulb yield and quality. At harvest, the total number of bulbs and the number of commercial bulbs were evaluated, and the data were used to determine the total bulb yield and commercial bulb yield.

To evaluate the total bulb yield, all bulbs from each plot were weighed in all treatments, and the results are expressed in $t\ ha^{-1}$. In turn, for the evaluation of commercial yield, bulbs in good phytosanitary condition that met the standards and had a cross-sectional diameter ≤ 32 mm (Luengo *et al.*, 1999) were taken from each plot and weighed (yield expressed in $t\ ha^{-1}$).

The data were submitted to analysis of variance ($p \leq 0.05$), and when significant, the isolated effects and their interactions were compared by Tukey's test at 5% significance. The analyses were performed within Sisvar software (Ferreira *et al.*, 2019).

3 RESULTS AND DISCUSSION

Plant emergence was significantly influenced ($p \leq 0.05$) only by planting season. Planting in March resulted in a higher emergence percentage than planting in April (Table 1). Both seasons showed excellent emergence percentages, greater than 90%, with a difference of only 4.19%. According to Hooley (1994), low temperatures stimulate the synthesis of gibberellins and positively influence germination (Luz *et al.*, 2023). Therefore, the results observed in the study indicate that both planting in March and planting in April presented favorable environmental conditions for good emergence of vernalized seed garlic.

Although the experiment was irrigated, the occurrence of a longer rainy season at the beginning of the planting in March (Figure 1) might have contributed to the difference between seasons, since favorable moisture conditions may have remained in the area for a longer time, reducing possible thermal and water stresses in the crop. However, the observed emergence values are higher than those found by Taula *et al.*, (2021), who did not identify differences in germination between 13 garlic genotype, whose mean germination was approximately 90% in the municipality of Diamantina, MG, indicating that our results were good.

Table 1- Emergence and emergence speed index (ESI) in garlic genotypes subjected to different vernalization periods and growing seasons. Lavras, Minas Gerais, Brazil, 2020

Season	Emergence (%)	
March 15	95.75 a	
April 15	91.56 b	

Vernalization	ESI	
	March 15	April 15
40	30.62 Aa	30.18 Aa
50	31.34 Aa	29.40 Aa
60	31.63 Aa	29.35 Ba

Means followed by the same uppercase letter in the same row and lowercase letter in the same column do not differ by Tukey's test at 5% significance.

Source: Authors (2025)

There was a significant interaction effect ($p \leq 0.05$) of vernalization period and planting season on the emergence speed index (ESI) (Table 1). No significant difference was observed between the vernalization periods within a planting season. However, when evaluating each vernalization period in isolation, the use of 60 days of vernalization showed a higher ESI in the March planting. In general, all the vernalization treatments used for the genotypes yielded similar ESIs, except for the treatment with 60 days of vernalization in the April planting. This indicates that long vernalization periods linked to late plantings may affect emergence speed, causing unevenness in the plant stand. Lucena *et al.*, (2016) evaluated vernalization periods in seed garlic bulbs planted in different locations and observed that approximately 25 days of vernalization resulted in a germination rate higher than 98%. This reinforces that garlic cultivars show different responses to vernalization (Fiorese & Vicelli, 2009).

Plant mortality, i.e., the percentage of harvested plants relative to the total that emerged, showed a significant response ($p \leq 0.05$) to the interaction between genotype, vernalization period, and planting season (Table 2). Planting in April favored the RAL 159 and RAL 751 genotypes, resulting in lower plant mortality. For the other genotypes, this trait did not vary significantly between the seasons. When comparing the genotypes within each season, significant differences were found only for the planting in March, in which the DDR 6024 and RAL 75 genotypes had the lowest mortality.

Table 2 - Percent plant mortality in garlic genotypes subjected to different vernalization periods and planting seasons. Lavras, Minas Gerais, Brazil, 2020

Genotype	Mortality (%)	
	Season	
	March 15	April 15
DDR 6024	17.06 Ab	11.00 Aa
RAL 159	34.02 Aa	9.56 Ba
RAL 75	13.79 Ab	8.57 Aa
RAL 751	28.93 Aa	11.91 Ba
Vernalization	March 15	April 15
40	14.28 Ab	12.71 Aa
50	22.15 Ab	7.94 Ba
60	33.92 Aa	13.12 Ba

Means followed by the same uppercase letter in the same row and lowercase letter in the same column do not differ by Tukey's test at 5% significance.

Source: Authors (2025)

The vernalization periods of 40 and 50 days resulted in lower mortality in the March planting, but there were no significant differences between the vernalization periods when planting was performed in April (Table 2). When comparing each vernalization period across planting seasons, we observed that plants subjected to vernalization periods of 50 and 60 days showed lower mortality when they were planted in April, and there were no differences between the seasons with 40 days of vernalization. On average, the mortality of the plants planted in April was approximately half that of the plants planted in March. In general, the mortality rates observed in this study were considered very high. In a study by Lopes *et al.*, (2016), in which vernalization periods and planting seasons in a semiarid region were evaluated, the authors found that the final plant stand was influenced exclusively by the planting season, and the mortality was lower than 15%.

The total number of bulbs was significantly influenced ($p \leq 0.05$) by genotype and by the interaction between the vernalization period and the planting season (Table 3). The DDR 6024 genotype differed only from the RAL 159 genotype, the former having a higher number of bulbs. When comparing the effect of the interaction, we found that within each planting season, the vernalization period of 40 days resulted in the highest total number of bulbs with March planting, though this did not differ from the number observed in the 50-day group. With April planting, there was no significant difference between the vernalization periods.

Table 3 -Total number of bulbs in garlic genotypes subjected to different vernalization periods and planting seasons. Lavras, Minas Gerais, Brazil, 2020

Genotype	Total number of bulbs (bulbs ha ⁻¹)	
DDR 6024	319772 a	
RAL 159	266944 b	
RAL 75	310277 ab	
RAL 751	277777 ab	
Total number of bulbs (bulbs ha ⁻¹)		
Vernalization	Season	
	March 15	April 15
40	317500 Aa	274999 Ba
50	299583 Aab	298333 Aa
60	256250 Bb	315416 Aa

Means followed by the same uppercase letter in the same row and lowercase letter in the same column do not differ by Tukey's test at 5% significance.

Source: Authors (2025)

When analyzing the planting seasons within each vernalization period (Table 3), we observed that under the 40-day vernalization period, the March planting showed more total bulbs than the April planting. The opposite was observed in the 60-day group. No variation was observed between the planting seasons in the 50-day group.

The total number of bulbs is a highly relevant characteristic because it is directly related to bulb yield. In addition, it is expected that the greater the total bulb production, the greater the number of commercial bulbs and, consequently, the higher the income for the producer. Total bulb number is influenced particularly by the predicted stand, the germination capacity of the cloves, and the mortality of the plants, which are directly linked to the growing techniques, propagule quality, and environmental conditions. Considering the values observed in this study, the total number of bulbs ranged from 64 to 80% of the predicted stand (400,000 plants ha⁻¹). Guimarães *et al.*, (2019) evaluated eight experimental genotypes and two commercial garlic cultivars in two planting locations and observed that the percentage of final bulbs in relation to the predicted stand (400,000 plants ha⁻¹) was 74% in garlic grown in Diamantina, MG, and 55% in Lavras, MG, lower mean values than those observed in this study.

The number of commercial bulbs was significantly affected ($p \leq 0.05$) by the interaction between genotype and vernalization period, as well as by the isolated effect of planting time (Table 4). When comparing the genotypes within each vernalization period, there was variation only when adopting 40 days of vernalization, in which the RAL 159 genotype had the highest number of commercial bulbs, though it did not differ from RAL 75 or RAL 751. The 50-day vernalization period favored the formation of commercial bulbs over the other periods, regardless

of the genotype studied. When evaluating the planting seasons within each genotype, it was observed that the DDR 6024 genotype had more commercial bulbs after 50 days of vernalization, whereas for RAL 75, this occurred under 50 and 60 days of vernalization. Regarding the planting seasons, planting in April resulted in more commercial bulbs, 68% more than that observed in the March planting, which may be associated with the more favorable climatic conditions.

Table 4 - Number of commercial bulbs in garlic genotypes subjected to different vernalization periods and planting seasons. Lavras, Minas Gerais, Brazil, 2020

Genotype	Number of commercial bulbs (bulbs ha ⁻¹)		
	Vernalization		
	40	50	60
DDR 6024	61666 Bb	166666 Aa	114116 Ba
RAL 159	137499 Aa	116666 Aa	112499 Aa
RAL 75	78333 Bab	185833 Aa	154999 Aa
RAL 751	114999 Aab	164999 Aa	118333 Aa
Season	Number of commercial bulbs (bulbs ha ⁻¹)		
March 15	94722 b		
April 15	159722 a		

Means followed by the same uppercase letter in the same row and lowercase letter in the same column do not differ by Tukey's test at 5% significance.

Source: Authors (2025)

There were far fewer commercial bulbs than total bulbs. Considering that the mean total number of bulbs was approximately 293,600 bulbs ha⁻¹, the average yield of commercial bulbs was 43%, a value considered low and indicating a large amount of waste. According to Ordinance No. 242 of September 17, 1992 of the Brazilian Ministry of Agriculture, Livestock and Food Supply (Luengo *et al.*, 1999), bulbs with diameter ≤ 32 mm are not considered commercial. This shows that even with bulb formation, the different vernalization treatments and planting seasons influenced the commercial quality of the bulbs of the evaluated genotypes. According to Macêdo, Souza & Pereira, (2006), inadequate vernalization may promote hormonal imbalance and favor the occurrence of secondary bulb growth, a recurrent and serious problem in the production of noble garlic. This points to the need to determine the best combination of these factors during cultivation.

Like the total and commercial bulb yields, the number of total and commercial bulbs are influenced by climatic factors throughout crop development (Souza & Macêdo, 2009). Therefore, the region also influences bulb formation performance, as variations in climatic conditions, especially photoperiod and temperature, directly influence morphological and production variables (Sedoguchi *et al.*, 2002).

The total and commercial bulb yields were significantly influenced ($p \leq 0.05$) only by the planting season and the vernalization period, with no interactions between the studied factors for these characteristics (Table 5). April planting resulted in a 38% higher total bulb yield than March planting. This increase was higher for the commercial bulb yield, since the planting in April showed a 94% higher value. Regarding vernalization, the 50-day period resulted in the highest total and commercial bulb yields.

Table 5 - Total and commercial bulb yields of garlic genotypes subjected to different vernalization periods and planting seasons. Lavras, Minas Gerais, Brazil, 2020

Season	Yield (ton ha ⁻¹)	
	Total	Commercial
March 15	3.35 b	1.80 b
April 15	4.63 a	3.49 a
Vernalization	Yield (ton ha ⁻¹)	
	Total	Commercial
40	3.51 b	2.08 b
50	4.51 a	3.34 a
60	3.95 b	2.51 b

Means followed by the same letter in the same column do not differ by Tukey's test at 5% significance.

Source: Authors (2025)

Taula *et al.*, (2021) evaluated 13 garlic genotypes (including those evaluated in this study) in Lavras, MG and obtained a mean total bulb yield of 8.46 t ha⁻¹. That yield was 52.8% higher than the mean found in this study, which might be associated with the differences in the climatic conditions of the periods, since in that study planting was performed in May. However, similar results were observed by Biesdorf *et al.*, (2015), who found that vernalized garlic had a total bulb yield between 3.74 and 4.53 ton ha⁻¹, while the range for nonvernalized garlic was 1.46 to 2.91 ton ha⁻¹, in a study conducted in southeastern Mato Grosso state, Brazil.

The bulb yields observed with the different planting seasons and vernalization periods were low and were even lower than the mean garlic yield in the state of Minas Gerais, which in 2018 was 14.5 t ha⁻¹ (SEAPA, 2020). However, the best planting time (April 15) and the best vernalization period (50 days) identified in this study showed a commercial yield close to those observed by Guimarães *et al.*, (2019). Those authors found mean yields of garlic genotypes of approximately 3.52 ton ha⁻¹ in Diamantina and 3.70 ton ha⁻¹ in Lavras.

Thus, our results and the results found in the literature exemplify the influence of the genotype × environment interaction on the production performance of garlic, highlighting the importance of vernalization and an appropriate environment for cultivation. According to Souza

& Macêdo, (2009), low yields may be related to the sensitivity of garlic cultivars to climatic factors, such as photoperiod and temperature, causing divergences in yields in different regions and planting times. This means that the genotypes used were sensitive to climatic factors, such as temperature and rainfall, occurring in the region during the different growing seasons (Figure 1), the oscillations of which may have contributed to the lower yields observed.

The flowering percentage and floral scape length and diameter were significantly influenced ($p \leq 0.05$) by the interaction between genotype and planting season (Table 6). The flowering percentage and floral scape length were also influenced by the vernalization period alone.

Table 6 - Flowering percentage and floral scape length and diameter in garlic genotypes subjected to different vernalization periods and planting seasons. Lavras, Minas Gerais, Brazil, 2020

Genotype	Flowering (%)		Floral scape length (cm)		Floral scape diameter (mm)	
	Season		Season		Season	
	March 15	April 15	March 15	April 15	March 15	April 15
DDR 6024	22.12 Aa	26.08 Ab	34.54 Aa	32.25 Aa	2.93 Aa	2.72 Aa
RAL 159	16.50 Ba	44.65 Aa	25.73 Ba	40.91 Aa	2.02 Bb	2.99 Aa
RAL 75	27.43 Aa	35.91 Aab	34.60 Aa	39.53 Aa	2.80 Bab	2.72 Ba
RAL 751	27.39 Aa	32.60 Aab	30.62 Aa	34.30 Aa	2.41 Aab	2.67 Aa
Vernalization	Flowering (%)		Floral scape length (cm)			
40	22.05 b		29.58 b			
50	33.59 a		36.32 a			
60	31.61 a		36.27 a			

Means followed by the same uppercase letter in the same row and lowercase letter in the same column do not differ by Tukey's test at 5% significance.

Source: Authors (2025)

When comparing the flowering percentage within each season, the genotypes did not show significant differences ($p \leq 0.05$) in the planting performed in March, with values ranging from 16.50% to 27.43%. For the planting performed in April, the genotypes differed from each other: The highest flowering percentage was observed for the RAL 159 genotype (44.65%), which differed significantly only from the DDR 6024 genotype (26.08%). When comparing between seasons, the RAL 159 genotype was the only one that showed significantly different flowering, with higher flowering in the April planting (44.65%). When considering the effect of vernalization period, the highest flowering was provided by the periods of 50 and 60 days.

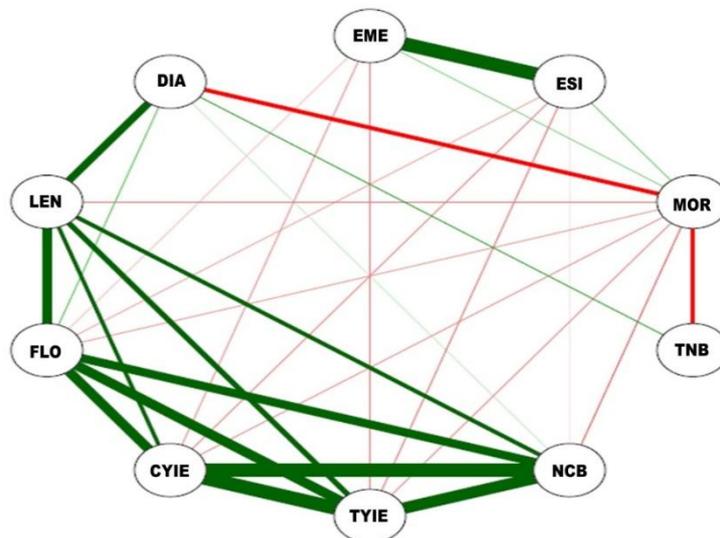
For floral scape length, all genotypes showed similar behavior, regardless of planting season, and did not differ from each other within each season. Conversely, the RAL 159 genotype

showed greater floral scape length when planted in April. Regarding the effect of vernalization period, the 50- and 60-day periods resulted in greater floral scape length. Good floral scape development indicates that the garlic cultivar is adapted to the location and may reach up to 1 meter in length, depending on the cultivar (Kimoto *et al.*, 1997). Therefore, the results observed in the present study indicate good adaptability of the genotypes to the conditions of the region in terms of flowering and, consequently, the potential for seed production and the development of crop improvement programs.

Regarding the floral scape diameter, in the March planting, only the DDR 6024 and RAL 159 genotypes differed from each other, the former being better than the latter. In the second season, there was no significant difference between the genotypes. When comparing the effect of the planting season on each genotype alone, we observed that for the RAL 159 genotype, planting in April resulted in the largest diameter, while the opposite was observed for RAL 75. According to Lopez-Bellido *et al.*, (2016), the floral scape is the part where seed production occurs, and it competes with the bulb for nutrient absorption. Therefore, it is desirable in breeding programs for the size of the floral scape to be larger, whereas if the goal is bulb production, the size of the scape should be reduced in favor of a higher-quality bulb.

Considering the correlations established between the traits evaluated in this study (Figure 2), it was found that there was a strong positive association between total bulb yield, commercial bulb yield, and the number of commercial bulbs, which is explained by these traits being interrelated. A similar situation was observed between plant emergence and ESI, which were strongly and positively correlated with each other.

Figure 2 Significant¹ phenotypic correlations between traits evaluated in garlic genotypes subjected to different vernalization periods and planting seasons. Lavras, Minas Gerais, Brazil, 2020.



Legend: plant emergence (EME), emergence speed index (ESI), plant mortality (MOR), total number of bulbs (TNB), number of commercial bulbs (NCB), total bulb yield (TYIE), commercial bulb yield (CYIE), flowering percentage (FLO), floral scape length (LEN) and floral scape diameter (DME). ¹Significant by the t-test at 5% probability.

Source: Authors (2025)

When analyzing the associations between traits related to flowering and bulb production, we found that the flowering percentage and the floral scape length showed a strong positive association with the number of commercial bulbs, total bulb yield, and commercial bulb yield (Figure 2). This indicates that treatments that promoted a higher flowering percentage and a larger floral scape were related to higher bulb production. This result was not physiologically expected because flowering usually competes with bulb formation for photoassimilates. In addition, it was also found that treatments with larger floral scape diameters had lower mortality, which indirectly resulted in higher production rates. This relationship between the occurrence of flowering and higher yields may be related to a better adaptation of the crop to the growing location and to aspects of its nutrition, since good plant nutrition is necessary for flowering to occur.

Even though it is not a trait of interest from an agronomic viewpoint, studying flowering in garlic is important for the genetic improvement of the crop. Identifying genotypes or techniques that stimulate this trait may in the future allow the recombination of genotypes and the production of botanical seeds, enabling the development of promising new clones. This way, it will be possible to generate genetic variability and explore genetic improvement aimed at bulb

yield, tolerance to abiotic stresses, and quality improvement (Kaur & Dhall, 2017). Despite their sterility, garlic genotypes with seed production capacity have already been identified (Vavilov, 1951; Etoh, 1986; Hong & Etoh, 1996). Some studies have identified genotypes that produce 400 seeds per umbel and have germination rates of 67% to 93% (Inaba *et al.*, 1995; Jenderek, 1998).

4 CONCLUSIONS

The highest flowering percentage was observed for the RAL 159 genotype in the April planting. For the other genotypes, the flowering percentage was not influenced by planting in March or April. The vernalization period of 50 and 60 days promoted a higher flowering percentage. Regarding the flowering capacity, the genotypes showed no difference in flowering percentage in the March planting. With April planting, the RAL 159 genotype had a higher flowering percentage than the DDR 6024 genotype. Treatments with higher flowering capacity are associated with higher production rates. Planting in April provided the highest total and commercial bulb yields. The vernalization period of 50 days resulted in higher bulb yield than 40 or 60 days. The experimental genotypes in general did not differ in the total or commercial bulb yield.

ACKNOWLEDGMENTS

The authors thank the Minas Gerais State Agency for Research and Development (FAPEMIG) and the National Council for Scientific and Technological Development (CNPq) for the financial resources and scholarships for the execution of the project.

REFERENCES

- ATIF, M. J. *et al.* Influence of different photoperiod and temperature regimes on growth and bulb quality of garlic (*Allium sativum* L.) cultivars. **Agronomy**, v. 879, p. 1–21, 2019.
- AZMI, C. *et al.* Temperature and duration of vernalization effect on the vegetative growth of garlic (*Allium sativum* L.) clones in Indonesia. **Open Agriculture**, v. 7, n. 1, p. 520–528, 2022.
- BIESDORF, E. M. *et al.* Desempenho agrônômico de cultivares de alho vernalizado e não vernalizado na região Sudeste de Mato Grosso. **Revista Agricultura Neotropical**, Cassilândia, v. 2, p. 44–48, 2015.
- COMISSÃO DE FERTILIDADE DO SOLO DO ESTADO DE MINAS GERAIS – CFSEMG. **Recomendações para o uso de corretivos e fertilizantes em Minas Gerais: 5ª aproximação**. Viçosa: SBCS; Editora UFV, 1999. 359 p.
- Empresa Brasileira de Pesquisa Agropecuária - EMBRAPA. Como plantar alho. 2020. Disponível em: <https://www.embrapa.br/hortalicas/alho/como-plantar> acesso em: 08 de novembro de 2020.
- ETOH, T. Fertility of the garlic clones collected in Soviet Central Asia. **Journal of the Japanese Society for Horticultural Science**, v. 55, p. 312–319, 1986.
- FERREIRA, D. F. SISVAR: a computer analysis system to fixed effects split plot type designs. **Revista Brasileira de Biometria**, v. 37, p. 529–535, 2024.
- FIGLIANO, E. J.; VIECELLI, C. A. Tratamento termoterápico sobre seis cultivares de alho. **Revista Cultivar Saber**, v. 2, p. 26–31, 2009.
- GUIMARÃES, A. G. *et al.* Potencial produtivo de genótipos de alhos em Minas Gerais. **Revista Agricultura Acadêmica**, v. 2, p. 106–114, 2019.
- HOOLEY, R. Gibberellins: perception, transduction and responses. **Plant Molecular Biology**, v. 26, p. 1529–1555, 1994.
- HORG, T.; ETOH, T. Fertile clones of garlic (*Allium sativum* L.) abundant around the Tien Shan Mountains. **Breeding Science**, v. 46, p. 349–353, 1996.
- INABA, A. T.; UJIIE, T.; ETOH, T. Seed productivity and germinability in garlic. **Breeding Science**, v. 45, supl. 2, p. 310, 1995. (In Japanese).
- JENDEREK, M. M. Generative reproduction of garlic (*Allium sativum*). **Sesja Naukowa**, v. 57, p. 141–145, 1998. (In Polish).
- KAUR, Y.; DHALL, R. K. Effect of vernalization on flowering and true seed production behaviour of garlic (*Allium sativum*) under North Indian Plains. **Indian Journal of Agricultural Sciences**, v. 87, p. 138–142, 2017.
- KIMOTO, T. *et al.* Eliminação do escapo floral em diferentes estádios de crescimento de três cultivares de alho. **Agropecuária Catarinense**, v. 10, p. 56–57, 1997.

- KÖPPEN, Wilhelm. **Climatologia con un estudio de los climas de la tierra**. México: Fondo de Cultura Económica, 1948.
- LOPES, W. A. R. *et al.* Produção de alho submetido a períodos de vernalização e épocas de plantio em região de clima semiárido. **Horticultura Brasileira**, v. 34, p. 249–256, 2016.
- LOPEZ-BELLIDO, F. J. *et al.* New phenological growth stages of garlic (*Allium sativum*). **Annals of Applied Biology**, v. 169, p. 423–439, 2016.
- LUCENA, R. R. M. *et al.* Productive performance of vernalized semi-noble garlic cultivars in western Rio Grande do Norte state, Brazil. **Revista Caatinga**, v. 29, p. 327–337, 2016.
- LUENGO, R. F. A. *et al.* Classificação de hortaliças. Brasília: **Embrapa**, 1999.
- LUZ, J. M. Q. *et al.* Vernalization temperature and maturation point of seed cloves on garlic production and quality. **Science and Agrotechnology**, 2023.
- MACÊDO, F. S.; SOUZA, R. J.; PEREIRA, G. M. Controle de superbrotamento e produtividade de alho vernalizado sob estresse hídrico. **Pesquisa Agropecuária Brasileira**, v. 41, p. 629–635, 2006.
- MAGUIRE, J. D. Speed germination: AID in selection and evaluation for seedling emergence and vigour. **Crop Science**, v. 2, p. 176–177, 1962.
- MARODIN, J. C. *et al.* Agronomic performance of both virus-infected and virus-free garlic with different seed bulbs and clove sizes. **Pesquisa Agropecuária Brasileira**, v. 54, p. 1–8, 2019.
- MINAS GERAIS. Secretaria de Estado de Agricultura, Pecuária e Abastecimento. **Alho**. Belo Horizonte: Subsecretaria de Política e Economia Agrícola, 2020. Disponível em: http://www.reformaagraria.mg.gov.br/images/documentos/perfil_alho_jan_2020.pdf. Acesso em: 8 nov. 2020.
- OLIVEIRA, F. L. *et al.* Características agrônômicas de cultivares de alho em Diamantina. **Horticultura Brasileira**, v. 28, p. 355–359, 2010.
- RESENDE, J. T. V. *et al.* Garlic vernalization and planting dates in Guarapuava. **Horticultura Brasileira**, v. 29, p. 193–198, 2011.
- SEDOGUCHI, E. T. *et al.* Características morfológicas, de produção e efeitos da vernalização sobre cultivares de alho em duas épocas de plantio em Seropédica-RJ. **Agronomia**, v. 36, p. 42–47, 2002.
- SOPHA, G. A. *et al.* Aerial bulbils as garlic alternative planting materials: a systematic review. **Chilean Journal of Agricultural Research**, v. 84, n. 1, p. 123–131, 2024.
- SOUZA, R J & MACÊDO, F S. **Cultura do alho: tecnologias modernas de produção**. Lavras: Universidade Federal de Lavras, 2009.

TAULA, A. J. V. *et al.* Agronomic performance, flowering, physicochemical characteristics and genetic divergence in garlic accessions from Brazil. **Australian Journal of Crop Science**, v. 15, n. 12, p. 1372–1380, 2021.

VAVILOV, N I. **The origin, variation, immunity and breeding of cultivated plants**. New York: Chronica Botanica, 1951.

VELÁSQUEZ-VALLE, R. *et al.* Efecto del tratamiento térmico sobre la presencia de virus em bulbos de ajo (*Allium sativum* L.). **Revista Facultad de Ciencias Agrarias, Universidad Nacional de Cuyo**, v. 49, p. 157–165, 2017.

WU, C. *et al.* Effect of plant age and vernalization on bolting, plant growth and enzyme activity of garlic (*Allium sativum* L.). **Scientia Horticulturae**, v. 201, p. 295–305, 2016.

WU, C. *et al.* Growth, bolting and yield of garlic (*Allium sativum* L.) in response to clove chilling treatment. **Scientia Horticulturae**, v. 194, p. 43–52, 2015.