Pesquisa Agropecuária Brasileira

Horticultural Science/ Original Article

ISSN 1678-3921

Journal homepage: www.embrapa.br/pab

For manuscript submission and journal contents, access: www.scielo.br/pab

Critical impact of defoliation on garlic yield during key developmental stages

Abstract – The objective of this work was to evaluate the effect of defoliation levels at different growth stages of garlic plants on total and marketable yields. The experiments were conducted during two crop seasons, when five dates (30, 60, 90, 110, and 130 days after planting – DAP) and four levels (33, 50, 67, and 100%) of defoliation were evaluated. The critical period for leaf loss in garlic crop occurs between 90 and 110 DAP (phenological stages 400 to 407), corresponding to the onset of bulbification and maximum leaf area index. Increasing defoliation levels progressively reduces marketable garlic yield, reaching losses of up to 50% under 50% defoliation and up to 100% under total defoliation during the critical period. Defoliation reduces the proportion of high-grade bulbs (grades 5, 6, and 7) and increases non-marketable production, severely impacting crop profitability.

Index terms: *Allium sativum*, bulbous vegetables, leaf removal, yield losses.

Impacto crítico da desfolha na produção de alho durante os principais estágios de desenvolvimento

Resumo – O objetivo deste trabalho foi avaliar o efeito de níveis de desfolha em diferentes fases de desenvolvimento de plantas de alho sobre produção total e comercial. Os experimentos foram realizados em duas safras, tendo-se avaliado cinco épocas (30, 60, 90, 110 e 130 dias após o plantio – DAP) e quatro níveis (33, 50, 67 e 100%) de desfolha. O período crítico à perda de área foliar na cultura do alho ocorre entre 90 e 110 dias após o plantio (estágios fenológicos 400 a 407), coincidindo com o início da bulbificação e o máximo índice de área foliar. O aumento nos níveis de desfolha reduz progressivamente o rendimento comercial do alho, provocando perdas de até 50% sob desfolha de 50% e de até 100% em desfolhas totais no período crítico. A desfolha reduz a proporção de bulbos nas classes comerciais superiores (classes 5, 6 e 7) e eleva a produção não comercializável, comprometendo severamente a rentabilidade da cultura.

Termos para indexação: *Allium sativum*, bulbos, diminuição da área foliar, perdas de rendimento.

Leandro Hahn(✉)
Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina, Urussanga, SC, Brazil.
E-mail: leandrohahn@epagri.sc.gov.br

Thyana Lays Brancher
Empresa de Pesquisa Agropecuária e Extensão Rural de Santa Catarina, Caçador, SC, Brazil.
E-mail: thyanabrancher@gmail.com

Mateus Barpp
Universidade Alto Vale do Rio do Peixe, Caçador, SC, Brazil.
E-mail: mateusbarpp132426@gmail.com

Bruna Gustmann Lazzaretti
Universidade Alto Vale do Rio do Peixe, Caçador, SC, Brazil.
E-mail: lbrunagustmann26@gmail.com

Douglas Luiz Grando
Universidade Federal de Santa Maria, Santa Maria, RS, Brazil.
E-mail: douglas.agn@hotmail.com

Allan Augusto Kokkonen
Universidade Federal de Santa Maria, Santa Maria, RS, Brazil.
E-mail: allan.kokkonen.agronomo@gmail.com

Gustavo Brunetto
Universidade Federal de Santa Maria, Santa Maria, RS, Brazil.
E-mail: brunettogustavo@gmail.com

✉ Corresponding author

Received
October 30, 2024

Accepted
November 13, 2025

How to cite
HAHN, L.; BRANCHER, T.L.; BARPP, M.; LAZZARETTI, B.G.; GRANDO, D.L.; KOKKONEN, A.A.; BRUNETTO, G. Critical impact of defoliation on garlic yield during key developmental stages. **Pesquisa Agropecuária Brasileira**, v.61, e03924, 2026. DOI: https://doi.org/10.1590/S1678-3921. pab2026.v61.03924.

Introduction

The reduction in garlic (*Allium sativum* L.) leaf area can be caused by several factors, such as insect pest attacks (Rosen et al., 2023). Among defoliating agents, hailstorms are the most important (Irigoyen et al., 1970), especially in Southern Brazil (Martins et al., 2017).

This is an open-access article distributed under the Creative Commons Attribution 4.0 International License

Studies evaluating the impact of a reduced leaf area have already been carried out in countries such as Spain (Irigoyen et al., 1970; Muro et al., 2000), Iran (Olfati et al., 2010), and Nigeria (Ahmed et al., 2015). However, these findings are dated and may not reflect the climatic patterns observed in Brazil.

Brazilian climatic conditions differ significantly from those of the abovementioned countries, likely causing different responses to defoliation in garlic cultivars, whose cultivation is strongly influenced by climatic conditions, such as photoperiod, air temperature, and rainfall, limiting their yield (Khar et al., 2020; Mahmudah et al., 2021). Negative effects reported in previous studies include delay in crop maturity, reduced yield and bulb development, and changes in bulb size grades due to defoliation (Muro et al., 2000; Ahmed et al., 2015). According to Lopez-Bellido et al. (2016), the bulb differentiation phase (stage 400) is the most critical in garlic cultivation, since this is when crop yield is mostly defined. Therefore, updates on the effects of defoliation can contribute to garlic crop management after such event. This is key considering that Brazil is the fifteenth largest garlic producer in the world, with a production of 132.9 thousand megagrams in the 2022 crop season (IBGE, 2024).

The objective of this work was to evaluate the effect of defoliation levels at different growth stages of garlic plants on total and marketable yields.

Materials and Methods

The experiments were conducted during the 2019/2020 and 2020/2021 crop seasons in commercial garlic fields located in the municipality of Lebon Régis, in the state of Santa Catarina, Southern Brazil (26°54'31"S, 50°46'10"W, at 980 m above sea level). According to Köppen's classification, the climate of the region is Cfb, warm temperate, with well-distributed rainfall throughout the year (Alvares et al., 2022). The soil is classified as a Nitossolo Bruno distrófico (Santos et al., 2018), i.e., a Typic Hapludox (Soil Survey Staff, 2022). The mean annual temperature is 15.5°C, and the mean annual rainfall is 1,674 mm. Precipitation and minimum and maximum air temperature during the experiments are presented in Figure 1.

A randomized complete block design was used, with four replicates, in a 5×4+1 factorial arrangement, with five garlic defoliation dates (30, 60, 90, 110, and 130 DAP), four defoliation levels (33, 50, 67, and 100%), and a control treatment without defoliation. The five defoliation dates correspond, respectively, to the following phenological stages proposed by Lopez-Bellido et al. (2016): 105, 108, 400, 407, and 408 in the 2019/2020 crop season; and 104, 109, 400, 407, and 408 in 2020/2021. Plant defoliation was carried out manually using scissors.

The defoliation of garlic leaves was based on leaf size, corresponding to the removal of one-third (33%), half (50%), two-thirds (67%), and all (100%) of the leaf blade. In plots with 100% defoliation, the entire leaf blade was cut from the sheath. The Chonan purple garlic cultivar, which is the most widely used in Southern Brazil, was planted on 7/19/2019 in the first cycle and on 7/20/2020 in the second. The used seed bulbs were from the fourth generation of multiplication, sanitized of viruses via meristem culture, and selected using sieves 5 (42–47 mm ∅) and 6 (47–56 mm ∅). Planting density was 31.9 seed bulbs per square meter, totaling a population of 319 thousand plants per hectare. The experimental plots consisted of a 1.5 m long raised bed composed of six plant rows, with a spacing of 0.23 m between rows and of 0.10 m between plants; the spacing between adjacent beds was 0.50 m.

At planting, 30 kg ha^{-1} N, 300 kg ha^{-1} P_2O_5, and 150 kg ha^{-1} K_2O were applied. The fertilizer was incorporated into the 0.00–0.20 m layer of the soil with a rotary hoe. As topdressing, 100 kg ha^{-1} N were applied in the form of urea, split in two applications of equal amounts at 30 and 105 DAP. Sprinkler irrigation was controlled by tensiometers installed at a depth of 0.20 m, and water applications were set to start at a soil matric potential of -30 kPa. Water requirements were assessed from crop evapotranspiration using the Class A tank method (Pereira et al., 1995).

At each defoliation stage, ten non-defoliated plants were sampled to record the number of green and fully expanded leaves, and bulb diameter was measured with a caliper (Table 1). For green leaves, blade length was measured along the midrib, and maximum width was recorded perpendicular to it. These measurements were used to calculate leaf area per plant, using the formula blade length × maximum width × 0.59 proposed by Wamser et al. (2007). The developmental stage of these sampled plants was defined according to the Biologische Bundesanstalt, Bundessortenamt and Chemische Industrie system (Lopez-Bellido et al., 2016).

Plants with four green leaves at 145 DAP were harvested from a 1.0 m bed section. This occurred 15 days after final defoliation at 130 DAP, allowing the complete formation and maturation of the bulbs.

The evaluated bulbs were kept for 60 days in a shed at room temperature for drying, after which they were cut and their diameter classified as marketable and non-marketable garlic according to Luengo et al. (1999). To determine marketable garlic, the bulbs were classified as grades 2 (< 32 mm), 3 (32–37 mm), 4 (37–42 mm), 5 (42–47 mm), 6 (47–56 mm), and 7 (> 56 mm). The yield sum of the graded bulbs was considered as "marketable yield", whereas the difference between total yield and marketable yield was considered "non-marketable yield".

Data were checked for assumptions of normality, homoscedasticity, and independence of residues using Shapiro-Wilk's test ($\alpha = 0.05$), the residues plot, and Durbin-Watson's test ($\alpha = 0.05$), respectively. When necessary, data were transformed to meet the assumptions. As autocorrelation was identified, the heteroskedasticity-autocorrelation consistent covariance estimator was used. The effects of defoliation levels and periods were analyzed through polynomial regression. The adjusted coefficient of determination (R^2) was used as fitting criteria for the models. All analyses were performed with the ExpDes.pt package (Ferreira et al., 2021) in the R, version 4.2.3, software (R Core Team, 2023). Table 2 shows both the transformation used for each variable and the adjusted R^2 as fitting criteria.

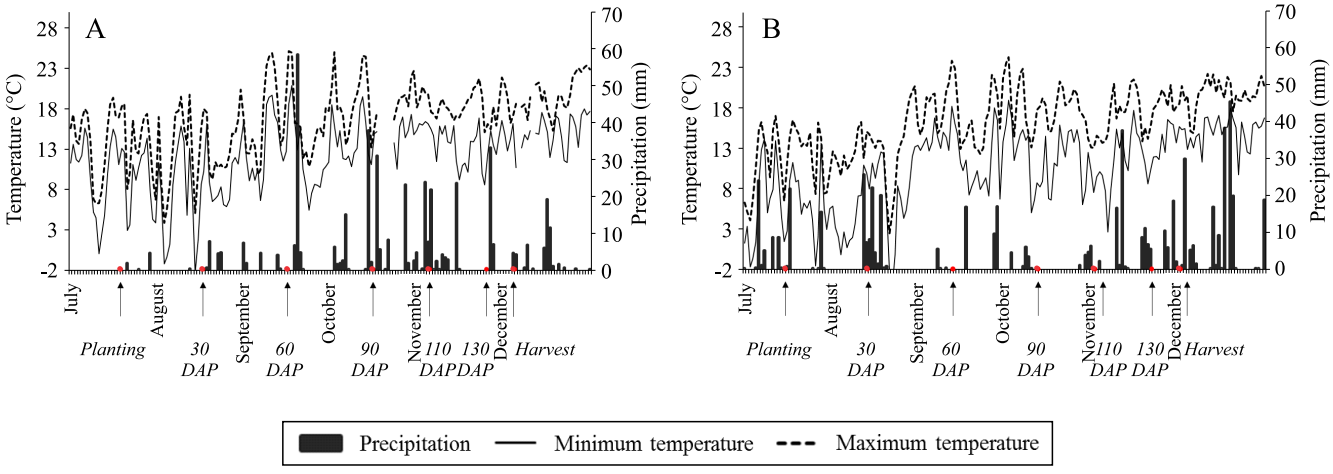

Figure 1. Precipitation and minimum and maximum air temperature recorded during garlic (*Allium sativum*) defoliation experiments in the 2019/2020 (A) and 2020/2021 (B) crop seasons in the municipality of Lebon Régis, in the state of Santa Catarina, Brazil. Red dots indicate sampling dates in terms of days after planting (DAP).

Table 1. Characterization of garlic (*Allium sativum*) plants under different defoliation treatments in the 2019/2020 and 2020/2021 crop seasons in the state of Santa Catarina, Southern Brazil.

Crop season	Days after planting	Number of expanded green leaves	Total number of expanded leaves	Phenological stage[(1)]	Leaf area (cm^2 per plant)	Bulb diameter (mm)
2019/2020	30	3.5	3.5	105	27.3	-
	60	4.7	6.5	108	226.3	-
	90	6.5	10.1	400	395.2	4.2
	110	6.9	10.4	407	256.5	35.6
	130	6.8	12.8	408	198.2	48.4
2020/2021	30	2.8	2.8	104	22.9	-
	60	4.9	7.4	109	206.2	-
	90	6.2	9.8	400	341.6	2.9
	110	6.7	10.6	407	225.6	40.1
	130	6.9	13.5	408	176.9	46.2

[(1)]Revised scale of the Biologische Bundesanstalt, Bundessortenamt, and Chemical industry system proposed by Lopez-Bellido et al. (2016).

Table 2. Summary of the main effects and significant interactions of defoliation percentage and days after planting (DAP) on garlic (*Allium sativum*) variables, as well as the best-fit model, model fit according to the coefficient of determination (R^2), and regression equation for each variable evaluated in the 2019/2020 and 2020/2021 crop season.

Garlic grade	Main effect	Model	R^2 (%)	Regression equation
2019/2020 crop season				
Non-marketable garlic[(1)]	Interaction: % defoliation within 90 DAP	Linear	94	$Y = 0.6587x - 5.09$
	Interaction: % defoliation within 110 DAP	Quadratic	97	$Y = 0.0097x^2 - 0.0936x + 6.44$
	Interaction: % defoliation within 130 DAP	Linear	92	$Y = 0.3772x + 8.98$
	Interaction: DAP within 67% defoliation	Cubic	89	$Y = -0.0002x^3 + 0.0537x^2 - 3.4237x + 84.70$
	Interaction: DAP within 100% defoliation	Cubic	98	$Y = -0.0007x^3 + 0.1561x^2 - 10.0203x + 200.69$
Grade 4[(2)]	Main: % defoliation	Linear	82	$Y = 0.0242x + 0.83$
Grade 5[(1)]	Interaction: % defoliation within 110 DAP	Quadratic	97	$Y = - 0.0316x^2 + 3.7828x - 48.28$
	Interaction: DAP within 50% defoliation	Cubic	85	$Y = - 0.0003x^3 + 0.0609x^2 - 3.8400x + 103.59$
	Interaction: DAP within 67% defoliation	Quadratic	91	$Y = - 0.0084x^2 + 1.6032x - 17.97$
	Interaction: DAP within 100% defoliation	Cubic	79	$Y = 0.0004x^3 - 0.0943x^2 + 6.2580x - 77.57$
Grade 6[(1)]	Interaction: % defoliation within 60 DAP	Linear	74	$Y = -0.3234x + 76.62$
	Interaction: % defoliation within 90 DAP	Linear	84	$Y = - 0.4948x + 64.54$
	Interaction: % defoliation within 110 DAP	Linear	84	$Y = - 0.7223x + 68.53$
	Interaction: DAP within 33% defoliation	Cubic	59	$Y = 0.0002x^3 - 0.0601x^2 + 4.3421x - 29.60$
	Interaction: DAP within 50% defoliation	Cubic	80	$Y = 0.0003x^3 - 0.0759x^2 + 5.1337x - 43.68$
	Interaction: DAP within 67% defoliation	Cubic	90	$Y = 0.0003x^3 - 0.0537x^2 + 2.8146x - 21.54$
	Interaction: DAP within 100% defoliation	Quadratic	64	$Y = 0.0091x^2 - 1.8217x + 106.92$
Grade 7[(3)]	Main: DAP	Linear	79	$Y = - 0.0612x - 5.36$
Marketable garlic	Interaction: % defoliation within 60 DAP	Linear	85	$Y = - 30.1596x + 10133.82$
	Interaction: % defoliation within 90 DAP	Linear	98	$Y = - 92.6227x + 11629.59$
	Interaction: % defoliation within 110 DAP	Linear	99	$Y = - 136.1878x + 13889.32$
	Interaction: % defoliation within 130 DAP	Linear	87	$Y = - 49.1733x + 10147.85$
	Interaction: DAP within 50% defoliation	Linear	78	$Y = - 21.0139x + 9806.58$
	Interaction: DAP within 67% defoliation	Quadratic	70	$Y = 0.9491x^2 - 180.6684x + 14245.03$
	Interaction: DAP within 100% defoliation	Quadratic	74	$Y = 1.4033x^2 - 288.4803x + 17285.53$
Total	Interaction: % defoliation within 60 DAP	Linear	98	$Y = -35.4549x + 12702.35$
	Interaction: % defoliation within 90 DAP	Linear	96	$Y = - 69.8949x + 13112.95$
	Interaction: % defoliation within 110 DAP	Linear	99	$Y = - 83.8476x + 13779.09$
	Interaction: DAP within 50% defoliation	Quadratic	80	$Y = 0.4587x^2 - 91.6801x + 14335.49$
	Interaction: DAP within 67% defoliation	Quadratic	84	$Y = 0.9112x^2 - 164.5132x + 16399.40$
	Interaction: DAP within 100% defoliation	Quadratic	81	$Y = 1.6189x^2 - 293.7467x + 19450.62$
2020/2021 crop season				
Non-marketable garlic[(1)]	Interaction: % defoliation within 60 DAP	Cubic	100	$Y= - 0.0002x^3 + 0.0297 x^2 - 1.6502 + 29.60$
	Interaction: DAP within 67% defoliation	Cubic	98	$Y= 0.0004x^3 - 0.0091 x^2 + 0.6595 - 10.87$
Grade 3[(2)]	Main: % defoliation	Linear	97	$Y = 0.0154x + 0.95$
	Main: DAP	Quadratic	86	$Y = - 0.0005x^2 + 0.0745x - 0.54$
Grade 4[(2)]	Main: DAP	Quadratic	70	$Y = - 0.0002x^2 + 0.0291x + 2.25$
Grade 5[(3)]	Interaction: % defoliation within 90 DAP	Linear	99	$Y= -0.5864x + 59.90$
	Interaction: % defoliation within 110 DAP	Linear	91	$Y= - 0.4041x + 58.30$
	Interaction: DAP within defoliation 67%	Cubic	50	$Y = 0.0002x^3 - 0.0428x^2 + 2.6682x - 7.19$
	Interaction: DAP within 100% defoliation	Cubic	94	$Y = 0.0002x^3 - 0.0490x^2 + 2.3909x - 8.04$
Grade 6[(2)]	Main: % defoliation	Linear	90	$Y = 0.0294x + 6.1777$
	Main: DAP	Quadratic	76	$Y = 0.0009x^2 - 0.1465x + 9.3238$
Marketable garlic[(3)]	Main: % defoliation	Linear	99	$Y= - 3892.29x + 11328.80$
	Main: DAP	Quadratic	79	$Y= 0.8354x^3 - 136.28x^2 + 13383$
Total[(3)]	Main: % defoliation	Linear	91	$Y= -660.21x + 11359$
	Main: DAP	Cubic	95	$Y= 0.0099x^3 - 1.5445x^2 + 32.286x + 10376$

[(1)]Untransformed data. [(2)]Data transformed by square root. [(3)]Data transformed by log(x).

Results and Discussion

In the 2019/2020 crop season, defoliation levels above 50% reduced yield from 30 DAP onwards (Figure 2 A), but did not show any significant effect at 30 DAP (Figure 2 B). Therefore, the later defoliation occurred, the higher the yield loss. For each garlic grade, the percentage of marketable yield was associated with defoliation levels and periods. In this case, the higher the percentage of defoliation, the higher the non-marketable yield, specifically from 67 to 100% defoliation at 110 DAP (Table 2). The control presented 70% less non-marketable garlic than the treatments subjected to defoliation.

Marketable yield was most negatively affected by defoliation at 90 and 110 DAP (Figure 2 A), reaching values near zero with complete defoliation at 110 DAP, i.e., the later defoliation was carried out, the lower the marketable yield (Figure 2 B). For example, 67% defoliation was associated to a marketable yield of about 6.0 Mg ha^{-1} per year at 90 DAP (Figure 2 A), which reduced to 4.0 Mg ha^{-1} per year after 90 DAP. However, these losses were exceptionally lower at 130 DAP, a later date but closer to harvest. With 100% defoliation, the loss in marketable yield was also lower at 130 DAP than at 90 DAP. These results show that yield is more sensitive to defoliations occurring from 90 to 110 DAP (Table 2).

In the 2020/2021 crop season, marketable yield decreased until 90 DAP and then increased, indicating that this critical period influences more significantly marketable yield (Figure 2 C). Once again, the higher

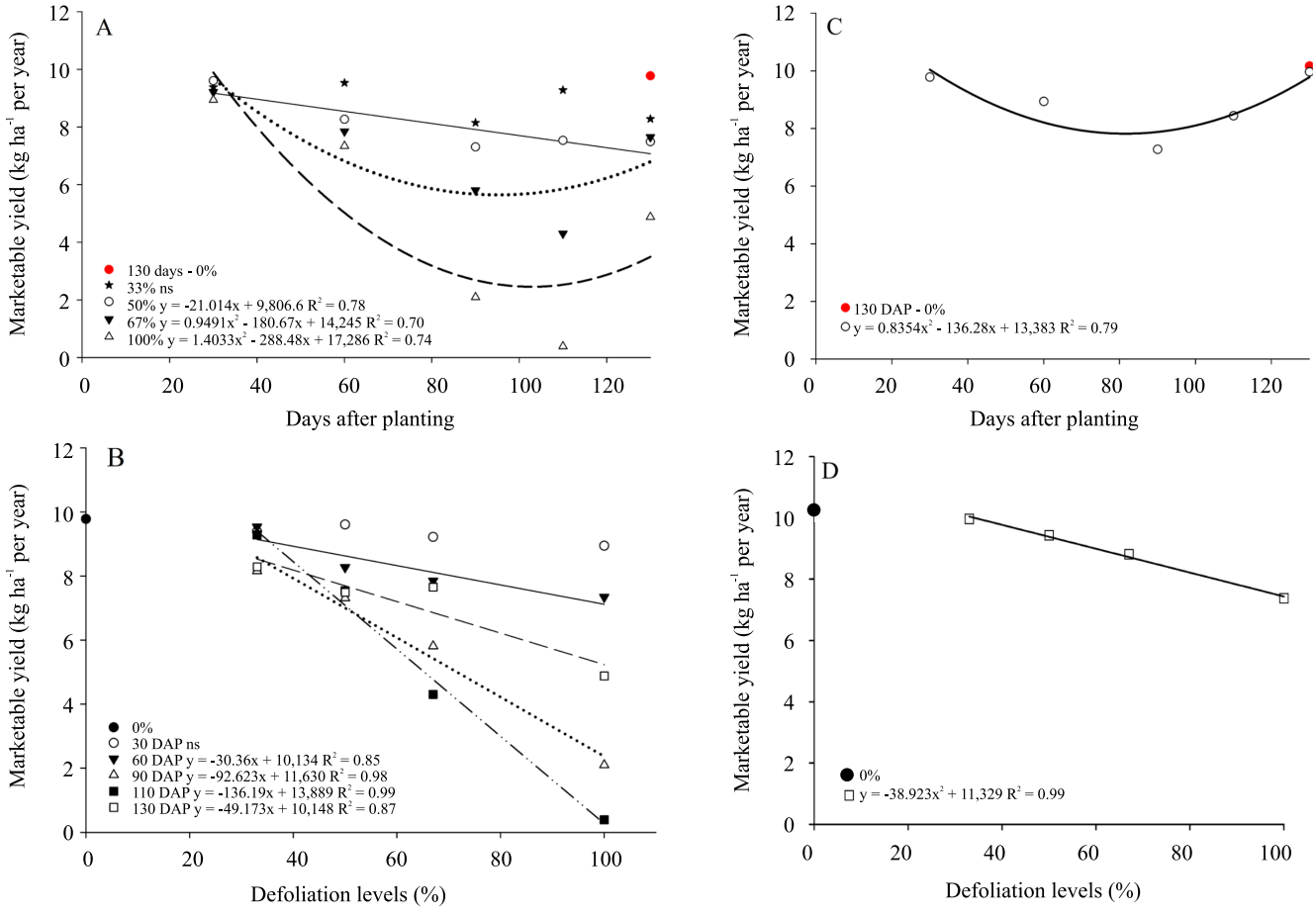

Figure 2. Garlic (*Allium sativum*) marketable yield as a function of days after planting (DAP) with different defoliation levels (A) and of defoliation levels at different DAP (B) in the 2019/2020 crop season, as well as of DAP (C) and different levels of defoliation (D) in the 2020/2021 crop season. The circle filled in black represents the control treatment, without defoliation. **Statically significant curves shown by plots C and D. nsNonsignificant.

the level of defoliation, the lower the marketable yield (Figure 2 D). Furthermore, 100% defoliation drastically increased the total percentage of non-marketable garlic to 6.3% (Table 2).

For both crop seasons, the critical period for garlic defoliation occurred from 90 to 110 DAP at phenological stages 400 to 407, a period coinciding with the onset of visible bulbification at 90 DAP, maximum leaf area, and peak of number of green leaves (Table 1). After the beginning of bulbification, leaf area loss markedly reduced solar radiation interception, resulting in smaller bulbs and a higher amount of non-marketable garlic. In addition, at this reproductive stage, garlic shifts the allocation of photosynthates from vegetative to clove growth, and leaf emergence ceases (Olfati et al., 2010; Lopez-Bellido et al., 2016). Muro et al. (2000) concluded that defoliation (13.5 total leaves, and 8 to 9 green leaves) at 128 DAP was the pivotal period for garlic, observing higher losses at 104 to 128 DAP, but not at prior stages or closer to harvest. These findings agree with those of Ahmed et al. (2015), who noted that defoliation had a lower effect on yield in phenological stages 104, 105, 108, 109, and 408 than in stages 400 to 407. This is likely because plants at the vegetative stage have potential to compensate partially for defoliation by producing new leaves from axillary meristems, leading to leaf area recovery (Lopez-Bellido et al., 2016).

In the 2019/2020 crop season, for each 1% of defoliation, the average loss of marketable yield was approximately 77 kg ha^{-1} per year, reaching 92 and 136 kg ha^{-1} per year at 90 and 110 DAP, respectively. In this season, the amount of garlic in each grade was associated with defoliation level and developmental stage. High defoliation levels at 90 to 100 DAP caused a lower frequency of bulbs in grades 5 and 6, for example.

In the 2020/2021 crop season, for each 1% of defoliation, the loss in marketable yield was 39 kg ha^{-1} per year. Muro et al. (2000) highlighted that these losses increase as the level of defoliation increases, reaching up to 30% of the total. The higher losses driven by the highest defoliation intensities led to a decrease in the percentage of bulbs in grades 5, 6, and 7, but to an increase in those in grades 3 and 4. This is problematic since the profitability of garlic production is associated with the sale of garlic in high grades. Therefore, the reduction in leaf area causes a substantial economic impact and may render cultivation unviable under severe yield losses.

Considering climatic conditions, higher rainfall volumes occurred during the critical period for obtaining marketable garlic in the 2019/2020 crop season, i.e., at 90–110 DAP (Figure 1). This means that there was a higher percentage of non-marketable garlic in the first cycle. Although no significant changes in temperature were observed in the two evaluated seasons, the presence of rainy and cloudy days favors the over-sprouting of garlic and a high incidence of bacteriosis (Hahn et al., 2024).

The Chonan purple garlic cultivar used in both harvests exhibits low levels of genetic diversity (Morales et al., 2013; Cunha et al., 2014). Therefore, the obtained results may be extrapolated to other cultivars of the same species in Brazil.

The obtained results may assist researchers in developing post-defoliation management strategies, especially to protect plants from pathogens that may enter through damaged leaf tissues (Wang et al., 2019; Kassaw et al., 2021). In this scenario, the use of biostimulant products, such as microbial inoculants, humic substances, protein hydrolysates, and algal or plant extracts, should be explored to mitigate defoliation-induced stress and promote plant recovery (Nephali et al., 2020; Mandal et al., 2023). Therefore, the findings of the present work underscore the need for further research to define effective management strategies to mitigate the stress caused by leaf loss.

Conclusions

1. The critical period for leaf loss in garlic (*Allium sativum*) crop occurs between 90 and 110 days after planting (phenological stages 400 to 407), corresponding to the onset of bulbification and maximum leaf area index.

2. Increasing defoliation levels progressively reduces marketable garlic yield, reaching losses of up to 50% under 50% defoliation and up to 100% under total defoliation during the critical period.

3. Defoliation reduces the proportion of high-grade bulbs (grades 5, 6, and 7) and increases non-marketable production, severely impacting crop profitability.

References

AHMED, H.G.; SAIDU, Y.I.; ALIYU, U.; BELLO, M.T. Effects of defoliation stages and defoliation intensity on growth and yield of garlic (*Allium sativum* L.) in Sokoto, Nigeria. **IOSR Journal of Agriculture and Veterinary Science**, v.8, p.96-99, 2015.

ALVARES, C.A.; SENTELHAS, P.C.; DIAS, H.B. Southeastern Brazil inland tropicalization: Köppen system applied for detecting climate change throughout 100 years of meteorological observed data. **Theoretical and Applied Climatology**, v.149, p.1431-1450, 2022. DOI: https://doi.org/10.1007/s00704-022-04122-4.

CUNHA, C.P. da; RESENDE, F.V.; ZUCCHI, M.I.; PINHEIRO, J.B. SSR-based genetic diversity and structure of garlic accessions from Brazil. **Genetica**, v.142, p.419-431, 2014. DOI: https://doi.org/10.1007/s10709-014-9786-1.

FERREIRA, E.B.; CAVALCANTI, P.P.; NOGUEIRA, D.A. ExpDes.pt: Pacote Experimental Designs (Portugues). 2021. Available at: <https://CRAN.R-project.org/package=ExpDes.pt>. Accessed on: Aug. 25 2025.

HAHN, L.; FELTRIM, A.L.; ENDER, M.M.; GRANDO, D.L.; MOURA-BUENO, J.M.; TASSINARI, A.; LIMA-RODRIGUES, M. de; BRUNETTO, G. Potassium reference values in garlic cultivars grown in a subtropical climate. **Journal of Soil Science and Plant Nutrition**, v.24, p.4049-4058, 2024. DOI: https://doi.org/10.1007/s42729-024-01829-3.

IBGE. Instituto Brasileiro de Geografia e Estatística. **Produção de cebola**. Available at: <https://www.ibge.gov.br/explica/producao-agropecuaria/cebola/br>. Accessed on: Sept. 10 2024.

IRIGOYEN, I.; DOMEÑO, I.; MURO, J. The effect of defoliation on the yield of leek (*Allium porrum* L.). **Spanish Journal of Agricultural Research**, v.8, p.434-439, 1970. DOI: https://doi.org/10.5424/sjar/2010082-1194.

KASSAW, A.; MIHRETIE, A.; AYALEW, A. Rate and spraying frequency determination of propiconazole fungicide for the management of garlic rust at Woreilu district, Northeastern Ethiopia. **Advances in Agriculture**, v.2021, art.8847782, 2021. DOI: https://doi.org/10.1155/2021/8847782.

KHAR, A.; HIRATA, S.; ABDELRAHMAN, M.; SHIGYO, M.; SINGH, H. Breeding and Genomic Approaches for Climate-Resilient Garlic. In: KOLE, C. (Ed.). **Genomic designing of climate-smart vegetable crops**. Cham: Springer, 2020. p.359-383. DOI: https://doi.org/10.1007/978-3-319-97415-6_8.

LOPEZ-BELLIDO, F.J.; LOPEZ-BELLIDO, R.J.; MUÑOZ-ROMERO, V.; FERNANDEZ-GARCIA, L.; LOPEZ-BELLIDO, L. New phenological growth stages of garlic (*Allium sativum*). **Annals of Applied Biology**, v.169, p.423-439, 2016. DOI: https://doi.org/10.1111/aab.12312.

LUENGO, R. de F.A.; CALBO, A.G.; LANA, M.M.; MORETTI, C.L.; HENZ, G.P. **Classificação de hortaliças**. Brasília: Embrapa Hortaliças, 1999.

MAHMUDAH, N.; JUNE, T.; IMPRON. Adaptive garlic farming on climate change and variability in Lombok. **Agromet**, v.35, p.116-124, 2021. DOI: https://doi.org/10.29244/j.agromet.35.2.116-124.

MANDAL, S.; ANAND, U.; LÓPEZ-BUCIO, J.; RADHA; KUMAR, M.; LAL, M.K.; TIWARI, R.K.; DEY, A. Biostimulants and environmental stress mitigation in crops: a novel and emerging approach for agricultural sustainability under climate change. **Environmental Research**, v.233, art.116357, 2023. DOI: https://doi.org/10.1016/j.envres.2023.116357.

MARTINS, J.A.; BRAND, V.S.; CAPUCIM, M.N.; FELIX, R.R.; MARTINS, L.D.; FREITAS, E.D.; GONÇALVES, F.L.T.; HALLAK, R.; DIAS, M.A.F.S.; CECIL, D.J. Climatology of destructive hailstorms in Brazil. **Atmospheric Research**, v.184, p.126-138, 2017. DOI: https://doi.org/10.1016/j.atmosres.2016.10.012.

MORALES, R.G.F.; RESENDE, J.T.V.; RESENDE, F.V.; DELATORRE, C.A.; FIGUEIREDO, A.S.T.; DA-SILVA, P.R. Genetic divergence among Brazilian garlic cultivars based on morphological characters and AFLP markers. **Genetics and Molecular Research**, v.12, p.270-281, 2013. DOI: https://doi.org/10.4238/2013.February.4.1.

MURO, J.; IRIGOYEN, I.; LAMSFUS, C.; FERNÁNDEZ MILITINO, A. Effect of defoliation on garlic yield. **Scientia Horticulturae**, v.86, p.161-167, 2000. DOI: https://doi.org/10.1016/S0304-4238(00)00145-X.

NEPHALI, L.; PIATER, L.A.; DUBERY, I.A.; PATTERSON, V.; HUYSER, J.; BURGESS, K.; TUGIZIMANA, F. Biostimulants for plant growth and mitigation of abiotic stresses: a metabolomics perspective. **Metabolites**, v.10, art.505, 2020. DOI: https://doi.org/10.3390/metabo10120505.

OLFATI, J.A.; PEYVAST, GH.; SANAVI, M.; SALEHI, M.; MAHDIPOUR, M. Effect of defoliation on the yield and quality of garlic. **Journal of Herbs, Spices & Medicinal Plants**, v.16, p.91-97, 2010. DOI: https://doi.org/10.1080/10496475.2010.481917.

PEREIRA, A.R.; VILLA NOVA, N.A.; PEREIRA, A.S.; BARBIERI, V. A model for the class A pan coefficient. **Agricultural Water Management**, v.76, p.75-82, 1995. DOI: https://doi.org/10.1016/0168-1923(94)02224-8.

R CORE TEAM. **R**: a language and environment for statistical computing [software]. Vienna: R Foundation for Statistical Computing, 2023.

ROSEN, C.; ARENZ, B.; HUTCHISON, B.; TONG, C.; BECKER, R.; SHARMA, V.; FORD, J.; NESSER, S. **Growing garlic in Minnesota**. [Saint Paul]: University of Minnesota Extension, 2023. p.1-28.

SANTOS, H.G. dos; JACOMINE, P.K.T.; ANJOS, L.H.C. dos; OLIVEIRA, V.Á. de; LUMBRERAS, J.F.; COELHO, M.R.; ALMEIDA, J.A. de; ARAÚJO FILHO, J.C. de; OLIVEIRA, J.B. de; CUNHA, T.J.F. **Sistema brasileiro de classificação de solos**. 5.ed. rev. e ampl. Brasília: Embrapa, 2018. 356p.

SOIL SURVEY STAFF. **Keys to soil taxonomy**. 13th ed. Washington: USDA, Natural Resources Conservation Service, 2022. 401p.

WAMSER, A.F.; MUELLER, S.; PALLADINI, L.A. Estimativa da área foliar do alho usando dimensões e biomassa seca do limbo foliar. **Agropecuária Catarinense**, v.20, p.49-52, 2007. DOI: https://doi.org/10.52945/rac.v20i1.876.

WANG, J.; SHI, L.; WANG, D.; LI, L.; LOAKE, G.J.; YANG, X.; JIANG, J. White rot disease protection and growth promotion of garlic (*Allium sativum*) by endophytic bacteria. **Plant Pathology**, v.68, p.1543-1554, 2019. DOI: https://doi.org/10.1111/ppa.13066

Author contributions

Leandro Hahn: conceptualization (equal), data curation (equal), funding acquisition (equal), investigation (equal), methodology (equal), project administration (equal), resources (equal), supervision (equal), writing - review & editing (equal); **Thyana Lays Brancher**: formal analysis (equal), software (equal), validation (equal), visualization (equal), writing - original draft (equal); **Mateus Barpp**: formal analysis (equal), investigation (equal); **Bruna Gustmann Lazzaretti**: formal analysis (equal)investigation (equal)methodology (equal) project administration (equal); **Douglas Luiz Grando**: data curation (equal), visualization (equal), writing - review & editing (equal); **Allan Augusto Kokkonen**: writing - review & editing (equal); **Gustavo Brunetto**: methodology (equal), resources (equal), validation (equal), visualization (equal), writing - review & editing (equal).

Chief editor: Edemar Corazza
Edited by: Daniel Kinpara

Data availability statement

Data available upon request: research data are only available upon reasonable request to the corresponding author.

Declaration of use of AI technologies

No generative artificial intelligence (AI) was used in this study.

Conflict of interest statement

The authors declare no conflicts of interest.

Acknowledgments

To Fundação de Amparo à Pesquisa e Inovação do Estado de Santa Catarina (FAPESC) and to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), for scholarship (contract number 2023TR000346).

Disclaimer/Publisher's note

The statements, opinions, and data contained in all texts published in Pesquisa Agropecuária Brasileira (PAB) are solely those of the individual author(s) and not of the journal's publisher, editor, and editorial team, who disclaim responsibility for any injury to people or property resulting from any referred ideas, methods, instructions, or products.

The mention of specific chemical products, machines, and commercial equipment in the texts published in this journal does not imply their recommendation by the publisher.