

Natural minerals as a means of limiting *Phytophthora infestans* and *Alternaria solani* on tomato

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Abstract

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Effective disease management requires the implementation of alternative and environmentally friendly approaches, including the use of natural mineral materials with the potential for direct and indirect suppression of phytopathogens. The aim of the study was to evaluate the effectiveness of natural mineral products (Glaucanite, Dolomite), their combinations and Fertilex Silicon on the pathogens *Phytophthora infestans* and *Alternaria solani* on tomato, *in vitro* and *in vivo* experiments. *In vitro* results show that all mineral variants significantly suppress mycelial growth, with inhibition in *Ph. infestans* reaching 82–100%, and in *A. solani* – 40–100%. The highest activity was demonstrated by Fertilex Silicon, which completely blocked the growth of the pathogens. Dolomite and Glaucanite exhibit moderate to high activity, and the combined variants have a stable, but not synergistic effect. *In vivo* experience confirmed the trends from laboratory tests. All treated variants significantly reduced the disease infestation index compared to the control, with Fertilex Silicon showing the strongest effect, followed by Dolomite 1.5% and Glaucanite 1.5%. Mineral products, at higher concentrations and in combination, provide stable and moderate disease suppression. The results obtained show that these products have direct fungicidal activity and contribute to increasing the physiological resistance of plants, and can be a valuable component in integrated disease management strategies.

Keywords: biological testing; mineral products; pathogens

Introduction

Diseases caused by *Phytophthora infestans* and *Alternaria solani* represent some of the most significant phytopathological problems in tomatoes, causing serious economic losses annually and hindering sustainable tomato production (Ivanov et al., 2021). Genetic plasticity of *Ph. infestans* is the main reason for the rapid development of fungicide resistance and the breakthrough of resistance in varieties based on single R-genes.

The disease causes losses of up to 10 billion USD per year. The pathogen is adaptable and possesses diverse molecular mechanisms of infection, including the formation of appressoria, haustoria, and the transition from a biotrophic to

necrotrophic phase. They emphasize that successful management of the disease requires a combination of agrotechnical measures, chemical control, prognostic systems, and genetic resistance (Dong and Zhou 2022).

Alternaria solani is a soil-dwelling fungal pathogen capable of surviving for more than ten years in soil, seeds, or plant debris. Isolates of *A. solani* from the USA, Greece, Cuba, Canada, Russia, Turkey, South Africa, Brazil and China show high genetic variability, which is associated with mutations, selection and gene flow. This diversity poses a serious risk to the resistance of varieties and the effectiveness of fungicides Mugao (2023). The author shows that both *A. solani* and *Ph. infestans* are pathogens with high morphological and genetic variability, which makes them highly

adaptable and difficult to control. This variability affects the epidemiology of the diseases, the effectiveness of fungicides and the resistance of varieties. The author emphasizes that knowledge of the genetic diversity of pathogens is key to the development of effective management strategies, including the selection of resistant varieties, population monitoring and integrated pest management systems.

Sustainable disease management requires the application of mineral resources that improve the chemical, physical and biological properties of the soil without leading to environmental risks. The particular importance among these resources is dolomite and glauconite, two natural minerals with different compositions and mechanisms of action, but with proven potential to increase yields and improve soil health. Dolomite, a mineral with the formula $\text{CaCO}_3\text{MgCO}_3$, is widely used in acidic soils. After its application, the calcium and magnesium carbonates react with hydrogen ions, which leads to a gradual increase in pH and neutralization of acidity. This is essential because in acidic soils phosphorus is often fixed in forms that are difficult to assimilate, and the toxicity of aluminum limits root development. Dolomite neutralizes soil acidity and reduces fertilizer costs, which highlights its role as an effective means of improving the nutrient environment (Jyothsna et al., 2024).

In addition to pH adjustment, dolomite supplies two key elements, calcium and magnesium, which are involved in the construction of cell walls, the regulation of enzymatic processes and photosynthesis. Their deficiency leads to chlorosis, poor growth and low productivity, and in crops such as peanuts, calcium is critical for pod formation. In field conditions, the application of dolomite leads to a significant increase in yield, with the increase reaching 31.7% compared to the control at optimal doses (Jyothsna et al., 2024). This highlights the importance of minerals for crops sensitive to calcium deficiency, as well as for systems in which acidity limits the absorption of nutrients.

Glauconite is a green phyllo-silicate mineral rich in potassium, iron, magnesium and trace elements, which is attracting increasing attention as a sustainable source of nutrients and soil conditioner. Its layered structure determines its high cation exchange capacity and its potential to retain and gradually release nutrients. Glauconite acts as a reservoir that gradually releases nutrients, making it a valuable resource for sandy soils subject to strong potassium leaching. In addition, the mineral improves soil structure, increases water retention and stimulates microbial activity, while acting as a natural sorbent of heavy metals through ion exchange and surface complexes. These properties make it a tool not only for improving fertility, but also for remediation of contaminated soils (Naeem et al., 2024).

The application of glauconite is diverse and includes broadcasting, incorporation by plowing, feeding during vegetation and foliar application (Naeem et al., 2024). Despite the many advantages, the authors emphasize the need for careful dosing, as excessive application can lead to nutrient imbalances or increased salinity.

Shchemelinina et al. (2017) showed that the combination of glauconite and immobilized bacteria *Pseudomonas yamanorum* leads to efficient degradation of petroleum products, while simultaneously restoring microbial activity – a key factor in suppressing pathogenic complexes activated in degraded soils.

In a broader context, Cataldo et al. (2021) showed that sustainable practices – compost, mycorrhizal fungi, Trichoderma, cover crops and zeolite improve the physical, chemical and biological properties of the soil, reduce the phytotoxicity of heavy metals and increase resistance to pathogens. This confirms that mineral and organic amendments are a key element in integrated soil health management.

Experimental data from Arrieta et al. (2020) show that glauconite acts as an effective source of K, Si and Mn, with the gradual release of these elements leading to increased biomass and better mineral nutrition in rice. Silicon and manganese are well-known factors for inducing systemic resistance and strengthening cell walls, which reduces susceptibility to pathogens such as *Fusarium*, *Erysiphe* and *Botrytis*. This highlights the importance of glauconite not only as a fertilizer, but also as a means of improving the phytosanitary status of crops.

In parallel with glauconite, dolomite also stands out as an important mineral improver with phytopathological significance. Shaaban et al. (2025) proves that dolomite is the most effective material for the remediation of acidic Cd-contaminated soils, by increasing pH, reducing mobile cadmium to minimal values and restoring enzymatic and microbial activity. Reducing oxidative stress and improving the physiological state of plants lead to lower susceptibility to pathogens. At the same time, Resigia and Kristina (2025) emphasize that the effect of dolomite depends on the initial state of the soil, which is important when planning fertilization and phytosanitary strategies.

In the context of increasing demands for sustainable agriculture, dolomite and glauconite represent two minerals with complementary functions: the former is key for correcting acidity and supplying calcium and magnesium, and the latter for slow release of potassium, improving soil structure and remediation. Understanding their mechanisms of action and their optimal application is essential for developing effective strategies for soil fertility management and enhancing the resilience of agroecosystems (Gupta et al., 2023).

Available research shows that glauconite, dolomite and related natural materials have significant potential to improve soil health, stimulate beneficial microbiota, reduce heavy metal toxicity and salt stress, and increase plant physiological resistance and limit phytopathogens. This makes them valuable tools for sustainable agriculture and integrated disease management (Xalmuratova, 2025).

The aim of the scientific work is to evaluate the effectiveness of various mineral and combination products on the development of *Phytophthora infestans* and *Alternaria solani* on tomato.

Material and Methods

In vitro experimental

The effect of various mineral products was tested using the Thornbury method (modified): Glauconite (G) 1% and 1.5%, Dolomite (D) 1% and 1.5%, combinations (Glauconite and Dolomite) G+D 1% and 1.5%, Fertilex Silicon (F 0.7%) (quartz). The experiment was conducted under laboratory conditions on potato dextrose agar (PDA), poured into standard Petri dishes (20 ml). A 14-day culture of the pathogens – *Ph. infestans* and *A. solani* – was used to inoculate the dishes. Mycelial bodies with a diameter of 8 mm were cut and placed in the center of the dishes on the surface of the nutrient medium. Each variant was set in 3 replicates, incubated in a thermostat at 25°C. *Ph. infestans* and *A. solani* are part of the phytopathological collection of the Maritsa Vegetable Crops Research Institute-Plovdiv, Bulgaria. The diameter of the colonies was measured on the 3rd, 6th and 9th day after inoculation. For each plate, two mutually perpendicular diameters of the colony were recorded, from which the average value was calculated (Vasileva, 2023).

The percentage of inhibition was calculated using the following formula:

$$I (\%) = (C - T) / C * 100, \text{ where:}$$

(I) – growth inhibition (%);

(C) – mean mycelial diameter in the control (mm);

(T) – mean mycelial diameter in the respective variant (mm).

In vivo experimental

The test was conducted with tomatoes in glass greenhouses under a natural infectious background. Three treatments were performed at 7-day intervals, with each replicate including 5 plants. The tested variants included individual mineral products Glauconite (G) 1% and 1.5%, Dolomite (D) 1% and 1.5%, combinations (Glauconite and Dolomite) G+D 1% and 1.5%, Fertilex (F 0.7%), as well as an untreated

control. Three consecutive treatments were carried out at an interval of seven days. The degree of attack by the pathogens was recorded before treatment with the mineral products. The following readings were: first reading on 7 days after first treatment, second on 14 days after first treatment/7 days after the second treatment and third on 21 days after first treatment/7 days after the third treatment. The products included in the study were provided by Agriflor Ltd – Sofia.

The disease development infestation index is calculated using the McKinney (1923) formula:

$$I = \sum(n*k)/N*K*100, \text{ where:}$$

I – Disease development index, %;

n – Number of samples scored for the corresponding score;

k – Infection rate score for the corresponding score;

N – Total number of samples scored;

K – Highest score for the score;

Five-point scale (0 – 4).

The effectiveness (%) was calculated using the Abbott (1925) formula:

$$E = (A - B)/A*100, \text{ where}$$

E – Effectiveness %;

A – Disease development infestation index, in the control;

B – Disease development infestation index, in the treated variants.

Disease development assessments were performed after each treatment by visually determining the degree of infestation on a five-point scale (0–4). The effectiveness of the individual variants was determined relative to the untreated control.

Statistical analysis

The data were statistically processed using analysis of variance (ANOVA), and differences between variants were determined using LSD or Tukey at a significance level of $p \leq 0.05$. Throughout the investigation, data processing and statistical analyses were performed using the MS Excel Analysis ToolPak Add-Ins (<https://support.office.com>), as well as the R statistical environment (version 3.1.3) operated through RStudio (version 0.98), with the implementation of the agricolae package (version 1.2-2).

Results and Discussion

Foliar applications of micronized mineral products have a complex positive effect on plants, simultaneously improving their physiological condition and limiting the development of pathogens. The products applied as fine suspension concentrates form a stable mineral film on the leaf surface and change

the local microenvironment in a way that makes infection more difficult. At the same time, the trace elements released by the minerals support the nutritional status of plants and stimulate their natural defense mechanisms (Acheuk et al., 2022).

The results show that all tested variants with the mineral products Glaucosite (G), Dolomite (D), their combined forms (G+D), as well as Fertilex Silicon (F), have a strong inhibitory effect on the mycelial growth of *Ph. infestans* from the third day after inoculation (Table 1, Figure 1). At this early stage, the inhibition varies between 83.3% and 98.3%, with the highest results demonstrated by Fertilex Silicon (F 0.7%), which completely stops the development of the pathogen. The mineral variants Dolomite (D 1% and D 1.5%) and Glaucosite (G 1%) also show extremely high activity. On the sixth day, the differences between the variants become even more pronounced. Fertilex Silicon (F 0.7%) and both variants of Dolomite (D 1% and D 1.5%) achieve almost complete inhibition (99.3 – 99.7%). Glaucosite 1.5% also showed strong mycelial inhibition (98.2%), while G

1% and G+D 1.5% demonstrated lower inhibition values. The combination G+D 1% remained consistently effective (96.6%), but did not outperform the individual mineral components, suggesting a lack of synergism between Glaucosite and Dolomite for this pathogen. On the ninth day, the trend was stabilized and even intensified. Fertilex Silicon (F 0.7%) completely blocked the growth of *P. infestans*, while Dolomite 1% and 1.5% again showed almost complete inhibition (99.5 – 99.8%). Glaucosite 1.5% remained highly effective (97.5%), while G 1% and especially G+D 1.5% showed weaker activity. This indicates a possible antagonistic effect at the higher concentration of the combined treatment.

The results for *A. solani* showed that all treatment options with Glaucosite (G), Dolomite (D), their combined forms (G+D) and Fertilex Silicon (F) have a distinct inhibitory effect on mycelial growth, but to a lesser extent compared to *Ph. infestans* (Table 1, Figure 1). The readings conducted on the third day show significant differences between the options. Fertilex Silicon (F 0.7%) completely inhibits growth. Glau-

Table 1. Effectiveness of mineral treatments on mycelial growth (mm) and inhibition (%) of *Phytophthora infestans* and *Alternaria solani* in vitro

Treatments	Average mycelia growth (mm) <i>Ph. infestans</i>	Inhibition (%) <i>Ph. infestans</i>	Average mycelia growth (mm) <i>A. solani</i>	Inhibition (%) <i>A. solani</i>
3-day				
Glaucosite 1%	0.17	91.70	3.00	66.70
Glaucosite 1.5%	0.33	83.30	1.00	88.90
Dolomite 1%	0.17	91.70	5.33	40.70
Dolomite 1.5%	0.17	91.70	1.33	85.20
Glaucosite + Dolomite 1%	0.20	90.00	1.67	81.50
Glaucosite + Dolomite 1.5%	0.13	93.30	1.33	85.20
Fertilex Silicon 0.7%	0.03	98.30	0.00	100.00
6-day				
Glaucosite 1%	1.00	89.70	7.00	66.10
Glaucosite 1.5%	0.17	98.20	6.00	71.00
Dolomite 1%	0.07	99.30	8.00	61.30
Dolomite 1.5%	0.03	99.70	7.33	64.50
Glaucosite + Dolomite 1%	0.33	96.60	6.33	69.40
Glaucosite + Dolomite 1.5%	0.83	91.40	7.67	62.90
Fertilex Silicon 0.7%	0.03	99.70	0.00	100.00
9-day				
Glaucosite 1%	1.00	92.30	12.00	59.10
Glaucosite 1.5%	0.33	97.50	10.00	65.90
Dolomite 1%	0.07	99.50	11.00	62.50
Dolomite 1.5%	0.03	99.80	9.00	69.30
Glaucosite + Dolomite 1%	1.33	89.80	11.67	60.20
Glaucosite + Dolomite 1.5%	2.33	82.10	10.67	63.60
Fertilex Silicon 0.7%	0.00	100.00	0.00	100.00

Abbreviations: G – Glaucosite; D – Dolomite; G + D – Glaucosite + Dolomite; F – Fertilex Silicon.

Source: Authors' own elaboration

conite 1.5% and Dolomite 1.5% also show a high percentage of inhibition (88.9% and 85.2%), while the combination G+D 1% and G+D 1.5% demonstrates a stable, but slightly lower inhibition (81.5–85.2%). The weakest efficacy at this stage is with Dolomite 1% (40.7%). On the sixth day, the activity of most products slightly decreased, which is characteristic of the faster growth and higher regenerative capacity of *A. solani*. However, Fertilex Silicon (F 0.7%) again achieved complete inhibition (100%). Glauconite 1.5% and the combination G+D 1% maintained high activity (71.0% and 69.4%), while the remaining variants – including Dolomite 1% and 1.5% – showed moderate inhibition in the range of 61.3–64.5%. The trend continued until the ninth day: Fertilex Silicon (F 0.7%) remained the only variant that completely blocked the growth of the pathogen (100%). Dolomite 1.5% and Glauconite 1.5% showed the highest efficiency (69.3% and 65.9%), while the combinations G+D 1% and 1.5% demonstrated similar values (60.2–63.6%).

The results of ANOVA and Tukey HSD clearly show that all treatment options have a strong and statistically significant effect on the inhibition of *Ph. infestans* at all reporting

times (Table 2). On each of the three days, ANOVA reports extremely high F-values (over 150, 200 and 250, respectively), confirming the presence of strong differences between the options ($p < 0.001$).

The results of ANOVA and Tukey HSD show clear and statistically significant differences between the treatment options at all reporting times (Table 3). The extremely high F-values (over 120, 140 and 180 for the 3rd, 6th and 9th days, respectively), and $p < 0.001$ confirm that *A. solani* responds differently to the individual products and combinations, with the effect of the treatments being stable and distinct over time.

Under natural conditions, treatment with Glauconitee, Dolomite and Fertilex Silicon have a clear impact on the development of *Phytophthora infestans*, with effectiveness evident after the third reading and increasing, duo to the three consecutive treatments (Table 4). The initial values of the infestation index show natural variability between the variants, but after application of the minerals, a clear reduction in disease intensity was observed in all variants compared to the control. The control remained the most affected 7-day after first treatment, while the treated variants were divided into two groups. Fer-

Table 2. ANOVA and Tukey HSD test for inhibition (%) of *Phytophthora infestans*

Treatments	Day 3 (Tukey)	Day 6 (Tukey)	Day 9 (Tukey)
Glauconite 1%	91.7% (b)	89.7% (d)	92.3% (c)
Glauconite 1.5%	83.3% (c)	98.2% (a)	97.5% (b)
Dolomite 1%	91.7% (b)	99.3% (a)	99.5% (a)
Dolomite 1.5%	91.7% (b)	99.7% (a)	99.8% (a)
Glauconite + Dolomite 1%	90.0% (b)	96.6% (b)	89.8% (d)
Glauconite + Dolomite 1.5%	93.3% (ab)	91.4% (c)	82.1% (e)
Fertilex Silicon 0.7%	98.3% (a)	99.7% (a)	100% (a)
Control	0% (d)	0% (e)	0% (f)

Abbreviations: G – Glauconite; D – Dolomite; G + D – Glauconite + Dolomite; F – Fertilex Silicon.

Legend: Means followed by different letters within a column differ significantly according to Tukey's HSD test.

ANOVA summary: Day 3 ($F > 150$, $p < 0.001$); Day 6 ($F > 200$, $p < 0.001$); Day 9 ($F > 250$, $p < 0.001$).

Source: Authors' own elaboration

Table 3. ANOVA and Tukey HSD test for inhibition (%) of *Alternaria solani*

Treatments	Day 3 (Tukey)	Day 6 (Tukey)	Day 9 (Tukey)
Glauconite 1%	66.7% (d)	66.1% (c)	59.1% (d)
Glauconite 1.5%	88.9% (b)	71.0% (b)	65.9% (c)
Dolomite 1%	40.7% (e)	61.3% (d)	62.5% (c)
Dolomite 1.5%	85.2% (b)	64.5% (c)	69.3% (b)
Glauconite + Dolomite 1%	81.5% (c)	69.4% (b)	60.2% (d)
Glauconite + Dolomite 1.5%	85.2% (b)	62.9% (d)	63.6% (c)
Fertilex Silicon 0.7%	100% (a)	100% (a)	100% (a)
Control	0% (f)	0% (e)	0% (e)

Abbreviations: G – Glauconite; D – Dolomite; G + D – Glauconite + Dolomite; F – Fertilex Silicon.

Legend: Means followed by different letters within a column differ significantly according to Tukey's HSD test. *ANOVA summary: Day 3 ($F > 120$, $p < 0.001$); Day 6 ($F > 140$, $p < 0.001$); Day 9 ($F > 180$, $p < 0.001$).

Source: Authors' own elaboration

tilex Silicon 0.7%, Glauconite 1% and Dolomite 1% formed an intermediate group with lower intensity, while Glauconite 1.5%, Dolomite 1.5% and the combined variants G+D showed even stronger suppression of the pathogen. This shows that the mineral products begin to show effectiveness after the first

reading, with higher concentrations and combinations leading to stronger suppression of symptoms. All variants with Glauconite, Dolomite and Fertilex Silicon 14 days after first treatment fall into one common statistical group, which means that the differences between them decrease and all mineral prod-

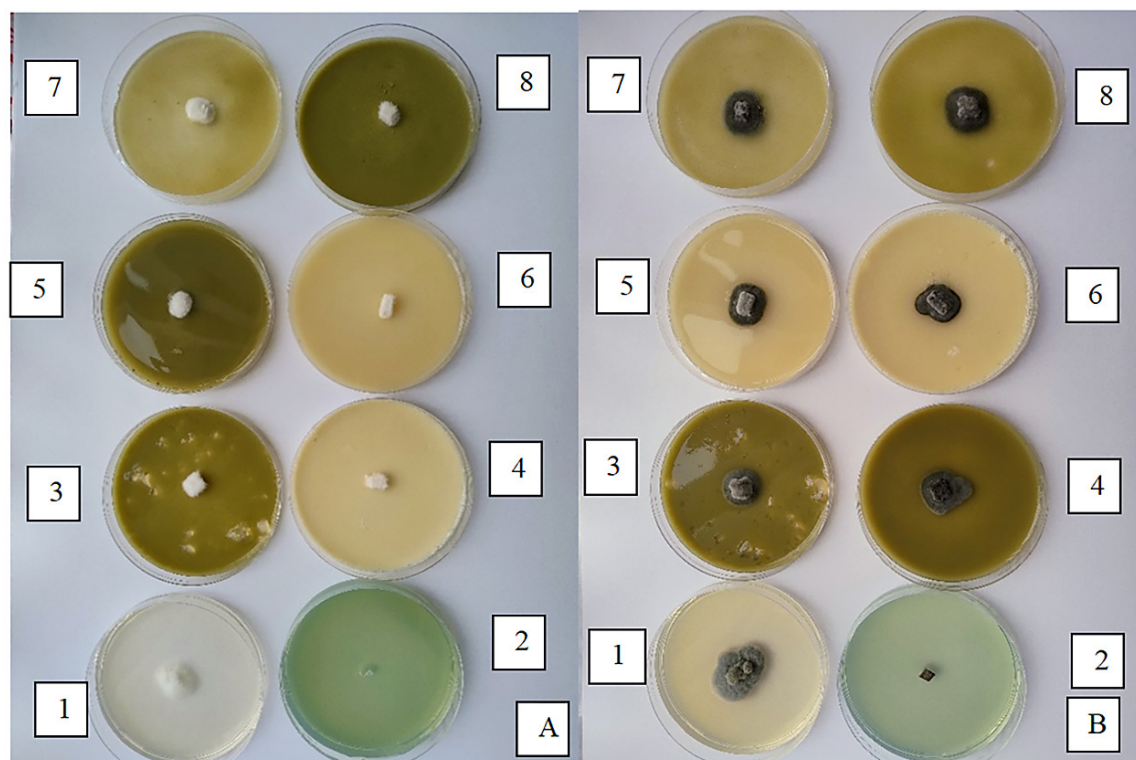


Fig. 1. Effect of mineral treatments on mycelial growth of *Phytophthora infestans* and *Alternaria solani*
Legend: *A – *Phytophthora infestans* – 1 – Untreated control; 2 – Fertilex Silicon 0.7%; 3 – Glauconite 1%;
4 – Dolomite 1%; 5 – Glauconite 1.5%, 6 – Dolomite 1.5%; 7 – G+D 1%; 8 – G+D 1.5%

B – *Alternaria solani* – 1 – Untreated control; 2 – Fertilex Silicon 0.7%; 3 – Glauconite 1.5%; 4 – Glauconite 1%;
5 – Dolomite 1.5%; 6 – Dolomite 1%; 7 – G+D 1.5%; 8 – G+D 1%

Source: Authors' own elaboration

Table 4. Mean values of disease infestation index (%) of *Phytophthora infestans* under in vivo conditions

Treatments	Before treatment	7-day after first treatment	14-day after first treatment	21-day after first treatment
Glauconite 1%	8.54 c	7.08 b	5.88 b	5.26 c
Glauconite 1.5%	9.85 c	6.64 c	5.79 b	4.93 c
Dolomite 1%	13.10 b	7.15 b	5.87 b	5.25 c
Dolomite 1.5%	16.31 a	6.15 c	5.08 b	4.85 c
Glauconite + Dolomite 1%	15.76 a	6.43 c	5.77 b	5.20 c
Glauconite + Dolomite 1.5%	16.49 a	6.19 c	5.34 b	5.07 c
Fertilex Silicon 0.7%	13.6 b	7.03 b	5.85 b	6.13 b
Control	13.50 b	17.54 a	18.15 a	20.15 a

Abbreviations: G – Glauconite; D – Dolomite; G + D – Glauconite + Dolomite; F – Fertilex Silicon.

Legend: Means followed by different letters within a column differ significantly at $p \leq 0.05$ according to Duncan's multiple range test.

Source: Authors' own elaboration

ucts show similar efficacy. The control remains the only one in the highest group, which emphasizes the significant effect of the treatment. This result shows stabilization of the action of the mineral products and Fertilex Silicon, regardless of the concentration or combination. After 21-day after first treatment, a new distinction between the variants is observed. Fertilex Silicon stands out as the most effective among the treated variants, forming a separate group with the lowest disease intensity. All variants with Glauconite and Dolomite, whether alone or combined, fall into one common group, which shows similar, moderate, but stable effectiveness.

The results of the four monitoring time points show distinct dynamics in the development of *A. solani* and clearly distinguish the effectiveness of Glauconite, Dolomite and

Fertilex Silicon compared to the control (Table 5). Natural differences between the variants were observed already at 7-day after first treatment, with the control having the highest intensity of symptoms and Glauconite 1% having the lowest. Fertilex Silicon, Glauconite 1% and Dolomite 1% form an intermediate group with moderately reduced intensity, while higher concentrations of Glauconite and Dolomite, as well as the G+D combinations, show even stronger suppression of the pathogen at 14-day after first treatment. The lowest intensity was recorded for G+D 1%, which places it in a separate group “d”. Glauconite, Dolomite, their combinations and Fertilex Silicon fall into a common group “b”, which means that the differences between them are no longer statistically significant. The control remains the only one in group

Table 5. Mean values of disease infestation index (%) of *Alternaria solani* under *in vivo* conditions

Treatments	Before treatment	7-day after first treatment	14-day after first treatment	21-day after first treatment
Glauconite 1%	6.92 c	5.24 b	4.12 b	3.69 c
Glauconite 1.5%	9.61 c	4.86 c	3.73 c	3.41 c
Dolomite 1%	7.25 b	5.21 b	4.09 b	3.64 c
Dolomite 1.5%	8.43 b	4.84 c	3.65 c	3.40 c
Glauconite + Dolomite 1%	8.22 b	3.36 d	3.75 c	3.48 c
Glauconite + Dolomite 1.5%	7.98 b	4.76 c	3.72 c	3.41 c
Fertilex Silicon 0.7%	7.93 b	5.17 b	4.10 b	3.72 b
Control	12.00 a	12.29 a	12.49 a	13.15 a

Abbreviations: G – Glauconite; D – Dolomite; G + D – Glauconite + Dolomite; F – Fertilex Silicon.

Legend: Means followed by different letters within a column differ significantly at $p \leq 0.05$ according to Duncan's multiple range test.

Source: Authors' own elaboration

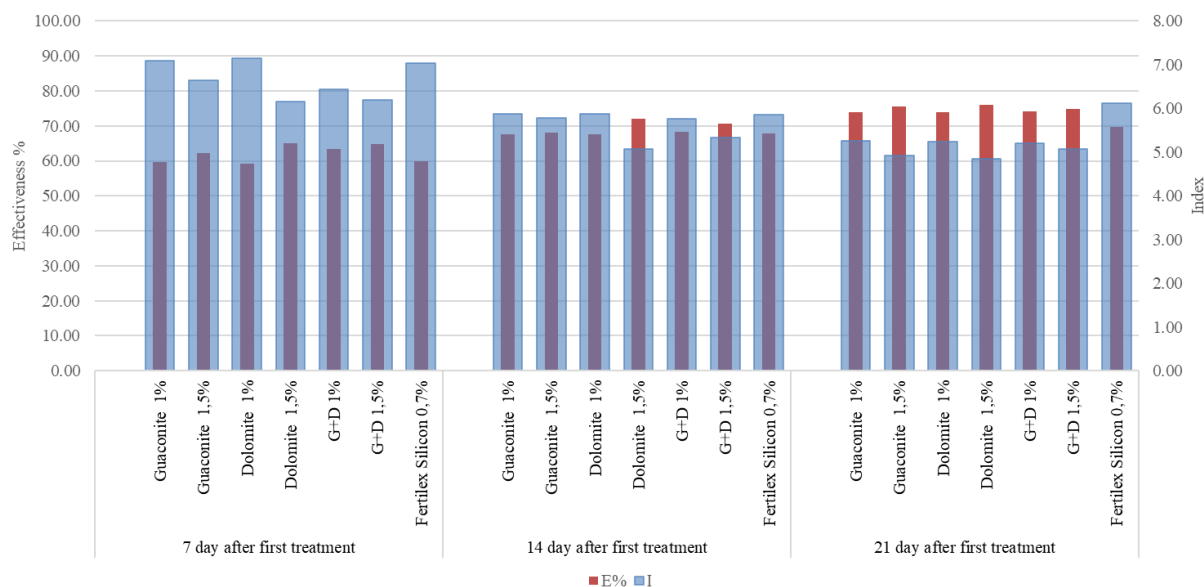


Fig. 2. Dynamics of the infestation index and the effectiveness of treatments against *Phytophthora infestans*

Source: Authors' own elaboration

“a”, which emphasizes the significant effect of all treatments. Fertilex Silicon is proven to be the most effectiveness among the treated variants 21-day after first treatment, forming a separate group “b”. All variants with mineral products fall into group “c”, which shows similar, moderate, but stable effectiveness.

When evaluating the effectiveness of the application of Fertilex Silicon, Glauconite, Dolomite and the combined variants on the development of *Phytophthora* and *Alternaria* under a natural infectious background, clearly distinguishable reactions to the individual products were established (Figure 2 and 3). In *Phytophthora*, mineral products exhibit more pronounced biological activity, and after the first reading, a trend towards a decrease in the attack index was outlined in all variants. The strongest effect was demonstrated by Fertilex Silicon, which achieved the lowest infestation index and the highest effectiveness throughout the entire observation period. The combination also showed a stable and increasing response, approaching Fertilex Silicon after the second and third readings, which suggests a synergistic interaction between the components. Glauconite shows moderate action, while Dolomite remained with the weakest manifestation and with the highest infestation index values (Figure 1).

In *Alternaria*, the overall response of the pathogen to mineral products is less pronounced, which is typical for this species in a natural infectious background. After the first observation, all variants showed low to moderate effectiveness. The combinations demonstrated better action than the individual minerals. Glauconite has average effectiveness, while Dolomite showed the weakest suppression of the pathogen.

After the second and third observation, the differences between the variants deepened: Fertilex Silicon achieved the highest effectiveness and the lowest index, the combined variants stabilized as the second strongest group, and the individual mineral products remained with limited action.

Environmentally friendly disease management in agriculture requires the use of natural mineral resources that improve the chemical, physical, and biological properties of plants, without creating a risk to the environment. In this context, dolomite and glauconite represent two key minerals with the potential to reduce dependence on synthetic chemical fungicides and increase plant resistance to pathogens. Our results from *in vitro* and *in vivo* testing against *Phytophthora* and *Alternaria* clearly show that although mineral products have limited direct fungicidal activity, they have a significant impact on plant physiological resistance and disease dynamics, especially when used in combination.

Dolomite, characterized by its high content of calcium and magnesium carbonates, is an important soil amendment widely used to regulate acid-base balance and optimize nutrient availability in agroecosystems. As reported by Jyothsna et al. (2024), its buffering capacity, combined with the increase in the efficiency of mineral fertilizer absorption, functions as a key physiological-biochemical mechanism that supports growth processes and enhances the adaptive resistance of plants.

In our experience, however, dolomite applied alone showed limited effect on the suppression of *Phytophthora* and *Alternaria*, which is expected, since its action is indirect and related to long-term improvement of soil health, rather than rapid biocidal activity in vegetative treatments.

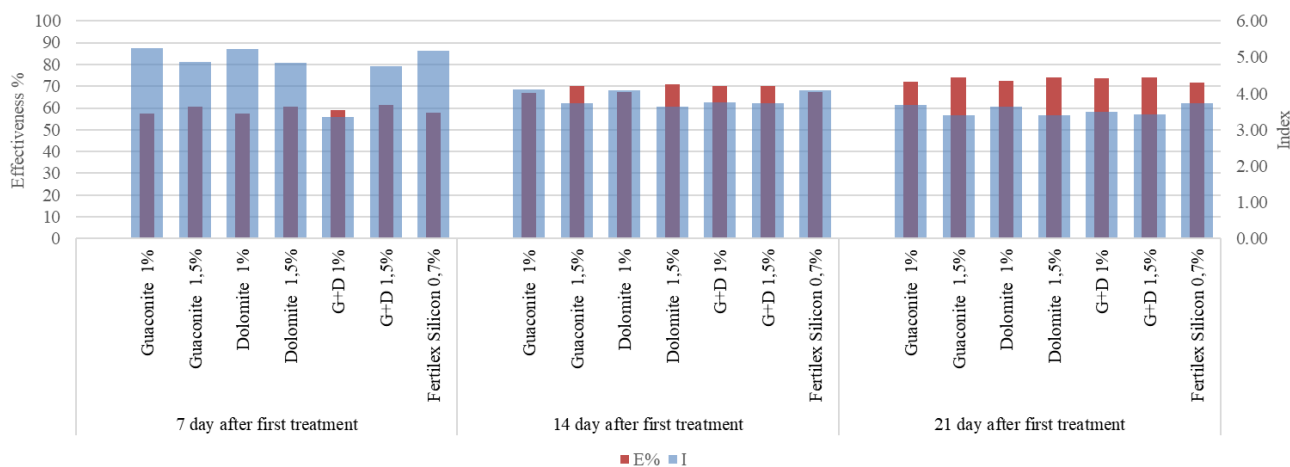


Fig. 3. Dynamics of the infestation index and the effectiveness of treatments against *Alternaria solani*
 Source: Authors' own elaboration

However, its inclusion in the combined variants (Glaucanite + Dolomite) led to significantly better results, especially against *Phytophthora*, where the combination approached the effect of Fertilex Silicon in the second and third readings. This proves that calcium and magnesium nutrition can enhance the structural resistance of tissues and reduce susceptibility to oomycete pathogens. Glaucanite, in turn, is a mineral with high cation exchange capacity and slow release of potassium, iron and trace elements. As noted by Naem et al. (2024), it acts as a “reservoir” that gradually releases nutrients and improves soil structure and water retention. In our results, glaucanite alone showed moderate efficacy against *Phytophthora* and weaker against *Alternaria*, which is again consistent with its mechanism of action – stimulation of physiological resistance, rather than direct suppression of the pathogen. However, when glaucanite is combined with dolomite, effectiveness is significantly enhanced, especially in *Phytophthora*, where the combined variants show a steady reduction in attack index after each treatment.

Glaucanite also has a strong impact on soil microbiology. Gorelnikova et al. (2018) demonstrated that the mineral restores microbial activity in soils contaminated with heavy metals by increasing the abundance of key microbial groups – actinomycetes, micromycetes and nitrogen fixers. These groups play a significant role in the suppression of soil pathogens through competition, antibiotic activity, and degradation of organic substrates. In addition, glaucanite serves as a high-quality carrier for the immobilization of beneficial microorganisms, extending their viability up to four months – significantly more than standard biological preparations. This makes it a valuable component in biological disease control. Glaucanite extracts, especially those obtained by fulvic acid and EDTA, show significant potential for the remediation of saline soils (Shabana et al., 2026). They reduce electrical conductivity and exchangeable sodium, increase enzyme activity, and improve sugar beet yield. Salt stress is a known factor for increased susceptibility to pathogens, therefore improving the soil environment has direct phytopathological relevance.

Despite the potential of mineral products, our data clearly show that Fertilex Silicon remains the most effective option against both pathogens, demonstrating the lowest index and the highest efficacy throughout the period. This highlights that bio stimulating and complex formulations that combine nutrients with biologically active substances can provide a faster and stronger effect under high infectious pressure. However, mineral products, especially in combination show significant potential as part of integrated disease management strategies, as they improve soil health, stimulate microbial activity and reduce the need for synthetic chemical fungicides.

Dolomite and glaucanite improve the soil environment (Conversa et al., 2024). Dolomite neutralizes soil acidity and reduces fertilizer costs by improving fertilizer use efficiency by increasing pH, reducing aluminum toxicity, and supplying essential Ca and Mg. At optimal doses, yield increases by 31.7% (Jyothsna et al., 2024).

Conclusion

In summary, the results of our study confirm that Dolomite and Glaucanite have a significant role in sustainable agriculture by contributing to limiting disease infestation. Although their effect on the pathogens *Phytophthora infestans* and *Alternaria solani* is more moderate, their individual and combined application at a concentration of 1.5% shows promising results and can be a valuable tool in ecologically oriented integrated disease management systems. The Fertilex Silicon has the best effectiveness among tested pathogens.

Conflict of interest

Disclose the presence or absence of a conflict of interest.

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