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Impact of Hydrogen Sulfide and Nitric Oxide on Productivity, Heat Use Efficiency and Quality of Potato Tubers Under Heat Stress

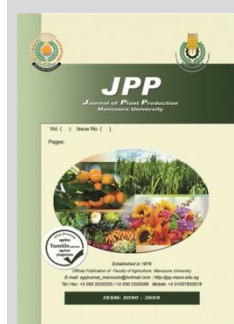
EL-Afify, S. S.T.^{1*}; Samar A. Bardisi² and H. M. B. EL-Metwally¹

¹Hort. Res. Inst., Agric. Res. Center, Giza, Egypt

²Hort. Dept., Fac. Agric., Zagazig University, Egypt



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ABSTRACT

The study was carried out on potato plants to assess the effects of foliar spraying with sodium hydrosulfide (NaSH) a donor of hydrogen sulfide (H₂S) at a concentration of 0, 1, 2.5, and 5.0 ml/L⁻¹ and nitric acid (HNO₃) a donor of nitric oxide (NO) at a concentration of 0, 1, 5.0, 7.5 and 10 ml/L⁻¹, either separately or in combination. However The experiment was conducted during the summers of 2024 and 2025 on a private vegetable farm in Bosat Karm El-Din Village, Sherbin district, Dakahlia Governorate, Egypt. Foliar of potato plants grown in summer plantation with sodium hydrosulfide (NaSH) a donor of hydrogen sulfide (H₂S) at 5 ml/L⁻¹ and with nitric acid (HNO₃) a donor of nitric oxide (NO) at 7.5 ml/L⁻¹ increased vegetative growth parameters, dry weight /plant, average tuber weight, yield / plant and total yield /fed. as well as heat use efficiency, in addition, the interaction between foliar spray with NaSH (H₂S - donor) at 2.5 ml/L⁻¹ and foliar spray with HNO₃ (NO donor) at 7.5 ml/L⁻¹ increased total chlorophyll and Superoxide dismutase enzyme (SOD) in leaves, while control treatment (spraying with water) increased Malondialdehyde (MDA) in leaves at 90 days after planting in both seasons. Whereas, spraying with NaSH (H₂S - donor) at 5 ml/L⁻¹ and nitric acid at 10 ml/L⁻¹ increased dry matter (%), TSS (Brix°), total sugars and starch content in tubers.

Keywords: Potato, Sodium hydrosulfide sulfide (H₂S – donor), nitric acid (NO – donor).

INTRODUCTION

Potato (*Solanum tuberosum* L.) is the fourth most significant essential crop for world food security after rice, wheat and maize. To maximize potato yields requires using certified seeds and planting at the ideal soil moisture and temperature (Darwish *et al.*, 2022). According to Camire *et al.* (2009), a significant source of potassium, resistant starch, high-quality proteins, vitamins C and B₆, and carbohydrates. Additionally, potatoes contain glycoalkaloids and antioxidants, in large amounts can have harmful effects to human but low concentrations may provide positive benefits, such as preventing the proliferation of cancer cells (Friedman, 2015).

Heat stress reduces yield and productivity by adversely affecting the plant's growth, developmental, biochemical, and physiological processes. also The bulking and reproductive stages are the crucial developmental phases that are impacted by heat stress (Hancock *et al.*, 2014). Furthermore root vegetable and tuber crops, which are also regarded as staple foods in many nations, are suffering from climate change. By the middle of this century, global warming is expected to reduce potato production by 18–32% around the world (Dahal *et al.*, 2019).

The perfect temperature for the growth and development of potato plants was 20 to 25°C, whereas 15 to 20°C is the best temperature for tuberization and tuber growth (Rykaczewska, 2013). Higher yield losses and a higher frequency of tuber quality deterioration are caused by warmer temperatures during the growing phases of potatoes. The partitioning of assimilates into the potato tubers is hampered by high temperatures above 20°C, which lowers the tuber yield. Reduced tuber output in hot, tropical climates causes leaves to retain more sugar, which

suggests that photoassimilates are not moving well to the sinks (tubers) (Dahal *et al.*, 2019). Under unfavorable environmental conditions, hydrogen sulfide (H₂S) protects the crops and has a role in a number of physiological processes, including seed germination, root growth, stomatal movement, leaf wilting, fruit ripening, etc. (Corpas *et al.*, 2019). Furthermore, H₂S shields plants from stressors like drought, salt, heavy metals, and extremely high or low temperatures (Pandey and Gautam, 2020).

Research raising shows that H₂S in higher plants acts as a central mediator of response to environmental stress. Adding H₂S to plants help protect it against stresses, such as salinity, drought, extreme temperatures and heavy metals, mainly through boosting antioxidant systems, that mitigate oxidative cellular damage. H₂S also acts a regulatory role in physiological functions, such as seed germination, stomatal movement and fruit ripening, likewise it affects molecules that preserve post-harvest quality and rhizobium-legume symbiosis. These features of H₂S create an emerging research frontier to decipher its functions moreover new opportunities for biotechnological treatments in agriculture in a changing environment. studies indicate a strong synergistic relationship between the functions of H₂S and nitric oxide (NO), another simple signaling molecule, whose metabolisms appear regulate each other (Corpas and Palma, 2020).

The most important feature of H₂S is its good solubility in water and its being a weak acid. Its common form is the neutral molecular form (H₂S). in the biological reactions HS⁻ is considered the main ionic form of H₂S while S₂⁻ is present in small proportions because of high dissociation constant of the second ionic form (Filipovic *et al.*, 2018)

Treated plants with H₂S improved root function in water and nutrient uptake, maintained cell membrane integrity, and reduced MDA contents, which promoted

* Corresponding author.

E-mail address: samersamir265@gmail.com

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growth and yield of strawberry plants (Bahmanbiglo and Eshghi, 2021) and (Yildirim *et al.*, 2023) on tomato. Shalaby *et al.*, (2023) they tested two levels of sodium hydrosulfide (NaHS), H₂S donor (0.1 and 0.2 mmol./ L⁻¹). They found that the largest decrease in malondialdehyde (MDA), was observed in plants treated with H₂S at 0.2 mmol./ L. Broccoli yield, nutritional content, and cell membrane stability index (CMSI) were increased with foliar treatments, all foliar treatments yielded larger and heavier broccoli heads than untreated plants. However, plants sprayed with H₂S at 0.2 mmol/ L that showed the most promising results, significantly enhancing broccoli yield parameters in terms of head fresh weight , head dry weight , and head diameter , and nutritional content such as vitamin C and total soluble solids , as well as, leaf nutrient content in terms of N and K. Kumari *et al.* (2025) They stated that treating cucumber with NaHS supplementation significantly boosted fresh weight, dry weight, plant height, and chlorophyll content and up regulating antioxidative enzymes like SOD and CAT, promoting growth under salt stress.

Further demonstrating the role of NO in plant heat response, exogenous application of NO donors has also been shown to lessen heat-induced cellular damage (Hasanuzzaman *et al.*, 2012). Exogenous injection of a specific dose of NO donors is typically a more economical method of shielding plants from heat stress. However, prior to large-scale agricultural uses, it is crucial to determine the appropriate NO donor, dosage, toxicity, full NO releasing mechanism, byproducts, and their bioactivities (Santisree *et al.*, 2015). Due to their involvement in several physiological, metabolic, and cellular processes, nitric oxide (NO) has gained attention recently and has been recognized as a key gaseous signaling molecule in plants [Gautam *et al.*, 2021].

In this regard , Ahmad *et al.* (2018) They showed that treated tomato seedling with NO at 100 µM promoted the shoot and root length of tomato also it enhancing total chlorophyll . Also, Badem and Söylemez (2022) on pepper plants indicated that plant height , stem diameter , leaf area , dry weight of stems and leaves , chlorophyll index, fruit weight and marketable yield significantly enhanced by treated pepper plants with SNP (sodium nitroprusside) donor of NO as compared to untreated plants . However, Sharaf *et al.* (2023) They found that spraying nitric oxide at 100 µM enhanced the leaf surface area, yield (the number of fruits per tree, fruit weight, and yield) and fruit quality of mango compared to the control or 50 µM nitric oxide.

In this concern, Iqbal *et al.* (2021) They detected that leaf area, dry mass , chlorophyll content of wheat significantly increased by treated plants with H₂S and NO under heat stress or under optimal conditions . However, the plants treated with NaHS donor of H₂S and SNP donor of NO being the activity higher at 69% and 142% for catalase and SOD, respectively, in comparison to control plants.

In order to maximize the productivity and quality standards of Cara potato tubers grown under heat stress during the summer, this study examines the effects of foliar spraying with hydrogen sulfide and nitric oxide at varying concentrations, either separately or in combination.

MATERIALS AND METHODS

The purpose of this study was to determine the effects of foliar spraying with sodium hydrosulfide (NaSH) a donor of hydrogen sulfide (H₂S) at a concentration of 0, 1, 2.5, and 5.0 ml/L⁻¹ and nitric acid (HNO₃) a donor of nitric oxide (NO)

at a concentration of 0, 1, 5.0, 7.5 and 10 ml/L⁻¹, either separately or in combination, which were imported by Sigma company, in order to achieve the highest productivity and best specifications for the quality of potato tubers of the Cara variety. The study was carried out during the summers of 2024 and 2025 on a private vegetable farm in Bosat Karm El-Din village, Sherbin district, Dakahlia Governorate, Egypt.

Table A. Initial soil characteristics in 2024 and 2025 seasons) according to Sparks *et al.* (2020)

Parameters	Values	
	1 st season	2 nd season
Clay (%)	80.5	79.52
Silt (%)	11.8	13.28
Sand (%)	7.70	7.20
Textural clay		
Organic matter (%)	3.39	3.48
EC (dS/m)	3.50	3.42
pH (soil suspension,1:2.5)	7.31	7.29
N (mg/Kg soil)	58.52	61.20
P (mg/Kg soil)	18.94	19.56
K (mg/Kg soil)	410.32	415.73

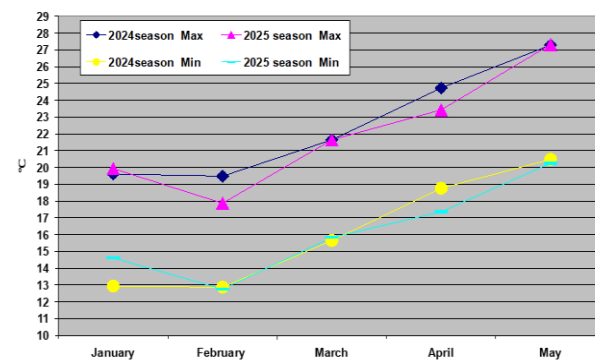


Fig. 1. Average of maximum, minimum temperature °C during plant growth period in 2024 and 2025 seasons under Dakahlia Governorate, Egypt according to Central Laboratory for Agricultural Climate (CLAC)

The experimental design was a split plot design , sodium hydrosulfide (NaSH) a donor of hydrogen sulfide (H₂S) concentrations were arranged in the main plot, while nitric acid (HNO₃) a donor of nitric oxide (NO) concentrations were distributed in the sub plot with three replications. Sodium hydrosulfide (NaSH) a donor of hydrogen sulfide (H₂S) and nitric acid (HNO₃) a donor of nitric oxide (NO) were imported by Sigma Company.

Potato seeds were planted with a constant 20 cm spacing on January 17th and 12th, respectively, for the first and second seasons of this study. Before being planted, the seeds were treated with an antifungal chemical to avoid fungal diseases. Each 10.5 m² experimental unit was made up of three ridges, each measuring 5 m in length and 0.7 m in breadth. Using a manual atomizer in the morning of both seasons, the plants were sprayed with varying concentrations of sodium hydrosulfide (NaSH) a donor of hydrogen sulfide (H₂S) concentrations and nitric acid (HNO₃) a donor of nitric oxide (NO) concentrations four times, starting 20 days after planting and continuing at 20-day intervals (20, 40, 60, and 80 days after planting). Meanwhile, a single watering was given to the untreated plants (control).

Conventional potato production parameters were adhered to by the furrow irrigation system and standard agronomic procedures.

Data recorded

Plant growth: Ninety days after planting, five plants were chosen at random from each experimental plot in both growing seasons. Plant height (cm), number of leaves per plant, number of stems per plant, leaf area (m²), and dry weight of foliage (g) were measured on these chosen plants.

2. Leaf chemical constituents: Leaf total chlorophyll (SPAD): Ninety days after planting in both seasons, the photosynthetic capacity (SPAD) was measured using a spade meter to produce a unit-free value that indicated a relative chlorophyll concentration, which was then analyzed in accordance with Picazo *et al.* (2013). Using spectrophotometric techniques described by Zhang *et al.* (2016) and Alici and Arabaci (2016), respectively, the levels of the enzymes superoxide dismutase (SOD) (u/ml) and malondialdehyde (MDA) (μmol.g⁻¹ FW) in leaves after 90 days from planting were measured as indicators of oxidative stress, and their activity was quantified as a measure of antioxidant enzyme activity.

3. N,P and K contents in shoots of potato at 90 days after planting in both seasons were determined according to AOAC (2008).

4. Tuber yield: In both seasons, the following parameters were measured at harvest time (130-140 days after planting): tuber weight (g), tuber weight/plant, and tuber yield/fed. (ton). Feddan = 0.42 hectares (4200 m²).

4. Some Agro-meteorological indices: such as growing degree days (GDD) and heat use efficiency HUE according to (Narayan *et al.*, 2014).

For every planting date, growing degree days (GDD) were computed during the season. The formula $GDD = [(min T + max T)/2 - T_b]$. T_b = Base temperature/or minimum threshold temperature taken as 4.5 for potato.

$$\text{Heat use efficiency (HUE)} = \frac{\text{Yield of potato (kg /fed.)}}{\text{GDD}}$$

5. Tuber quality: Ten healthy potato tubers were chosen at random for quality investigation from each harvested plot.

Dry matter percentage: The dry matter (%) was calculated after 100 g of the shred mixture were dried at 105°C till their weight remained constant. A hand refractometer was used to quantify the percentage of total soluble solids (TSS). Total sugars were calculated using the Forsee (1938) method and given as a percentage of dry weight. Using the formula $\text{Starch} = 17.55 + 0.891 \times (\text{Dry matter \%} - 24.18)$, the starch content, expressed as a percentage, was determined based on the dry matter percentage (AOAC, 2008).

Statistical analysis

According to Snedecor and Cochran (1980), the collected data was properly statistically analyzed of variance, and Duncan's multiple range test (Duncan, 1958) was used to assess the differences across treatments.

RESULTS AND DISCUSSION

Plant Growth

Effect of sodium hydrosulfide (NaHS)a donor of hydrogen sulfide (H₂S)

Data in Tables from 1 to 6 indicate that the foliar spray with NaHS a donor of H₂S at 5 ml /L⁻¹ increased plant height (61.48 and 61.93 cm) , number of leaves/ plant (34.41 and 35.41) , number of stems / plant (5.66 and 5.83) , leaves area / plant (0.508 and 0.582 m²), foliage fresh weight (168.25 and 155.04g) and foliage dry weight (21.47 and

22.61 g) with no significant differences with NaSH at 2.5 ml/l with respect to leaves area, foliage fresh and dry weight/plant at 90 days after planting in the both summer seasons of potato.

The increases in foliage dry weight (%) were about 3.55 and 4.41 for H₂S at 1 ml/l, 8.51 and 9.69 for NaSH at 2.5 ml/l and 11.35 and 8.44% for NaSH at 5 ml/l over control treatment in the 1st and 2nd seasons , respectively.

Hydrogen sulfide (H₂S) is an important gaseous signaling molecule that plays an essential role in many physiological functions, and developmental processes, including germination, root growth as well as defense mechanisms against abiotic stresses (Caverzan *et al.*, 2012).

These results are harmony with those Ahmad *et al.* (2020) on cauliflower , Bahmanbiglo and Eshghi (2021) on strawberry, Raju *et al.* (2021) using H₂S (donor NaHS; 40 μM produced the best on the growth attributes of eggplant and tomato compared to un treated plants. in addition, Yildirim *et al.* (2023) on tomato they showed that treated with H₂S produced the highest values of plant height , number of leaves / plant, root stem and leaf dry weight as compared to control treatment .

Effect of nitric acid (HNO₃)a donor of nitric oxide (NO)

Plant height, number of leaves/ plant , number of stems / plant, leaves area / plant, foliage fresh weight and foliage dry weight significantly increased with increasing HNO₃ a donor of NO up to 10 ml/l at 90 days after planting in the both summer seasons of potato (Tables from 1 to 6). This means that foliar spray with NO donor at 10 ml/l produced the best plant height (58.56 and 60.27 cm) , number of leaves/ plant (28.07 and 29.16) , number of stems / plant (4.41 and 4.91) , leaves area / plant (0.459 and 0.524 m²) , foliage fresh weight (158.33 and 150.85g) and foliage dry weight (21.26 and 22.31 g in both seasons.

The increases in foliage dry weight were about 2.31 and 2.23 for NO donor at 5 ml/l, 4.28 and 3.16 for NO donor at 7.5 ml/l and 5.91 and 3.57 % for NO donor at 10 ml/l over control treatment in the 1st and 2nd seasons , respectively.

It has been discovered that nitric oxide (NO) improves plant survival in stressful situations. Additionally, research has examined the relationship between heat stress and nitrogen availability in plants, and nitric oxide has been found to be a possible mediator of stress responses (Zayed *et al.*, 2023).

These findings concur with those published using Ahmad *et al.* (2018) They showed that treated tomato seedling with NO at 100 μM promoted the shoot and root length of tomato compared to control treatment. Also, Badem and Söylemez (2022) on pepper plants indicated that plant height , stem diameter , leaf area , dry weight of stems and leaves significantly enhanced by treated peeper plants with 100 IM SNP (sodium nitroprusside) donor of NO as compared to untreated plants

Effect of the interaction

The interaction between spraying with NaSH at 5 ml/l and foliar spray with NO donor (HNO₃) at 7.5 or 10 ml/l gave the tallest plants and recorded maximum number of leaves/ plant , number of stems / plant, leaf area / plant and foliage dry weight of potato at 90 days after planting in both seasons .

The stimulate effect of the interaction between NaSH at 5 ml/l and NO donor at 7.5 ml/l on foliage dry weight may be due to that this treatment increased number of leaves (Table 2) number of stems / plant (Table 3) and leaves area / plant (Table 4) and foliage fresh eight (Table 5). There were

positive correlation among number of leaves, number of stems/ plant, foliage fresh weight and foliage dry weight.

In this concern, Iqbal *et al.* (2021) detected that leaf area, dry mass of wheat significantly increased by treated plants with H₂S and NO under heat stress or under optimal conditions

Table 1. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on plant height (cm) at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	54.09 g	55.66 f	54.55 g	56.18 f	55.12 D
1 ml/l	56.43 f	55.73 f	55.76 f	56.38 f	56.07 C
2.5 ml/l	58.93 e	59.07 e	59.57 de	60.25 cd	59.45 B
5.0 ml/l	61.07 bc	61.17 bc	62.11 a	61.43 ab	61.44 A
Mean (NO)	57.63 B	57.90 B	57.99 B	58.56 A	
2025 season					
0 (Control)	52.73 h	56.25 g	57.06 fg	57.35 fg	55.85 C
1 ml/l	56.29 g	55.85 g	56.68 g	58.32 ef	56.79 C
2.5 ml/l	59.10 de	59.46 de	60.11 cd	62.35 ab	60.25 B
5.0 ml/l	61.47 bc	60.43 cd	62.75 ab	63.07 a	61.93 A
Mean (NO)	57.40 C	58.00 C	59.15 B	60.27 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 2. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on number of leaves / plant at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	18.33 k	19.00 k	20.33 j	22.66 hi	20.08 D
1 ml/l	21.33 j	22.33 i	23.66 gh	24.33 g	22.91 C
2.5 ml/l	26.66 f	27.33 f	28.33 e	29.66 d	27.99 B
5.0 ml/l	32.66 c	34.00 b	35.33 a	35.66 a	34.41 A
Mean (NO)	24.74 D	25.66 C	26.91 B	28.07 A	
2025 season					
0 (Control)	20.00 h	20.00 h	21.33 gh	23.66 fg	21.25 D
1 ml/l	21.33 gh	23.66 fg	24.66 f	25.33 ef	23.75 C
2.5 ml/l	27.33 de	28.33 cd	28.66 cd	30.33 c	28.66 B
5.0 ml/l	33.00 b	34.66 ab	36.66 a	37.33 a	35.41 A
Mean (NO)	25.41 C	26.66 BC	27.83 AB	29.16 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 3. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on number of stems/ plant at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	3.33 i	3.66 h	3.33 i	4.00 g	3.58 D
1 ml/l	4.00 g	4.33 f	4.33 f	4.66 e	4.33 C
2.5 ml/l	4.66 e	4.66 e	5.33 c	5.00 d	4.91 B
5.0 ml/l	5.33 c	5.66 b	5.66 b	6.00 a	5.66 A
Mean (NO)	4.33 C	4.57 B	4.66 B	4.91 A	
2025 season					
0 (Control)	2.33 i	3.33 h	3.66 gh	4.00 fgh	3.33 D
1 ml/l	4.33 efg	4.33 efg	4.00 fgh	4.33 efg	4.25 C
2.5 ml/l	4.66 def	4.66 def	5.00 cde	5.00 cde	4.83 B
5.0 ml/l	5.66 abc	5.33 bcd	6.00 ab	6.33 a	5.83 A
Mean (NO)	4.25 B	4.41 B	4.66 AB	4.91 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 4. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on leaves area / plant (m²) at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	0.343f	0.343 f	0.346 f	0.350 f	0.345C
1 ml/l	0.398e	0.420 d	0.420 d	0.436 d	0.418B
2.5 ml/l	0.463c	0.493 b	0.510 ab	0.523 a	0.497A
5.0 ml/l	0.470 c	0.515a	0.510 ab	0.528 a	0.505A
Mean (NO)	0.418 C	0.442 B	0.446 B	0.459 A	
2025 season					
0 (Control)	0.333 f	0.350 ef	0.370 def	0.393 de	0.361C
1 ml/l	0.380def	0.376 def	0.420 d	0.540 bc	0.429B
2.5 ml/l	0.543bc	0.516 c	0.560abc	0.546 bc	0.541A
5.0 ml/l	0.553bc	0.556 bc	0.603ab	0.616a	0.582A
Mean (NO)	0.452 C	0.450C	0.488 B	0.524 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 5. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on foliage fresh weight/ plant (g) at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	125.00 f	129.00 f	129.33 f	140.00 e	130.83D
1 ml/l	128.67 f	140.00 e	145.33 e	160.00bcd	143.50C
2.5 ml/l	142.33 e	156.33 d	158.33 cd	168.33ab	156.33B
5.0 ml/l	166.33abc	172.00 a	169.67 a	165.00abc	168.25A
Mean (NO)	140.58 C	149.33 B	150.66 B	158.33 A	
2025 season					
0 (Control)	119.29 h	125.47 gh	130.23 fg	137.48 ef	128.12C
1 ml/l	132.49 fg	135.55efg	139.91def	141.02def	137.24B
2.5 ml/l	145.52cde	150.38bcd	154.95bc	165.50a	154.09A
5.0 ml/l	150.82bcd	154.24 bc	155.73abc	159.39ab	155.04A
Mean (NO)	137.03 C	141.41BC	145.21 B	150.85 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 6. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on foliage dry weight/ plant (g) at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	19.40g	19.50g	19.42g	20.60de	19.73D
1 ml/l	19.76fg	19.84fg	20.93d	21.20cd	20.43 C
2.5 ml/l	20.20ef	21.70bc	21.98ab	21.78bc	21.4 B
5.0 ml/l	21.91ab	22.09ab	22.42a	22.48a	22.22 A
Mean (NO)	20.31 D	20.78 C	21.18 B	21.51 A	
2025 season					
0 (Control)	20.12 j	20.96 i	21.08 hi	21.25 h	20.85D
1 ml/l	21.15hi	21.93 g	21.93 g	22.08 fg	21.77C
2.5 ml/l	22.59 cde	22.71bcd	23.14 a	23.04 a	22.87 A
5.0 ml/l	22.33ef	22.49 de	22.74 bc	22.88ab	22.6 B
Mean (NO)	21.54 C	22.02 B	22.22 A	22.31 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

2. Total chlorophyll, Malondialdehyde (MDA) and Superoxide dismutase (SOD)enzyme Effect of NaSH (H₂Sdonor)

The obtained results in Tables 7 to 9 indicate that the spraying with NaSH at 5 ml/l increased total chlorophyll in

leaf tissues (48.00 and 49.36) and Superoxide dismutase enzyme (SOD) (5.74 and 6.19 u/ml) with no significant differences with NaSH at 2.5 ml/l with respect to total chlorophyll. This means that NaSH at 2.5 ml/l increased total chlorophyll in leaf tissues, whereas H₂S at 5 ml/l increased SOD. Respecting Malondialdehyde (MDA) data in table 8 show that, foliar spray with water (control) or with H₂S at 1 ml/l increased MDA in leaves (8.39 and 8.83 $\mu\text{mol.g}^{-1}$ F.W) in both seasons.

The increases in total chlorophyll were about 4.34 and 5.81 % due to spraying with H₂S at 2.5 ml/l and 5.24 and 6.96 % for NaSH at 5 ml/l over control treatment in the 1st and 2nd seasons, respectively.

In this regard, Zhang *et al.* (2009) They indicated that the spraying with H₂S prevented chlorophyll loss, increased SOD, CAT, and APX activities, and alleviated oxidative damage induced by osmotic stress in sweet potato plants. also, Ahmad *et al.*, (2020) They indicated that treated cauliflower with H₂S at 200 μM produced the highest concentrations of Chl a and Chl b, total Chl and carotenoids as compared to control treatment also, Yildirim *et al.* (2023) on tomato showed that treated plants with H₂S treatment increased total chlorophyll content, and decreased MDA, in tomato seedlings under heat stress.

Effect of NO donor

Foliar spray with NO donor at 10 ml/l significantly increased total chlorophyll (47.62 and 48.82 SPAD) and SOD (5.98 and 5.49u/ml) in leaves in both seasons (tables 7 and 9), whereas NO donor at 5ml/l significantly increased MDA enzyme (7.91 and 8.28 $\mu\text{mol.g}^{-1}$ F.W) in leaves in both seasons (Table 8).

The increases in total chlorophyll were about 3.30 and 2.49 % due to spraying with NO donor at 5 ml/l and 5.64 and 4.63 % for NO donor at 10 ml/l over control treatment in the 1st and 2nd seasons, respectively.

Heat stress poses a serious threat to photosynthesis, a crucial plant function that serves as the only foundation for all assimilations (Allakhverdiev *et al.*, 2008). High temperatures cause irreversible damage to the chloroplast protein complexes, including the photosystem, by altering the thylakoid membrane's physical characteristics and functional organization (Brestic *et al.*, 2012). It has been demonstrated that NO can stop this heat-induced chlorophyll loss and keep the photosystem active, which helps to mitigate the decline in photosynthesis (Misra, 1980).

Table 7. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on total chlorophyll (SPAD) in leaves at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	44.65 e	45.53 cde	45.98 cde	46.28 cd	45.61 B
1 ml/l	44.83 e	45.05 de	45.28 de	46.89 bc	45.51 B
2.5 ml/l	45.56 cde	47.87 ab	48.52 a	48.42 a	47.59 A
5.0 ml/l	46.95 bc	47.94 ab	48.20 ab	48.92 a	48.00 A
Mean (NO)	45.49 C	46.59 B	46.99 AB	47.62 A	
2025 season					
0 (Control)	43.45 f	46.31 de	47.14 cd	47.69 bcd	46.15 B
1 ml/l	47.01 cd	44.96 ef	45.57 def	47.61 bcd	46.28 B
2.5 ml/l	47.30 cd	48.90 abc	49.10 abc	50.02 a	48.83 A
5.0 ml/l	48.88 abc	49.14 abc	49.47 ab	49.96 a	49.36 A
Mean (NO)	46.66 C	47.32 BC	47.82 B	48.82 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 8. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on Malondialdehyde (MDA)($\mu\text{mol.g}^{-1}$ F.W) Enzyme in leaves at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	8.81a	8.97a	7.99 bc	7.81 c	8.39 A
1 ml/l	8.57a	8.69a	8.45 ab	7.75 c	8.36 A
2.5 ml/l	6.98 d	7.20 d	6.80 de	6.32 ef	6.82 B
5.0 ml/l	6.23 f	6.80 de	5.70 g	5.49 g	6.05 C
Mean (NO)	7.64 B	7.91 A	7.23 C	6.84 D	
2025 season					
0 (Control)	9.43 a	8.77 bc	8.60 c	8.55 c	8.83 A
1 ml/l	9.29 ab	9.23 ab	8.65 c	8.31 c	8.87 A
2.5 ml/l	7.10 e	7.66 d	7.18 de	6.56 fg	7.12 B
5.0 ml/l	7.02 ef	7.49 de	6.33 gh	5.98 h	6.70 C
Mean (NO)	8.21 A	8.28 A	7.69 B	7.35 C	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 9. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on Enzyme Superoxide dismutase (SOD)u/ml in leaves at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	3.21 j	3.41 i	3.66 h	3.96 g	3.56 D
1 ml/l	3.97 g	4.44 f	4.54 f	4.89 e	4.46 C
2.5 ml/l	5.03 de	5.14 d	5.35 c	5.50bc	5.25 B
5.0 ml/l	5.53bc	5.57b	5.91a	5.98a	5.74 A
Mean (NO)	4.43 D	4.64 C	4.86 B	5.08 A	
2025 season					
0 (Control)	3.91 g	4.04 fg	4.08 fg	4.56 ef	4.14 D
1 ml/l	4.55 ef	4.84 de	5.10 de	5.38cd	4.97 C
2.5 ml/l	5.39 cd	5.68 bc	5.70 bc	5.79 bc	5.64 B
5.0 ml/l	5.92 bc	6.14ab	6.51 a	6.21 ab	6.19 A
Mean (NO)	4.94 C	5.17BC	5.34AB	5.49 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Ahmad *et al.* (2018) They showed that treated tomato seedling with NO at 100 μM enhanced chlorophyll a , b and carotenoids compared to control treatment. In addition , Badem and Söylemez (2022) They indicated that chlorophyll index in pepper significantly increased by treated plants with 100 IM SNP (sodium nitro prusside) donor of NO as compared to untreated plants.

Effect of the interaction

The interaction between foliar spray with NaSH at 2.5 or 5 ml/l and foliar spray with NO donor at 7.5 or 10 ml/l significantly increased the concentration of total chlorophyll in leaf tissues and SOD in leaves (Tables 7 and 9). This means that the interaction between foliar spray with NaHS at 2.5 ml/l and foliar spray with NO donor at 7.5 ml/l increased total chlorophyll and SOD in leaves.

Respecting MDA enzyme data in Table 8 indicate that control treatment (spraying with water) without any NaSH or NO donor increased MDA (8.81 and 9.41 $\mu\text{mol.g}^{-1}$ F.W) in leaves at 90 days after planting in both seasons. On the other hand, the lowest concentration of MDA in leaves were produced with the interaction between the highest levels of NaSH and NO donor (5.49 and 5.98 $\mu\text{mol.g}^{-1}$ F.W) in both seasons.

In this concern, Iqbal *et al.* (2021) detected that the plants treated with NaHS donor of H₂S and SNP donor of NO being the activity higher at 69% and 142% for catalase and SOD, respectively, in comparison to control plants.

N, P and K contents in leaves

Effect of NaSH (H₂S donor)

N, P and K in shoots (foliage) significantly increased with increasing foliar spray with H₂S up to 5 ml/l with no significant differences with NaSHat 2.5 ml/l in both seasons (Tables 10, 11 and 12). This means that NaSHat 2.5 ml/l increased N, P and K content in leaves. When NaSH was sprayed at a rate of 2.5 milliliters per liter, the nitrogen content of the shoots increased by approximately 14.13 and 34.53%, while the potassium content increased by approximately 7.21 and 25.33% in comparison to the control treatment in the first and second seasons, respectively.

Results are harmony with Valivand and Amooaghaie (2021) who showed that treated *Cucurbita pepo* L. with H₂S significantly increased, nutrient content (N, P, K, Ca, and Mg) in shoots than untreated plants.

Effect of NO donor

Foliar spray with NO donor at 10 ml/l significantly increased, N (3.09 and 2.88 %), P (0.352 and 0.360 %) and K (2.43 and 2.72%) against N (2.90 and 2.51 %), P (0.315 and 0.321 %) and K (2.22 and 2.43%) for control treatment in shoots at 90 days after planting in both seasons (Tables 10, 11 and 12). Spraying NO donor at 10 ml/l increased the amount of nitrogen in the shoots by approximately 6.55% and 14.74%, while the amount of potassium increased by approximately 9.46% and 11.93% in comparison to the control treatment in the first and second seasons, respectively.

The outcomes are consistent with those that were achieved using Ahmad *et al.* (2018) They showed that the highest values of S, Mn, Mg, Ca, and K contents in the shoot were obtained by treated tomato seedling with NO at 100 µM compared to control treatment.

Effect of the interaction

The interaction between foliar spray with H₂S at 2.5 or 5 ml/l and foliar spray with NO at 10 ml/l increased N, P and K in shoots (tables 10, 11 and 12). This means that the interaction between foliar spray with NaSHat 2.5 ml/l and foliar spray with NO donor at 10 ml/l increased N, P and K in shoots in both seasons.

Table 10. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on nitrogen parentage in shoots at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	2.59 h	2.81 g	2.82 g	2.83 fg	2.76 C
1 ml/l	2.84 fg	2.89 ef	2.93 e	3.05 d	2.92 B
2.5 ml/l	3.11 bcd	3.13 bc	3.14 bc	3.23a	3.15 A
5.0 ml/l	3.09 cd	3.12 bc	3.16 b	3.25a	3.15 A
Mean (NO)	2.90 C	2.98 B	3.01 B	3.09 A	
2025 season					
0 (Control)	2.13 g	2.14 g	2.23 g	2.43 f	2.23 C
1 ml/l	2.23 g	2.30 fg	2.64 e	2.74 de	2.47 B
2.5 ml/l	2.83 cd	2.92 bcd	3.08 ab	3.18 a	3.00 A
5.0 ml/l	2.85 cd	2.97 bc	3.09 ab	3.19 a	3.02 A
Mean (NO)	2.51 C	2.58 C	2.76 B	2.88 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 11. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on phosphorus percentage in shoots at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	0.301 i	0.320 h	0.333 ef	0.340 de	0.323 D
1 ml/l	0.305 i	0.322 h	0.342 d	0.350 bc	0.329 C
2.5 ml/l	0.325 gh	0.330 fg	0.345 cd	0.360a	0.340 B
5.0 ml/l	0.330 fg	0.342 d	0.355ab	0.360a	0.346 A
Mean (NO)	0.315 D	0.328 C	0.343 B	0.352A	
2025 season					
0 (Control)	0.286 i	0.312 h	0.330 fg	0.346 de	0.318 B
1 ml/l	0.290 i	0.320 gh	0.336 ef	0.353 cd	0.324 B
2.5 ml/l	0.355 cd	0.356 bcd	0.368 ab	0.365abc	0.361 A
5.0 ml/l	0.356 bcd	0.359 bcd	0.360 bc	0.376 a	0.362 A
Mean (NO)	0.321 D	0.336 C	0.348 B	0.360 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 12. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on potassium percentage in shoots at 90 days after planting of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/	7.5 ml/	10 ml/	
2024 season					
0 (Control)	2.11 i	2.19 hi	2.22 gh	2.39 bcd	2.22 B
1 ml/	2.18 hi	2.24 fgh	2.29 efg	2.38 b-e	2.27 B
2.5 ml/	2.30 d-g	2.32 c-f	2.41 bc	2.52 a	2.38 A
5.0 ml/	2.31 d-g	2.45 ab	2.36 b-e	2.43 ab	2.38 A
Mean (NO)	2.22 C	2.30 B	2.32 B	2.43 A	
2025 season					
0 (Control)	2.16 g	2.22 fg	2.36 ef	2.43 de	2.29 C
1 ml/	2.42 de	2.33 ef	2.42 de	2.48 cde	2.41 B
2.5 ml/	2.60 c	2.91 ab	2.98 a	3.01 a	2.87 A
5.0 ml/	2.56 cd	2.79 b	2.95 a	2.97 a	2.81 A
Mean (NO)	2.43 C	2.56 B	2.67 A	2.72 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

In the first and second seasons, the interaction between spraying with NaSHat 2.5 ml/l and NO donor at 10 ml/l increased the nitrogen content in shoots by approximately 24.71% and 49.50%, respectively, and the potassium content by approximately 19.43% and 30.35% over the control treatment.

Yield and its components

Effect of NaSH (H₂S donor)

Average tuber weight, average number of tuber / plant, tuber weight / plant and total yield /fed. as well as heat use efficiency (HUE) significantly increased by increasing NaSH up to 5 ml/l with no significant differences with NaSH at 2.5 ml/l with respect to yield / plant and total yield /fed. in both seasons (Tables 13,14 , 15 and 16). This means that NaSH at 2.5 ml/l increased average tuber weight (154.97 and 163.00 g), whereas NaSH at 2.5 ml/l increased yield / plant (778.83 and 787.08 g) and total yield /fed. (15.327 and 15.491 ton) and HUE (5.947 and 6.582 kg tuber / °C day) in the both seasons.

Compared to the control treatment, the average gains in total/yield (ton) throughout the two seasons were around

0.159 tons for NaSH at 1 ml/l, 2.644 tons for NaSH at 2.5 ml/l, and 2.859 tons for H₂S at 5 ml/l.

The perfect temperature for the growth and development of potato plants was 20 to 25°C, whereas 15 to 20°C is the best temperature for tuberization and tuber growth (Rykaczewska, 2013). Higher yield losses and a higher frequency of tuber quality deterioration are caused by warmer temperatures during the growing phases of potatoes. The partitioning of assimilates into the potato tubers is hampered by high temperatures above 20°C, which lowers the tuber yield. Reduced tuber output in hot, tropical climates causes leaves to retain more sugar, which suggests that photo assimilates are not moving well to the sinks (tubers) (Dahal *et al.*, 2019). Under unfavorable environmental conditions, hydrogen sulfide (H₂S) protects the crops and has a role in a number of physiological processes, including growth, stomatal movement, leaf wilting, tuber formation, etc. (Corpas *et al.*, 2019). Furthermore, H₂S shields plants from stressors like drought, salt, and extremely high or low temperatures (Pandey and Gautam, 2020). These findings concur with those published using Bahmanbiglo, and Eshghi (2021) they indicated that spraying strawberry with hydrogen sulfide at 0.2 or 0.5 mM produced the highest fruit yield as compared to unsprayed plants. Additionally, Shalaby *et al.* (2023) on broccoli, how showed that all foliar treatments with (NaHS), H₂S donor (0.1 and 0.2 mmol/L) yielded larger and heavier broccoli heads than untreated plants. However, plants sprayed with H₂S at 0.2 mmol/L showed the most promising results, significantly enhancing broccoli yield parameters in terms of head fresh weight, head dry weight, and head diameter.

Effect of NO donor

The obtained results in Tables 13,14,15 and 16 indicate that foliar spray with NO donor at 10 ml/l significantly increased average tuber weight, tuber weight / plant and total yield /fed. as well as HUE with no significant differences with NO donor at 7.5 ml/l. in both seasons. This means that NO donor at 7.5 ml/increased average tuber weight (152.95 and 156.83 g), tuber weight / plant (740.35 and 758.24 g) and total yield /fed. (14.557 and 14.965 ton) as well as HUE (5.648 and 6.358 kg tuber / °C day) in the both seasons.

The increases in total /yield (ton) as average of the two seasons were about 0.617 ton for NO donor at 5ml/l, 1.543 ton for NO donor at 7.5 ml/l and 1.634 ton for NO donor at 10 ml/l over the control treatment.

Plants grown under heat stress reduces yield and productivity by adversely affecting the plant's growth, developmental, biochemical, and physiological processes. The bulking and reproductive stages are the crucial developmental phases that are impacted by heat stress (Hancock *et al.*, 2014). Root vegetable and tuber crops, which are also regarded as staple foods in many nations, are suffering from climate change. By the middle of this century, global warming is expected to reduce potato production by 18–32% around the world (Dahal *et al.*, 2019).

These findings are consistent with those of Badem and Söylemez (2022), who found that treating pepper plants with a 100 IM SNP (sodium nitroprusside) donor of NO greatly increased pepper fruit weight and marketable production as compared to untreated plants.

Effect of the interaction

Data in Tables 13,14, 15 and 16 show that the interaction between foliar spray with NaSHat 5 ml/l and foliar spray with

NO donor at 7.5 or 10 ml /l significantly increased average tuber weight, tuber weight / plant and total yield /fed. as well as HUE with no significant differences between NaSHat 2.5 ml/l and NO at 7.5 ml/l with respect to yield / plant and total yield /fed. in the both seasons. For all the interaction treatments, average tuber weight around from 144.0 to 157.20 g in the 1st season and 146.33 to 165.33 g in the 2nd season.

Table 13. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on average tuber weight (g) of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	144.00 h	144.60h	148.60 g	149.60 fg	146.70 D
1 ml/l	148.00 g	148.30 g	150.90ef	151.10ef	149.58 C
2.5 ml/l	148.60 g	152.40 de	155.30 bc	156.30ab	153.15 B
5.0 ml/l	152.00 e	153.70 cd	157.00ab	157.20 a	154.97 A
Mean (NO)	148.15 C	149.75 B	152.95 A	153.55 A	
2025 season					
0 (Control)	146.33 j	150.33 hij	153.00fi	154.00e-h	150.91 C
1 ml/l	147.00 ij	151.00 g-j	152.00g-j	154.00e-h	151.00 C
2.5 ml/l	155.33 d-h	156.67 c-g	158.33 b-f	159.33ae	157.42 B
5.0 ml/l	160.33 a-d	162.33 abc	164.00ab	165.33A	163.00 A
Mean (NO)	152.25 C	155.08 BC	156.83 AB	158.17 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S), nitric acid (HNO₃) : a donor of nitric oxide (NO). Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 14. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on yield / plant (g) of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5ml/l	7.5ml/l	10ml/l	
2024 season					
0 (Control)	623.52 f	626.12 ef	643.44 def	647.77 de	635.21 C
1ml/l	640.84 def	642.14 def	653.40 d	704.13 c	660.13 B
2.5ml/l	692.48 c	762.00 b	827.75 a	833.08 a	778.83 A
5.0ml/l	708.32 c	768.50 b	836.81 a	837.88 a	787.88 A
Mean (NO)	666.29 D	699.69 C	740.35 A	755.71 A	
2025 season					
0 (Control)	585.32 e	601.32 e	712.98 cd	717.64 cd	654.31 B
1ml/l	588.00 e	604.00 e	708.32 cd	666.82 d	641.79 B
2.5ml/l	776.65 ab	783.35 ab	791.65 ab	796.65 ab	787.08 A
5.0ml/l	747.14 bc	811.65 a	820.00 a	826.65 a	801.36 A
Mean (NO)	674.28 C	700.08 B	758.24 A	751.94 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S), nitric acid (HNO₃) : a donor of nitric oxide (NO). Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 15. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on total yield (ton/fed.) of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5 ml/l	7.5 ml/l	10 ml/l	
2024 season					
0 (Control)	12.370 d	12.422 d	12.669 d	12.755 d	12.554 C
1 ml/l	12.617 d	12.743 d	12.968 d	13.689 c	13.004 B
2.5 ml/l	13.750 c	14.840 b	16.255 a	16.462 a	15.327 A
5.0 ml/l	14.066 c	15.170 b	16.336 a	16.458 a	15.507 A
Mean (NO)	13.201 C	13.794 B	14.557 A	14.841 A	
2025 season					
0 (Control)	11.606 g	11.926 g	14.060 e	14.153 e	12.936 B
1 ml/l	11.660 g	12.080 g	14.166 e	13.336 f	12.811 B
2.5 ml/l	15.233 d	15.467 cd	15.533 bcd	15.733 abc	15.491 A
5.0 ml/l	14.443 e	16.033 ab	16.100 a	16.233 a	15.702 A
Mean (NO)	13.236 C	13.877 B	14.965 A	14.864 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S), nitric acid (HNO₃) : a donor of nitric oxide (NO). Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 16. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on heat use efficiency (kg / oc) of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5ml	75ml	10ml	
2024 season					
0 (Control)	4800 g	4820 fg	4916 efg	4950 ef	4871 C
1ml/l	4896 fg	4945 ef	5032 e	5312 d	5046 B
25ml/l	5336 cd	5759 b	6308a	6388a	5947 A
5.0ml/l	5458 c	5887b	6339a	6386a	6017 A
Mean(NO)	5122 C	5352 B	5648 A	5759 A	
2025 season					
0 (Control)	4931 h	5067 gh	5974 e	6014 e	5496 B
1ml/l	4954 h	5133 g	6019 e	5666 f	5443 B
25ml/l	6472 d	6572 cd	6600 cd	6685 bc	6582 A
5.0ml/l	6137 e	6812ab	6841ab	6897a	6671 A
Mean(NO)	5623 C	5896 B	6358 A	6315 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

The stimulative effect of the interaction between NaSH at 5 ml/l and NO donor at 7.5 ml/l on tuber yield, may be due to that H₂S at 5 ml/l and NO at 7.5 ml/l increased number of stems/ plant (Table 3), dry weight of foliage (Table 6) , average tuber weight (Table 13) and yield / plant (Table 14).

Tuber quality

Effect of NaSH (H₂S donor)

Data in Tables 17 to 20 show that DM% (22.20 and 23.16%), TSS (7.18 and 7.70 Brix°) , total sugars(6.98 and 7.32%) and starch (17.65 and 18.31%) significantly increased with increasing foliar spray with NaSH up to 5ml/l against control treatments which produced (16.90 and 17.98%), (6.37 and 6.89 Brix°), (4.78 and 5.29%) and (14.11 and 14.27%) for DM% TSS, total sugars and starch in tubers after harvesting time in both seasons.

The increases in dry matter (%) were about 31.36 and 28.81 %, TSS were about (12.72 and 11.76%), starch were about (25.09 and 28.31%) for spraying with NaHS at 5ml/l over control treatment in the 1st and 2nd seasons , respectively.

In this regard, Shalaby *et al.* (2023) They showed that plants sprayed with H₂S at 0.2 mmol/ L showed the most promising results, significantly enhancing broccoli nutritional content such as vitamin C and total soluble solids.

Table 17. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on tuber dry matter (%) of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5ml	75ml	10ml	
2024 season					
0 (Control)	1590 h	1677 gh	1717 fg	1776 ef	1690 D
1ml/l	1676 gh	1739 fg	1866 de	1877 d	1789 C
25ml/l	1954 cd	1988 c	1987 c	2100 b	2007 B
5.0ml/l	2132 b	2181 b	2186 b	2382 a	2220 A
Mean(NO)	1838 C	1896 B	1939 B	2033 A	
2025 season					
0 (Control)	1733 f	1821 f	1808 f	1832 f	1798 D
1ml/l	1796 f	1815 f	1984 e	2057 de	1913 C
25ml/l	2009 e	2110 cde	2057 de	2186 bcd	2090 B
5.0ml/l	2202 bc	2246 b	2267 b	2548 a	2316 A
Mean(NO)	1935 C	1998 B	2029 B	2156 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 18. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on total soluble solids (TSS) of potato tuber in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5mM	75mM	10mM	
2024 season					
0 (Control)	596 h	650 e	635 fg	670 d	637 C
1mM	584 h	641 ef	626 g	666 d	629 C
25mM	667 d	642 ef	715 b	693 c	679 B
5.0mM	715 b	720 ab	734 a	706 bc	718 A
Mean(NO)	640 C	663 B	677 A	683 A	
2025 season					
0 (Control)	648 e	700 be	682 cde	727 ae	689 B
1mM	644 e	711 be	671 de	737 ad	690 B
25mM	683 cde	710 be	776 ab	746 ad	729 B
5.0mM	746 ad	772 ab	804 a	760 abc	770 A
Mean(NO)	680 B	723 AB	733 A	742 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 19. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on total sugars (%) of potato tuber in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5mM	75mM	10mM	
2024 season					
0 (Control)	467 f	457 f	494 de	496 de	478 C
1mM	473 ef	481 ef	508 d	473 ef	483 C
25mM	560 c	544 c	587 b	601 b	573 B
5.0mM	698a	712a	691a	693a	698A
Mean(NO)	549 B	548 B	570 A	565 A	
2025 season					
0 (Control)	476 g	531 efg	560 cf	547 d-g	529 C
1mM	507 fg	528 fg	535 efg	531 efg	525 C
25mM	623 bcd	615 cde	627 bcd	637 bc	626 B
5.0mM	738a	736a	709ab	743a	732 A
Mean(NO)	586B	603A	608A	615A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Table 20. Effect of spraying with Hydrogen Sulfide (H₂S) and Nitric Oxide (NO) and the combination between them on starch content (%) in tubers of potato in both summer seasons

Hydrogen Sulfide (H ₂ S) donor	Nitric Oxide (NO) donor				Mean (H ₂ S)
	0 (Control)	5mM	75mM	10mM	
2024 season					
0 (Control)	12.79 k	14.64 gh	14.11 i	14.91 fg	14.11 C
1mM	13.35 j	14.46 ghi	14.21 hi	15.16 ef	14.29 C
25mM	15.57 e	16.23 cd	16.10 d	16.04 d	15.98 B
5.0mM	16.68 c	17.39 b	17.72 b	18.83 a	17.65 A
Mean(NO)	14.59 C	15.68 B	15.53 B	16.23 A	
2025 season					
0 (Control)	13.30 i	14.30 h	14.24 hi	15.26 fg	14.27 C
1mM	13.88 hi	14.70 gh	14.73 gh	15.76 ef	14.76 C
25mM	15.98 ef	17.00 cd	16.43 de	16.68 de	16.52 B
5.0mM	17.32 cd	17.95 bc	18.61 ab	19.36 a	18.31 A
Mean(NO)	15.12 C	15.99 B	16.00 B	16.76 A	

Sodium hydrosulfide (NaSH) : a donor of hydrogen sulfide (H₂S) , nitric acid (HNO₃) : a donor of nitric oxide (NO) . Duncan's multiple range test revealed that values with the same alphabetical letter(s) did not substantially differ at the 0.05 level of significance.

Effect of NO donor

Spraying with NO at 10 ml/l increased dry matter (20.33 and 21.56%), TSS, (6.83 and 7.42) total sugars (5.65 and 6.15%) , and starch (16.23 16.76%) against control treatment which scored (18.38 and 19.35%), (6.40 and 6.80) , (5.49 and 5.86%)

, and (14.59 and 15.12%) for DM%, TSS, totals sugars and starch content in tubers in both seasons , respectively at harvesting time (Tables17,18 , 19 and 20).

The increases in dry matter (%) were about 10.61 and 11.42 % , TSS were about (6.72 and 9.12%), starch were about (11.24 and 10.85%) for spraying with NO at 10 ml/l over control treatment in the 1st and 2nd seasons , respectively.

The results are consistent with those of Sharaf *et al.* (2023), They discovered that, as compared to the control or 50 µM nitric oxide, spraying 100 µM nitric oxide improved the mango fruit quality (TSS%, (B) total acidity%, and (C) TSS/acid ratio).

Effect of the interaction

The interaction between foliar spray with NaSHat 5 ml/l and foliar spray with NO donor at 10 ml/l increased dry matter (23.82 and 25.48%), total sugars(6.93 and 7.43 , and starch (18.83and 19.36 %) in tuber in both seasons, while the interaction between foliar spray with NaSHat 5 ml/l and foliar spray with NO donor at 7.5 ml/l increased TSS (7.34 and 8.04 Brix°) in both seasons (Tables17 to 20).

The dry matter percentage in tubers for all interaction treatments ranged from 15.90 to 23.82 percent in the first season and 17.37 to 25.48 percent in the second, while the starch content ranged from 12.79 to 18.83% in the first season and 13.3 to 19.3617.95 percent in the second. The percentage of dry matter and the amount of starch in tubers were positively correlated.

CONCLUSION

Foliar of potato plants grown in summer plantation with sodium hydrosulfide at 5 ml/l and nitric oxide donor at 7.5 ml/l increased plant height, number of leaves / plant , number of stems/ plant , leaf area /plant foliage fresh and dry weight average tuber weight, yield/plant and total yield /fed., whereas spraying with sodium hydrosulfide at 5 ml/l and nitric oxide donor at 10 ml/l increased dry matter (%) TSS (Brix°), total sugars and starch content in tubers.

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تأثير كبريتيد الهيدروجين وأكسيد النيتريت على الإنتاجية وكفاءة استخدام الحرارة وجودة درنات البطاطس تحت ظروف الإجهاد الحراري

سامر سمير طه العفيفي^١ ، سمر عبد الله برديسي^٢ و حماده ماهر بدير المتولي^١

^١شعبة بحوث الخضار – معهد بحوث البساتين- مركز البحوث الزراعيه مصر
^٢قسم البساتين- كلية الزراعة- جامعة الزقازيق

المخلص

هذه الدراسة تهدف إلى تقييم تأثير الرش الورقي بمحلول هيدروسلفيد الصوديوم مانح كبريتيد الهيدروجين بتركيزات ١، ٢، ٥، ١٠، ٢٠، ٥٠، ١٠٠ مل/لتر، وحمض النيتريك مانح أكسيد النيتريك بتركيزات ١، ٢، ٥، ١٠، ٢٠، ٥٠، ١٠٠ مل/لتر، منفردا وفي توليفات، بهدف الحصول على أعلى إنتاجية وأفضل مواصفات لجودة درنات البطاطس للصنف كرا. وقد أجريت الدراسة خلال صيفي عامي ٢٠٢٤ و ٢٠٢٥ في مزرعة خضر خاصة بقرية بساط كرم الدين، مركز شربين، محافظة الدقهلية، مصر. أدى التفاعل بالرش الورقي لنباتات البطاطس النامي في العروة الصيفية بهيدروسلفيد الصوديوم مانح كبريتيد الهيدروجين بتركيز ٥ مل/لتر وأكسيد النيتريك بتركيز ٢٠ مل/لتر إلى زيادة في صفات النمو الخضري والوزن الجاف، متوسط وزن الدرنة، محصول/نبات والمحصول الكلي/فدان بالإضافة إلى كفاءة استخدام الحرارة. كما أدى التفاعل بين الرش الورقي بهيدروسلفيد الصوديوم بتركيز ٢٠ مل/لتر والرش الورقي بكمض النيتريك بتركيز ٢٠ مل/لتر إلى زيادة محتوى الأوراق من الكلوروفيل الكلي وأنزيم سوبر أكسيد ديسميوتاز (SOD) في الأوراق، بينما أدت معاملة الكونترول (الرش بالماء) إلى زيادة في أنزيم مالونديالدهيد (MDA) في الأوراق بعد ٩٠ يوما من الزراعة في كلا الموسمين. في حين أن الرش بمانح كبريتيد الهيدروجين بتركيز ٥ مل/لتر والرش الورقي بمانح أكسيد النيتريك بتركيز ١٠ مل/لتر أدى إلى زيادة محتوى الدرنات من المادة الجافة، المواد الصلبة الذائبة الكلية (بركس) ومحتوى السكريات الكلية والنشا.