Hydrogen Sulfide Acts as a Fungicide to Alleviate Senescence and Decay in Fresh-cut Sweetpotato

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Abstract. Hydrogen sulfide (H₂S) has been shown to be a gaseous molecule in the regulation of many processes in plants such as abiotic stress tolerance, root organogenesis, stomatal movement, and postharvest fruit senescence. We studied the role of H₂S in the regulation of senescence and fungal decay in fresh-cut sweetpotato (*Ipomoea batatas* L., cv. Xushu 18) roots. H₂S donor sodium hydrosulfide (NaHS) alleviated senescence in fresh-cut sweetpotato root tissue in a dose-dependent manner with the optimal concentration of 2.0 mmol·L⁻¹ NaHS solution. At the optimal concentration of 2.0 mmol·L⁻¹ NaHS, H₂S fumigation maintained higher levels of reducing sugar in sweetpotato fresh-cut root. H₂S treatment also significantly increased the activities of guaiacol peroxidase (POD) and decreased those of polyphenol oxidase (PPO) in sweetpotato during storage. Further investigation showed that H₂S treatment maintained a lower level of lipoxygenase (LOX) activity compared with water control. Consistently, the accumulation of malondialdehyde (MDA) was reduced in H₂S-treated groups. Three fungal pathogens, *Rhizopus nigricans*, *Mucor rouxianus*, and *Geotrichum candidum*, were isolated from sweetpotato tissue infected with black rot or soft rot. H₂S fumigation at 1 to 2.5 mmol·L⁻¹ NaHS resulted in effective inhibition of the three fungi when grown on medium. When the three fungi were inoculated on the surface of sweetpotato slices, H₂S fumigation greatly reduced the percentage of fungal infection. In conclusion, these data suggest that H₂S effectively alleviated the senescence and decay in sweetpotato slices and might be developed into a novel fungicide for reduction of black rot or soft rot in sweetpotato.

Sweetpotato [*Ipomoea batatas* (L.) Lam] is grown in regions ranging from the tropics to the subtropics and ranks sixth or seventh among the most important food crops in the world (Scott, 1992). Fleshy storage roots of sweetpotato are used as a staple food and provide vitamin C, provitamin A, vitamin B,

and iron and also as a raw material for production of starch, organic acids, and alcoholic beverages (Azhar and Hamdy, 1981; Woolfe, 1992). Sweetpotatoes are usually stored for several months between harvest seasons. As a result of physical damage occurring during harvesting and handling, sweetpotato roots frequently suffer from rapidly developing postharvest diseases, which lead to short-term storage loss (Harrison et al., 2001). Many storage rots are caused by fungi such as *Fusarium oxysporum* f. sp. *batatas*, *Fusarium solani*, *Lasioidiplodea theobromae*, *Rhizopus stolonifer*, and *Rhizopus nigricans* (Harrison et al., 2001; Ray and Ravi, 2005). Microbial infection of sweetpotato roots is manifested by changes in starch, total sugars, organic acids, enzymes, and phytoalexin content (Thompson, 1981). Besides fungal spoilage, respiration, transpiration, and sprouting also lead to loss in weight and alteration of appearance and internal metabolism in sweetpotato roots (Ray and Ravi, 2005). Therefore, the development of effective fungicides is important for controlling spoilage and enhancing storage life of postharvest sweetpotato.

H₂S, which was regarded as a toxic molecule both to plants and animals, has been recently shown to be a gaseous signaling molecule (Lisjak et al., 2013; Wang, 2012; Zhang et al., 2008). Previous studies showed that H₂S can be released by various plant species such as cucumber, squash, pumpkin, and soya bean (Rennenberg, 1983; Wilson et al., 1978). Endogenous H₂S generation is catalyzed by sulfite reductase or desulfhydrases (Rausch and Wachter, 2005). Accumulating evidence has demonstrated that H₂S can regulate many processes in plants, including seed germination, stomatal movement, root organogenesis, and photosynthesis (García-Mata and Lamattina, 2010; Jin et al., 2011, 2013; Lisjak et al., 2013; Zhang et al., 2008, 2009). A senescence-alleviating role of H₂S has been found in fresh-cut flowers, strawberry, and kiwifruit (Gao et al., 2013; Hu et al., 2012; Zhang et al., 2011). However, whether H₂S can alleviate the senescence and decay in fresh-cut sweetpotato roots and the mechanisms underlying this effect are largely unknown.

Several naturally occurring gases have been shown to have effects as antifungal compounds. Nitric oxide (NO), which like H₂S is also a bioactive gaseous signal, exhibits antifungal effects on several postharvest horticulture pathogens, including *A. niger*, *M. fructicola*, and *P. italicum* (Lazar et al., 2008). H₂S has been shown to be released on pathogen attack in several plant species (Bloem et al., 2004), suggesting a possible endogenous role of H₂S in fungal inhibition. Additionally, inorganic and organic sulfur compounds have long been used as fungicides. Thus, in the present study, we aim to study the effect of H₂S on the growth of horticultural pathogens and physiological changes in sweetpotato slices.

Materials and Methods

Plant materials and treatments. Sweetpotato (*Ipomoea batatas* L., cv. Xushu 18) was supplied by the National Sweet Potato Improvement Center, Xuzhou, Jiangsu Province, China. Sweetpotato tubers, without physical damage and microbial infection, were washed in flowing tap water and then cut into slices of 1 cm × 1 cm × 7 cm. NaHS (Sigma, St. Louis, MO) was used as a H₂S donor. Aqueous NaHS solutions (150 mL) of 0, 0.5, 1.0, 1.5, 2.0, and 2.5 mmol·L⁻¹ were prepared in sealed containers (volume 3 L). These solutions could release H₂S gas rapidly, reaching a stable level of H₂S concentration within 30 min. Approximately 11 sweetpotato slices were placed on a plate with pores. The plate was located in the middle part of the container, the bottom of which was water or NaHS solution. This method allows the sweetpotato slices to be fumigated by H₂S released from NaHS solution instead of being immersed in solutions. Incubation temperature was 20 ± 0.5 °C at a relative humidity of 85% to 90%. NaHS solutions were renewed daily and the sweetpotato slices were observed every 24 h for 4 d. For physiological

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parameters, sweetpotato slices were sampled until 6 d. Three containers were used for a single experiment. This work was repeated three times with similar results.

Sensory evaluation of sweetpotato samples.

Sensory evaluation of sweetpotato samples was conducted by a panel of 10 experts. Before the test, the expert was trained to recognize and score tissue quality. A 9-point hedonic scale, where 9 = like extremely, 7 = like moderately, 5 = neither like nor dislike, 3 = dislike moderately, and 1 = dislike extremely, was used for the evaluation (Meilgaard et al., 1991).

Determination of reducing sugar concentration. Reducing sugar content was measured according to the method of Miller (1959). Samples (5.00 ± 0.05 g) of sweetpotato slices until 6 d of storage were ground in 5 mL phosphate buffer (pH 7.0, 200 mmol·L⁻¹). The homogenate was centrifuged at 10,000 g for 30 min, and the supernatant was used for reducing sugar determination. The supernatant (0.2 mL) was mixed with 1.5 mL 3, 5-dinitrosalicylic acid and 1.8 mL distilled water. The mixture was heated at 100 °C for 5 min, cooled on ice, and 25 mL distilled water added. Reducing sugar was determined spectrophotometrically at 540 nm and the results are expressed as milligrams per gram fresh weight (FW).

Determination of guaiacol peroxidase, polyphenol oxidase, lipoxygenase activities, and malondialdehyde. Activities of POD and LOX were determined by procedures described by Zhang et al. (2008). Sweetpotato samples (5.00 ± 0.05 g) in up to 6 d of storage were homogenized in 1 mL of 200 mmol·L⁻¹ ice-cold phosphate buffer (pH 7.8) containing 1.0 mmol·L⁻¹ ethylene diamine tetra acetic acid. The homogenate was centrifuged at 12,000 g at 4 °C for 20 min, and the supernatant was used for activity measurement. Analysis of POD activity was based on the oxidation of guaiacol by hydrogen peroxide. The reaction mixture contained 2.6 mL of 50 mmol·L⁻¹ phosphate buffer (pH 6.1), 1 mL of 3% H₂O₂, 1 mL of 1% guaiacol, and 100 to 200 µL of enzyme extract. The increase in absorbance at 420 nm was recorded. One unit of POD activity was defined as an increase or decrease of 0.01 in absorbance per minute. The values of POD activities are indicated as units per gram FW.

For LOX, samples (5.00 ± 0.05 g) of sweetpotato slices in up to 6 d of storage were homogenized in 1 mL of 200 mmol·L⁻¹ phosphate buffer (pH 6.0). The homogenate was centrifuged at 15,000 g at 4 °C for 10 min, and the supernatant was used for LOX activity assay. The assay mixture in a total volume of 3 mL contained 200 mmol·L⁻¹ borate buffer (pH 6.0), 0.25% linoleic acid, 0.25% Tween-20, and 50 µL of enzyme extract. The reaction was carried out at 25 °C for 3 min, and the activity of LOX was determined in the presence of linoleic acid by monitoring the changes in absorbance at 234 nm.

Activity of PPO was determined by procedures described by Benjamin and Montgomery (1973). Samples (2.00 ± 0.05 g) of

sweetpotato slices in 6 d of storage were homogenized in 5 mL of sodium phosphate buffer (50 mmol·L⁻¹, pH 7.2). The homogenate was centrifuged at 5000 g at 4 °C for 15 min, and the supernatant was used for the activity assay with catechol as substrate. One unit of PPO activity was defined as an increase of 0.01 O.D. value in absorbance at 410 nm per minute. The results were expressed as U·g⁻¹ FW. Each experiment was repeated three times.

Contents of MDA were determined according to the methods of Zhang et al. (2010). Samples (5.00 ± 0.05 g) of sweetpotato slices were ground in 3 mL of 0.1% trichloroacetic acid (TCA) and centrifuged at 15,000 g for 10 min, and 0.5 mL of the supernatant was mixed with 2 mL of 20% TCA containing 0.5% thiobarbituric acid. The mixture was heated at 90 °C for 20 min, cooled on ice, and centrifuged at 10,000 g for 5 min. Absorbance was recorded at 532 nm and the value for nonspecific absorption at 600 nm was subtracted. An extinction coefficient of 155 mm⁻¹·cm⁻¹ was used to calculate MDA content.

Fungi isolation from sweetpotato and H₂S treatment of fungi. *R. nigricans*, *M. rouxianus*, and *G. candidum* were isolated from the surface of sweetpotato showing soft rot and black rot lesions and cultured on agar rose bengal medium at 28 °C in the dark. Spore suspensions were prepared by flooding 6-d-old sporulating cultures with sterile distilled water. The spore concentrations of the pathogen were determined with a hemacytometer and diluted with sterile distilled water to 1×10^4 spores/mL. Aliquots of spore suspension (2 µL) were placed on 9-cm diameter petri dishes maintained in sealed 3-L containers. NaHS solutions at 150 mL in concentrations of 0, 0.5, 1.0, 1.5, 2.0, and 2.5 mmol·L⁻¹ were placed in the bottom of the sealed containers at 20 °C with a relative humidity of 90% to 95% to fumigate fungi for the time indicated in the figure legends. For fungal infection of sweetpotato roots, roots were cut into slices of 5 cm × 5 cm × 1 cm. Spore suspension at 5 µL of $1 \times$

10^4 spores·mL⁻¹ of *R. nigricans*, *M. rouxianus*, or *G. candidum* were inoculated onto the sweetpotato slices with 20 inoculations on a slice (Zheng et al., 2007). After inoculation, slices were stored at 20 °C in 3-L sealed containers with 150 mL of 0, 0.5, 1.0, 1.5, 2.0, or 2.5 mmol·L⁻¹ NaHS on the bottom for 5 d. The number of infected inoculations and the lesion diameters were examined on Day 5. Inoculation with infection diameter above 2 mm was defined as infected and those below 2 mm as the uninfected. The infection percentage was calculated from 100 inoculations. Each experiment was repeated three times.

Measurement of endogenous H₂S in sweetpotato. Hydrogen sulfide was determined by formation of methylene blue from dimethyl-*p*-phenylenediamine in H₂SO₄ according to the method described by Sekiya et al. (1982).

Statistics. Data were analyzed by one-way analysis of variance, and the results are expressed as the mean values ± SD of three independent experiments. Fisher's least significant differences were calculated following a significant ($P < 0.01$ or $P < 0.05$) test. The symbols * and ** in the figures stand for a significant difference between treatments at $P < 0.05$ and $P < 0.01$, respectively.

Results

H₂S alleviates the decay of fresh-cut sweetpotato roots. In this work, fresh-cut sweetpotato slices were fumigated with H₂S released from NaHS solutions (0, 0.5, 1.0, 1.5, 2.0, or 2.5 mmol·L⁻¹). As shown in Figure 1 and sensory evaluation in Table 1, H₂S fumigation effectively alleviated the decay of fresh-cut sweetpotato tissue and showed a higher score of sensory evaluation in a dose-dependent manner. After 3 d of storage, sweetpotato slices from water controls rotted quickly with obvious fungal growth, whereas H₂S treatment alleviated fungal growth and browning of the surface. A concentration of 2 mmol·L⁻¹ NaHS was found to be the most effective, whereas higher concentrations conferred no further effect on the

Fig. 1. Effect of hydrogen sulfide (H₂S) on senescence and decay of fresh-cut sweetpotato slices. Fresh-cut slices were fumigated with H₂S gas released from different concentrations (0, 0.5, 1.0, 1.5, 2.0, 2.5 mmol·L⁻¹) of sodium hydrosulfide (NaHS) solutions and photographed from Day 0 to Day 4. The experimental treatment concentrations are shown in the lower right part.

senescence of sweetpotato compared with the optimal 2 mmol·L⁻¹.

Effect of H₂S on the content of reducing sugar in sweetpotato. To study the nutrient level in sweetpotato, we determined the level of reducing sugar in sweetpotato under H₂S fumigation. Figure 2 showed that H₂S maintained significantly higher levels of reducing sugar than water control during storage. In the early stage of storage (0 to 3 d), reducing sugar content in water control decreased steadily but thereafter increased slightly. A similar pattern of change in reducing sugar content was observed in H₂S-treated sweetpotato slices, and the levels were always higher than those of water control.

Effect of H₂S on the activities of POD, PPO, LOX, and the content of MDA in sweetpotato. We studied changes in senescence related enzymes such as POD, PPO, and LOX and the lipid peroxidation marker MDA content in sweetpotato under H₂S treatment. The overall change pattern of POD activity was similar in the water control and H₂S treatment (Fig. 3A). During the first 3 d of storage, POD activity increased steadily and then decreased gradually in both of water control and H₂S treatment. However, H₂S treatment maintained a significantly higher level of POD activity compared with the water control.

PPO, which participates in the oxidation of phenolics into brown-colored pigments

(Mishra et al., 2013), was also examined in sweetpotato slices (Fig. 3B). PPO activities in water controls increased gradually up to Day 4 of storage and then maintained relatively a stable level. In contrast, PPO activities in H₂S-treated sweetpotato tissue decreased dramatically during the first 3 d and then sustained a stable level from 3 to 6 d of storage. During Day 3 to Day 6, PPO activity in water controls was ≈2-fold of that in H₂S treatment, suggesting that H₂S maintained a lower level of PPO activity.

The effect of H₂S treatment on the changes of LOX activity in sweetpotato slices is shown in Figure 3C. LOX activity in water controls increased dramatically during the first 3 d of storage and then decreased rapidly until the end of storage. In comparison with the water control, LOX activity increased slightly and peaked to ≈30 U·g⁻¹ FW on Day 3 and then decreased gradually. During the entire storage time, H₂S was found to maintain a lower level of LOX activity in sweetpotato slices.

As shown in Figure 3D, there was a rapid accumulation of MDA during the first 3 d of storage in water controls followed by a decrease on Day 4 to a level that remained stable level until the end of the storage period. As for H₂S treatment, MDA content increased during the first 2 d of storage and then fluctuated at a lower level compared with water controls.

Inhibitory effect of H₂S on fungi isolated from fresh-cut sweetpotato slices. The reduced fungal growth in H₂S-fumigated sweetpotato slices directed us to study the effect of H₂S on fungal growth. Three fungi, *R. nigricans*, *M. rouxianus*, and *G. candidum*, were isolated from the surface of sweetpotato infected with soft rot and black rot. As shown in Figure 4, the fungi were subjected to different concentrations of NaHS (0, 0.5, 1.0, 1.5, 2.0, 2.5 mmol·L⁻¹). With increased concentrations of NaHS, fungal growth was inhibited gradually. As observed in the lower part of Figure 4A–C, the colony diameters of the three pathogens were severely decreased under 2 mmol·L⁻¹ NaHS fumigation, suggesting the effective fungicide role of H₂S. The effects of H₂S fumigation on fungal infection of sweet slices are shown in Figure 5. At 2 mmol·L⁻¹ NaHS, the percentage fungal infection was decreased sharply for all three pathogens tested further suggesting an effective fungicidal role of H₂S.

Discussion

Sweetpotato roots are commonly subjected to postharvest spoilage as a result of mechanical injury, sprouting, pests, and especially fungal diseases (Ray and Ravi, 2005). Several fungi have been shown to induce spoilage in sweetpotatoes such as *Fusarium* spp., *L. theobromae*, *R. stolonifer*, and *R. nigricans* (Harrison et al., 2001; Ray and Ravi, 2005). Accordingly, considerable research effort has focused on developing new fungicides to control horticulture pathogens. Sulfur compounds have been widely used as fungicides from the time of antiquity. Marsh (1929) reported that H₂S was toxic to germinating fungal spores and Haneklaus et al. (2007) calculated that a minimum uptake of 10 μM H₂S/h by pathogens could generate a fungicidal effect. In the present study, we found that H₂S treatment alleviated the senescence and fungal decay in fresh-cut sweetpotato slices (Fig. 1). Three fungal pathogens, *R. nigricans*, *M. rouxianus*, and *G. candidum*, were isolated from sweetpotato having black rot or soft rot. Concentrations of NaHS from 0.5 to 2.5 mmol·L⁻¹ inhibited growth of these three fungal pathogens on petri dishes in a dose-dependent manner. When the three pathogens were inoculated on the cut surface of sweetpotato slices, 2 mmol·L⁻¹ NaHS effectively reduced fungal infection (Fig. 5). These antifungal effects suggest the potential use of H₂S as a natural fungicide to inhibit microbial spoilage on sweetpotato roots.

Fungal spoilage of sweetpotato roots is associated with a decrease in starch, total sugar, and organic acid contents (Ray and Ravi, 2005). In the present study, H₂S treatment was found to maintain a higher level of reducing sugar than water control (Fig. 2), suggesting the protective role of H₂S in post-harvest storage of sweetpotato. In response to wounding, peeling, or fungal spoilage of sweetpotato, many enzymes are induced such as those in the phenyl propanoid pathway, i.e., phenylalanine ammonia lyase and transcinnaic acid

Table 1. Sensory scores of sweetpotato slices treated with different concentrations of sodium hydrosulfide (NaHS) and control (water) during storage at 20 ± 0.5 °C.^a

Overall quality	Storage time (day)				
	0	1	2	3	4
Water control	9 ± 0 a	6.8 ± 0.55 bc	5.8 ± 0.12 c	3 ± 0.35 e	1.4 ± 0.27 f
0.5 mmol·L ⁻¹ NaHS	9 ± 0 a	7.6 ± 0.27 bc	6.4 ± 0.27 c	4.6 ± 0.27 d	3.9 ± 0.11 e
1 mmol·L ⁻¹ NaHS	9 ± 0 a	7.9 ± 0.11 b	6.5 ± 0.25 c	6.1 ± 0.27 c	4.5 ± 0.25 de
1.5 mmol·L ⁻¹ NaHS	9 ± 0 a	7.9 ± 0.37 b	7.3 ± 0.22 bc	6.7 ± 0.22 c	5.7 ± 0.22 c
2 mmol·L ⁻¹ NaHS	9 ± 0 a	8.1 ± 0.27 b	7.5 ± 0.25 bc	7 ± 0.27 bc	6.1 ± 0.27 c
2.5 mmol·L ⁻¹ NaHS	9 ± 0 a	7.9 ± 0.37 b	7.3 ± 0.22 bc	6.9 ± 0.37 bc	5.9 ± 0.11 c

^aData are presented as means ± SD (n = 10). Different letters indicate significant differences (*P* < 0.05) between the treatments.

Fig. 2. Effect of hydrogen sulfide (H₂S) on the accumulation of reducing sugar in fresh-cut sweetpotato. Fresh-cut sweetpotato was fumigated with 2 mmol·L⁻¹ sodium hydrosulfide (NaHS) aqueous solution (T) with water as a control (CK) for 0 to 6 d. Data are presented as means ± SD (n = 3). The symbols * and ** in this figure and following ones stand for significant difference between CK (water) and T (H₂S fumigation) at *P* < 0.05 and *P* < 0.01, respectively.

Fig. 3. Role of hydrogen sulfide (H_2S) in the regulation of the activities of guaiacol peroxidase (POD) (A), polyphenol oxidase (PPO) (B), lipoxygenase (LOX) (C), and the content of malondialdehyde (MDA) (D) in fresh-cut sweetpotato. Fresh-cut sweetpotato were fumigated with $2 \text{ mmol}\cdot\text{L}^{-1}$ sodium hydrosulfide (NaHS) aqueous solution (T) with water as the control (CK) for 0 to 6 d. Data are presented as means $\pm$ SD ($n = 3$).

Fig. 4. Inhibitory effect of hydrogen sulfide (H_2S) on the growth of pathogenic fungi isolated from sweetpotato, *R. nigricans* (A), *M. rouxianus* (B), and *G. candidum* (C). The upper photographs in the figure indicate the growth of the fungi on medium subjected to different concentrations from left to right, upper to lower 0, 0.5, 1.0, 1.5, 2.0, and $2.5 \text{ mmol}\cdot\text{L}^{-1}$ sodium hydrosulfide (NaHS) for 5 d, and the lower part of the figure shows the diameters of fungal colonies.

Fig. 5. Effect of hydrogen sulfide (H_2S) on the infection of sweetpotato root tissue by pathogenic fungi. Spore suspension of *R. nigricans*, *M. rouxianus*, or *G. candidum* was inoculated onto the surface of the sweetpotato roots that were then fumigated with 2 mmol·L⁻¹ sodium hydrosulfide (NaHS) solution (T) or water (CK) in a 3-L sealed container for 5 d and photographed (A). The infection percentage was calculated from 100 inoculations (B). Each experiment was repeated three times.

4-hydroxylase (Tanaka and Uritani, 1977; Uritani, 1998; Yin et al., 2012). Besides, fresh-cut results in a severe wounding response, including oxidative browning, tissue softening, water loss, and production of undesirable flavors and odors (Martín-Belloso et al., 2007). In infected sweetpotato tissue, POD and PPO activities are increased (Arinze and Smith, 1982). When treated with H_2S , the activities of POD are enhanced in sweetpotato slices (Fig. 3A), whereas the activities of catalase, ascorbate peroxidase, and superoxide dismutase are not significantly different between H_2S treatment and controls. POD, which is an effective antioxidant enzyme, may help to scavenge reactive oxygen species generated during postharvest senescence of fruits and vegetables (Hu et al., 2012; Reyes et al., 2007; Zhang et al., 2011).

Consistent with a previous report (Arinze and Smith, 1982), we observed an increase in the activity of PPO in water controls during sweetpotato storage (Fig. 3B), which might be a response to fungal growth. Meanwhile, H_2S maintained PPO activity at a low level for the duration of storage (Fig. 3B). PPO is commonly induced during fruit injury, fungal infection, and senescence (Arinze and Smith, 1982). Thus, we propose H_2S indirectly inhibited PPO activity by reducing fungal infection and alleviating senescence in sweetpotatoes.

The senescence of fresh-cut fruit or vegetables is accompanied by lipid peroxidation. Increased LOX activity is found to be associated with enhanced lipid peroxidation in plants (Hodges and Toivonen, 2008). LOX catalyze the oxygenation of polyunsaturated

fatty acids into lipid hydroperoxides and lead to the formation of hydroperoxides (Duan et al., 2007). MDA, a secondary end product of polyunsaturated fatty acid oxidation, is an index of lipid peroxidation (Lana and Tijskens, 2006). In our work on sweetpotato senescence, there was an increase in LOX activity and MDA content. During the first 3 d of storage, H_2S treatment reduced the activities of LOX and a concomitant lowering of MDA content was observed (Fig. 3C–D). We propose that H_2S alleviated lipid peroxidation by activating the antioxidant enzyme POD and attenuating LOX activity, thereby delaying postharvest senescence in sweetpotato.

NO used to be regarded as a toxic gas but has now been found to act as a signaling molecule in plants and is extensively studied in postharvest storage of fruits and vegetables (Leshem et al., 1998; Wills et al., 2000). For instance, NO treatment was able to protect wounded sweetpotato roots from an increase in MDA, H_2O_2 , and O_2^- by activating antioxidant enzymes (Yin et al., 2012). Considering the successful use of NO in postharvest storage, we propose that low concentrations of H_2S could also be used to alleviate postharvest senescence and decay. In this study, the application concentration of NaHS solution at 0.5 to 2.5 mmol·L⁻¹ releases ≈ 0.005 to 0.01 ppm H_2S gas in a sealed container, sufficient to act as an effective fumigant during sweetpotato storage (Hu et al., 2012). As stated in the patent, “A process of food preservation with hydrogen sulfide, WO2013106277 A1,” 0.0047 ppm is the recognition threshold and 10 ppm has an exposure limit of 8 h·d⁻¹, suggesting NaHS concentrations that we used are relatively safe. In our previous work, we showed that H_2S treatment induced an increase in endogenous H_2S levels in strawberry by 10% to 20% compared with that of the water control (Hu et al., 2012). Thus, we propose that fumigation with trace H_2S gas released from NaHS solution on sweetpotato could be safe and practical.

In conclusion, our results indicate that H_2S inhibits fungal growth and modulates senescence-related enzymes in treated sweetpotato tissue, thereby alleviating postharvest fungal spoilage and senescence.

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