



Potential of basic substances in plant protection to reduce *Podosphaera pannosa* in cut roses

Florian Wulf^{1,2} · Jana Podhorna² · Martina Bandte² · Malgorzata Rybak¹ · Carmen Büttner²

Received: 10 June 2022 / Accepted: 1 August 2022 / Published online: 10 August 2022
© The Author(s) 2022

Abstract

Alternative strategies in plant protection are required due to political and environmental conditions. Basic substances can potentially benefit for modern plant protection in conventional and organic horticulture. In the case of plant protection in ornamentals, little is known about the effect of basic substances within the canopy to reduce foliar diseases. *Podosphaera pannosa* is one of the most severe diseases in the production of cut roses. In this study, different cultivars of cut roses were sprayed weekly with an extract of *Equisetum arvense* (4 g dried plant material/L), an aqueous solution of hydrogen peroxide (10 g/L) and a commercial plant protection product containing potassium hydrogen carbonate (VitiSan, Biofa GmbH, Münsingen, Germany) during two experimental trials. As a result, the symptoms of infected leaf area could be reduced significantly as the experiments progressed. Furthermore, no negative effects such as a reduction of plant growth or the number of marketable flowers were observed. The results indicate that the foliar application of the basic substances hydrogen peroxide and *E. arvense*-extract has the potential to reduce the use of synthetic plant protection products in conventional and organic horticulture.

Keywords *Rosa* · Hydrogen peroxide · *Equisetum arvense*-extract · Powdery mildew

Introduction

Modern horticulture requires alternative plant protection. Due to political and environmental requirements, the number of registered conventional products in the field of horticultural plant protection is limited. Additionally, the growers face many uncertainties regarding new pathogens and limitations in application of plant protectants. In regard to practical application, there is a lack of knowledge about the utilization of basic substances. Moreover, these approaches are not sufficiently explored to implement them directly in the field, orchard or greenhouse.

Basic substances, such as sodium carbonate, beer, whey or sunflower oil, are regularly accessible products used as food ingredients or for other common uses, including pharmaceuticals, biocides and fertilizers. They are not predominantly used as plant protection products but they could be considered as an additional component of a plant protection strategy (Marchand 2015). Basic substances are not characterized as harmful, and they have no direct or cumulative effects on human or animal health or on the environment (EU 2009). They can represent an alternative to plant protectants including those that contain synthetic active ingredients. Furthermore, basic substances can support organic and sustainable agriculture (Đurić et al. 2019; Marchand 2017). They are officially listed with further “report reviews” in the European Union (EU) pesticides Database (EU 2022).

Equisetum arvense L. (field horsetail), a common widespread weed, has long been known as a medicinal plant for pharmaceutical or cosmetic treatments (Čanadanović-Brunet et al. 2009; Carneiro et al. 2019; Oh et al. 2004; Pallag et al. 2018). The most common compounds found in field horsetail are flavonoids, phenolic acids, alkaloids, phytosterols, tannins, and triterpenoids (Četojević-Simin et al. 2010; Godlewska et al. 2020). Some of the substances were studied

✉ Florian Wulf
florian.wulf@bwi.hamburg.de

¹ Plant Protection Service Hamburg, Ministry of Economy and Innovation, Free and Hanseatic City of Hamburg, Brennerhof 123, 22113 Hamburg, Germany

² Division Phytomedicine, Albrecht Daniel Thaer-Institute of Agricultural and Horticultural Sciences, Humboldt-Universität zu Berlin, Lentzeallee 55/57, 14195 Berlin, Germany

for inhibition properties of the phytopathogenic late blight disease fungi *Phytophthora infestans* (Rogozhin et al. 2020; Taylor et al. 2022).

The above ground plant material of *E. arvense* contains a high content of silica (García-Gaytán et al. 2019). The extract helps to strengthen plant cell tissues, due to an implementation of silica. This physical barrier prevents the penetration of the fungal appressorium into the plant (Fauteux et al. 2005; Marchand 2016). Many studies deal with an artificial increased content of elementary silicon in plants and its influence on plant fitness (Fauteux et al. 2005; Fawe et al. 2001; Guntzer et al. 2012; Voogt and Sonneveld 2001). The effect of higher silicon content by root uptake protects the plant from sucking insects, but there is a lack of knowledge considering the foliar application of Si-containing molecules (Gomes et al. 2005; Goussain et al. 2005; Moraes et al. 2004). For its strengthening effects, the field horsetail extract (EU 2017b) has been authorized by the Commission Implementing Regulation (EU) 2021/1165 of 15 July 2021 (EU 2021) for the use in conventional and organic plant protection as a basic substance.

Hydrogen peroxide (H_2O_2) is an oxidizing and reducing agent, used mostly for disinfection of surfaces, seeds or nutrient solutions and is listed as a basic substance in the EU (Carrasco and Urrestarazu 2010; Eicher-Sodo et al. 2019; EU 2017a; Lau and Mattson 2021; Raudales et al. 2014). Copes et al. (2003) concluded that the disinfectant kills fungal propagules and bacterial cells by direct contact without remaining harmful residuals. Hydrogen peroxide is active only for minutes and provides no systemic resistance. The degradation of hydrogen peroxide into oxygen and water is fast and easy, which means it is biodegradable and not harmful. The potential of the disinfection is also dependant on chemical reactions with water and organic material on the surface (Copes et al. 2003).

Besides the disinfecting effect, hydrogen peroxide applied as a foliar spray in low doses was examined for its positive influence on growth and antioxidant compounds in leaves in *Capsicum chinense* and *Amaranthus hypochondriacus* (Espinosa-Villarreal et al. 2017; Vargas-Hernández et al. 2016). There are also first reports of a positive effect on *Oryza sativa* under drought stress (Jira-anunkul and Pattanagul 2021).

Assuming a positive effect on plant growth and depending on the Good Agricultural Practice validated in the relevant Review Reports, basic substances could be used more frequently in conventionally and organically produced plants (Đurić et al. 2019; Richter et al. 2021). Here, we evaluated the effects of a weekly foliar application of the two basic substances on growth and leaf health of roses in the greenhouse. For this purpose, *E. arvense* extract and hydrogen peroxide were applied to different cultivars of cut roses and visually observed during two experimental trials. These

applications were compared to water and a chemical plant protectant that is commonly used in practice.

Material and methods

Two experiments were conducted in the greenhouse under controlled conditions from May to June 2021 and June to July 2021, respectively. The greenhouse is located at longitude 10° 05' 00.2'' E, latitude 53° 30' 33.5'' N and altitude of 3 m above mean sea level. The experimental set-up was the same for both trials.

Plant material and greenhouse set-up

For the experiments, two cultivars of cut roses (*Rosa* spp.), Susan and Beluga, were planted in growbags in March 2021. The Growbags were filled with 70% of coconut fibre and 30% of perlite. The size of the bags was 1.2 × 0.2 m. For the trial, the cultivars were placed alternating with ten plants per plot and cultivar. The plots had a size of 1 × 2 m. The temperature in the greenhouse was adjusted between 22 and 18 °C. No artificial light was given and the canopy was shaded when the natural light was higher than 70 kLux.

The plots were distributed in a randomized block design. Each treatment was replicated four times. The infection of *P. pannosa* occurred naturally and no artificial infection was necessary. The infestation with *P. pannosa* was checked randomly by identification of propagules via microscope. During the experiments, the infected leaf area of eight plants per plot and cultivar was weekly estimated as percent infected leaf area. The evaluation was conducted directly prior to the first application (day 0) and subsequently at day 7, 14, 21 and 28. Border plants from the next plot were not considered. It was always the same person who evaluated the infected leaf area.

At the beginning and at the end of the experimental trials, the height of the plant was measured. In addition, at the end of the first period, the number of marketable flowers per plot was determined.

Treatments

Within both experiments, the amount of spray mixture was adjusted to the canopy height. Up to 0.5 m plant height 100 mL/m² and above 0.5 m plant height 150 mL/m² of the solution was used. The different substances (Table 1) were applied weekly using a 5-L backpack sprayer (Inox, Mesto Spritzenfabrik Ernst Stockburger GmbH, Freiberg, Germany). Besides the basic compounds and a water control, a practice-standard treatment was implemented applying the contact fungicide VitiSan, (Biofa GmbH, Münsingen, Germany). This plant protectant (Reg.no. 007593-00)

Table 1 Substances and their dosage for testing the suitability for reducing an infestation with powdery mildew in roses

Active substance	Doses
Potassium hydrogen carbonate	2.49 g active substance /L
Hydrogen peroxide	10 g H ₂ O ₂ /L
<i>Equisetum arvense</i>	4 g dried plant material /L fresh extract

Depending on the plant height the water volume was adjusted from 100 (plant height below 0.5 m) to 150 mL/m² (above 0.5 m plant height)

provides both a preventive and a curative effect (Table 1). At contact, the active ingredient potassium hydrogen carbonate (994.9 g/kg) covers fungal pathogens such as powdery mildew and botrytis, which subsequently disintegrate and dry out the mycelium or spores and prevents new infection of the plant.

Extract of *E. arvense* was prepared with dried plant material, which was soaked for eight hours in water and later boiled for 45 min. Afterwards, the tea was filtered and diluted for the foliar spray application. Before using the extract, the pH value was checked and if applicable adjusted to ensure the expected range from 6.3 to 6.7. The preparation of the extract is derived from the EU references, although the amount of plant material is slightly increased (EU 2017b; Marchand 2016). The hydrogen peroxide (Carl Roth GmbH & Co. KG, Karlsruhe, Germany) was applied immediately after the dilution.

Statistical analysis

All data were analysed using R in combination with RStudio (R Version 4.0.3, RStudio Version 1.3.1093) with a one-way analysis of variances (ANOVA). Mean comparisons were done with a $P=0.05$ significance level (R package emmeans Version 1.7.0). All statistical differences are in comparison to the water control. In the statistical model, the randomized block design was included.

Results

Growth of *P. pannosa* on rose cultivars

The infected leaf area differed between the two trials and the cultivars. In the first period, the infected leaf area of the water control from both cultivars started at a low level (Beluga $0.16 \pm 0.2\%$, Susan $0.72 \pm 1.25\%$) and ended up with a slight difference between the cultivars (Beluga $4.06 \pm 1.44\%$, Susan $8.88 \pm 3.23\%$, Fig. 1). In the water treated plants of the cultivar Susan in the second period, *P. pannosa* reached a higher infected leaf area at day 28 after

the first application during the first period ($19.06 \pm 2.44\%$). Although there was a higher growth in the cultivar Beluga in the second period, the infected leaf area ended up with a similar amount as in the first period ($4.63 \pm 0.71\%$). Overall, a significantly higher susceptibility of the cultivar Beluga to *P. pannosa* ($P < 0.01$) was determined.

Effect of potassium hydrogen carbonate on the growth of *P. pannosa*

Application of plant protectant VitiSan resulted only partially in a significant reduction of the infected leaf area with *P. pannosa* compared to the water control. Thus, significant differences on the cultivar Beluga occurred 21 and 28 days after experimental set-up ($1.00 \pm 0.32\%$, $P=0.02$; $1.44 \pm 0.44\%$, $P=0.04$) in the first and 14 and 28 days ($1.41 \pm 0.35\%$, $P < 0.01$; $3.66 \pm 0.78\%$, $P < 0.01$) in the second period. In contrast, the cultivar Susan showed only once in the first period a significant difference on day 28 ($5.09 \pm 2.04\%$, $P < 0.01$). After day 14 ($7.88 \pm 1.37\%$, $P < 0.01$), the infected leaf area remained significantly below the value of the water control during the second period.

Effect of *E. arvense* extract on the growth of *P. pannosa*

Weekly application of an *E. arvense* extract resulted in a significant reduction of *P. pannosa* on rose cultivar Beluga on the days 21 and 28 ($0.94 \pm 0.42\%$, $P=0.02$; $2.25 \pm 0.44\%$, $P < 0.01$) in the first period. But during the second period, they could not be confirmed. However, rose cultivar Susan showed significant reduction of infected leaf area on the last two evaluations ($1.94 \pm 0.45\%$, $P=0.01$; $3.53 \pm 0.86\%$, $P < 0.01$) and days 21 and 28 ($11.75 \pm 1.49\%$, $P < 0.01$; $15.38 \pm 2.43\%$, $P < 0.01$) after the use of *E. arvense* extract field horsetail in the first and second observation period, respectively. *E. arvense* extract did not cause phytotoxic effects in any of the two cultivars at any time.

Effect of hydrogen peroxide on the growth of *P. pannosa*

A significant reduction of the powdery mildew could be achieved on the cultivar Beluga only once, on day 28 ($1.75 \pm 0.47\%$, $P < 0.01$) in the first period. In the second experimental period, we found significantly reduced infected leaf area after day 14 ($1.50 \pm 0.24\%$, $P=0.01$). In the cultivar Susan, we could find a significantly decreased infection on days 21 and 28 ($2.47 \pm 0.81\%$, $P=0.04$; $3.19 \pm 1.13\%$, $P < 0.01$) in the first experiment and continuously after day 14 ($7.91 \pm 2.03\%$, $P < 0.01$) in the second period.

In both cultivars, the spray application of hydrogen peroxide damaged the leaves of the cut roses. Slight necrosis

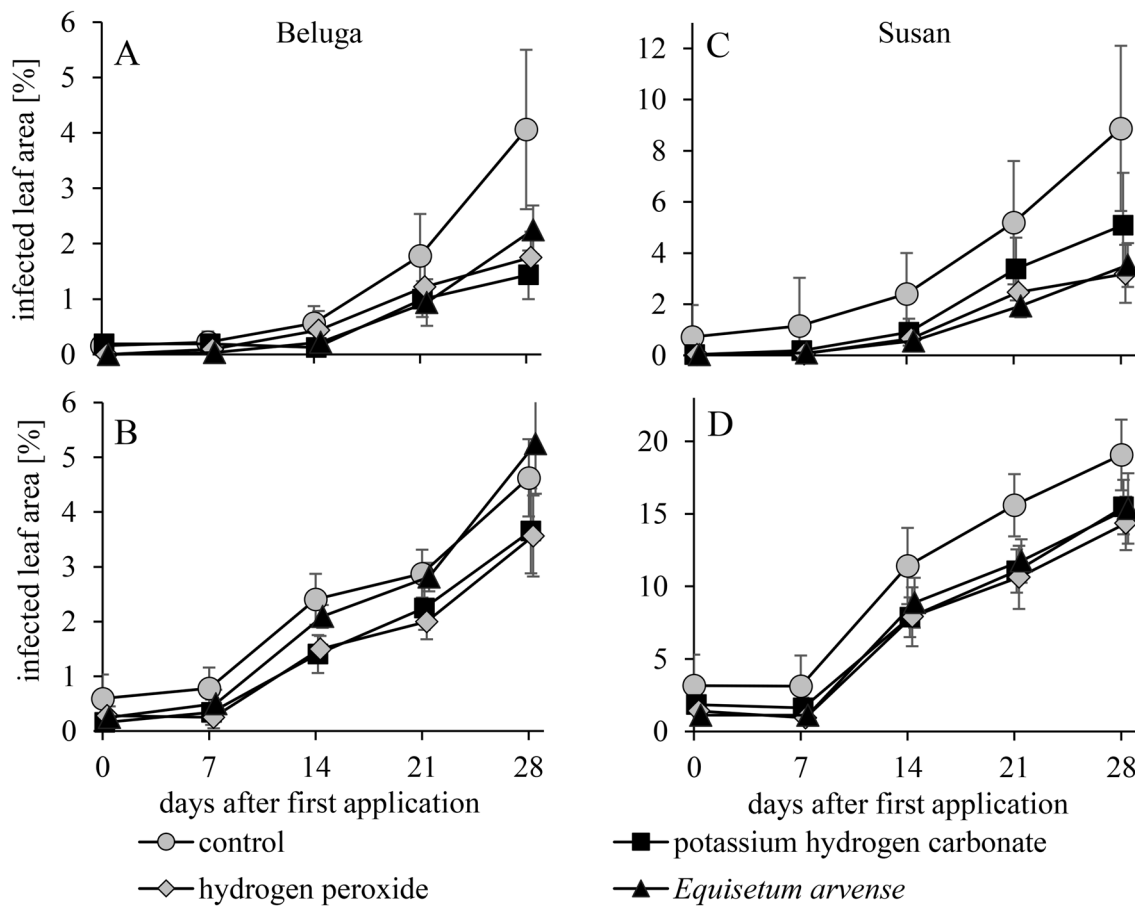


Fig. 1 Effect of foliar applications of the basic substances hydrogen peroxide and *E. arvense*-extract and the plant protectant VitiSan (potassium hydrogen carbonate) on the infection of rose leaves with

P. pannosa (mean $\pm$ standard error, $n=32$). Means are differentiated between the cultivars Beluga (A, B) and Susan (C, D) and the first (A, C) and second (B, D) trial

und deformation occurred on the older leaves of the plant (Fig. 2).

Effects of the foliar treatment on plant height and number of marketable flowers

At the beginning of first experiment, plant height of control plants ranged from 22.96 ± 0.71 cm (Beluga) up to 23.96 ± 0.98 cm (Susan, Fig. 3). At the end of the first experiment, the plants in the control reached a height of 77.79 ± 1.48 cm (Beluga) and 70.58 ± 1.68 cm (Susan). In the second trial, the plant height in the control started higher with 41.92 ± 0.87 cm (Beluga) and 33.75 ± 1.03 cm (Susan) and ended up with 78.96 ± 1.28 cm (Beluga) and 79.88 ± 0.87 cm (Susan).

Neither foliar application of the basic substances nor the plant protectant VitiSan led to any significant differences in plant height during the four-week trial period (Fig. 3).

The number of marketable flowers could only be determined in the first trial. Within a plot, plants of the cultivar

Beluga produced 23.5 ± 1.56 (hydrogen peroxide) up to 27.75 ± 1.49 (*E. arvense*) flowers (Fig. 4). Cultivar Susan yielded less flowers: 16.5 ± 2.99 (*E. arvense*) flowers up to 17.75 ± 1.49 (control) flowers per plot. Similar to the plant height, we could not find any significant differences when comparing the different treatments.

Discussion

Alternative strategies to control pathogens will be a key element in horticultural systems in the future (Brzozowski and Mazourek 2018). To implement such strategies in practice, additional information on their use and behaviour within the canopy are needed. Although many studies were carried out to examine and promote the use of nutrients, plant extracts and biostimulants in agriculture or vegetable production, there is still a lack of knowledge in the field of ornamentals. Among foliar diseases, powdery mildew is probably one of the most severe fungal pathogens in the

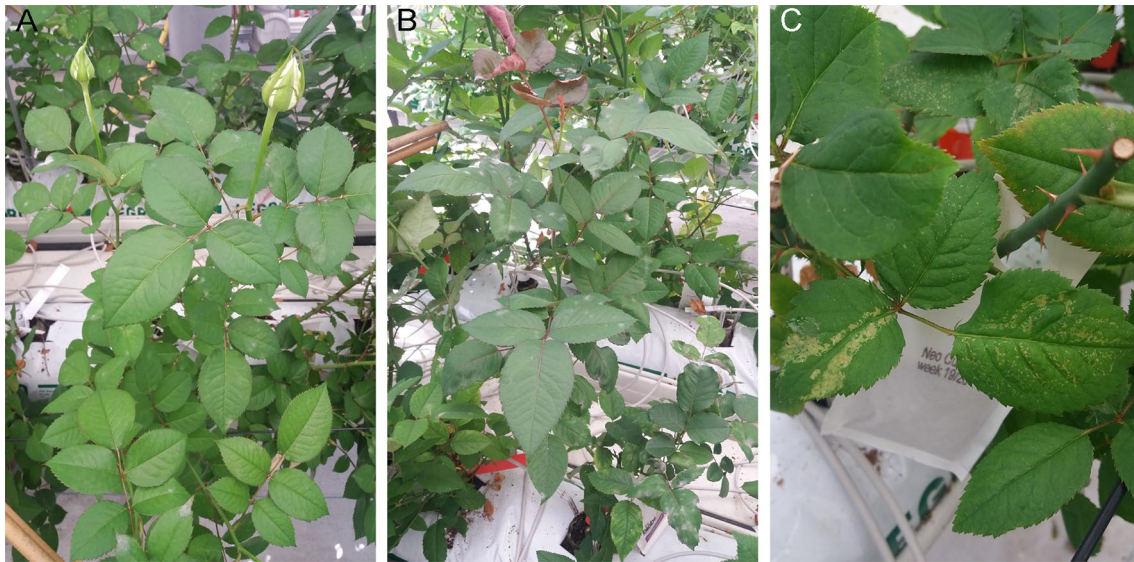


Fig. 2 Damaged leaves of cut roses **A** 10% of leaf area infected with *P. pannosa* (cultivar Beluga), **B** 30% of leaf area infected with *P. pannosa* (cultivar Susan) and **C** Necrosis on the older leaves after the application of hydrogen peroxide (cultivar Susan)

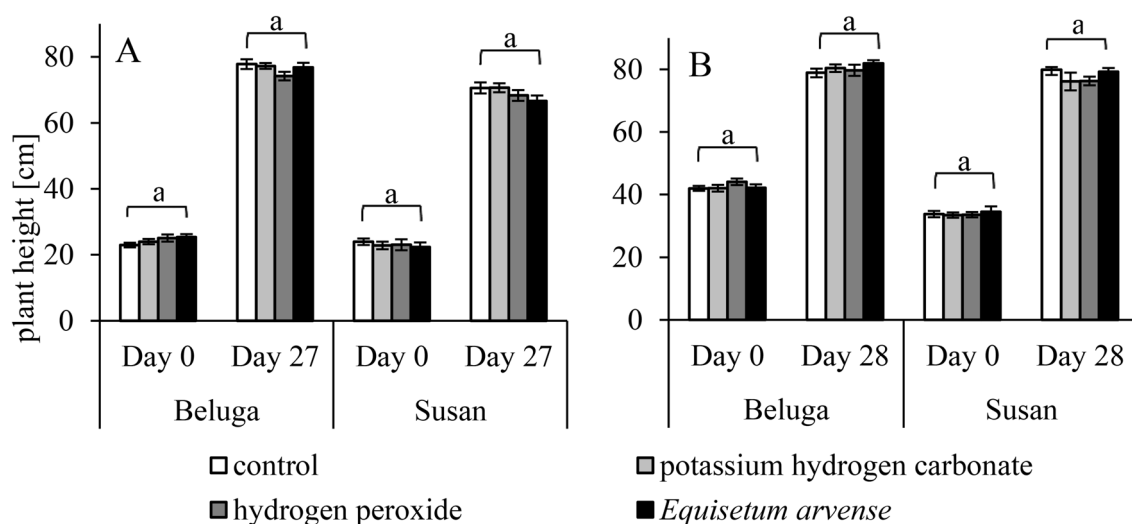


Fig. 3 Effect of foliar applications of the basic substances hydrogen peroxide and *E. arvense* extract and the plant protectant VitiSan (potassium hydrogen carbonate) on the plant height (mean $\pm$ standard error, $n=24$) of cut roses. **A** first trial (May–June) and **B** sec-

ond trial (June–July); the letters indicate no significant differences of the treatment compared to the water control within the cultivars ($P>0.05$)

production of cut roses in the greenhouse. It is no coincidence that over 80 plant protection products (including sales extensions) to control powdery mildew are authorized in Germany (BVL 2022; Richter et al. 2021).

The present study shows the potential of the basic substance *E. arvense* extract to control the pathogen *P. pannosa*. In particular, under low-inoculum pressure, decrease in disease severity was observed without any negative effects on appearance and crop yield.

Due to the high amount of silica in the aerial parts, *E. arvense* can be used as a natural resource of silicon (García-Gaytán et al. 2019; Labun et al. 2013). Although the mechanism is not completely clear, the leaf uptake of foliar sprayed silicon is generally accepted (Guntzer et al. 2012; Laane 2018). Different studies describe the potential of silicon considering abiotic and biotic stresses as the infection of powdery mildew on Cucurbitaceae, *Vitis vinifera* or *Fragaria* sp. (Fauteux et al. 2005, 2006; Fawe et al. 2001; Laane 2018;

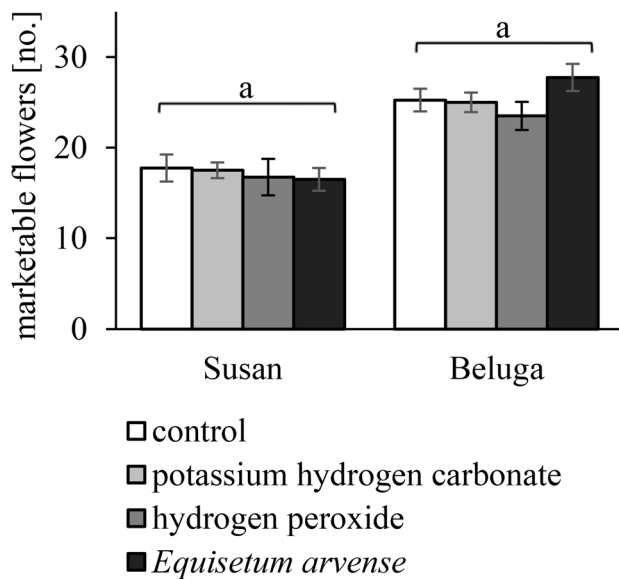


Fig. 4 Effect of foliar applications of the basic substances hydrogen peroxide and *E. arvense* extract and the plant protectant VitiSan (potassium hydrogen carbonate) on the mean number of marketable flowers per plot (mean $\pm$ standard error, $n=4$) of cultivar Beluga and Susan during the first experimental period. The same letters indicate no significant differences of the treatment compared to the water control within the cultivars ($P > 0.05$)

McAvoy and Bible 1996; Tebow et al. 2021). It is hypothesized that the role of foliar sprayed silicon, regarding plant diseases, is primarily based on a mechanical barrier (Bowen et al. 1992; Pozza et al. 2015). Due to a high amount of silicon in the outer cells of the leaf tissue, the fungus could not penetrate into the plant tissue (Guével et al. 2007). In addition to the high silicon load, the extract carries a high amount of active ingredients with a phytosanitary potential, like phenols and flavonoids (Đurić et al. 2019; Garcia et al. 2011). The knowledge on the impact of an extract from *E. arvense* contributes primarily to a protective mode of action while already developed infections are not disrupted conclusively.

Trebbi et al. (2021) showed a reduction of *P. infestans* on tomato and *Puccinia triticina* on Durum wheat after application of a mixture of *E. arvense* extract and copper. They point out the relationship of pathogen density and effectiveness of the basic substance to hamper the pathogen. Langa-Lomba et al. (2021) found synergistic effects, while using chitosan-polymers in combination with an *E. arvense*-extract. For a phytosanitary programme, these approaches, the combination of copper or chitosan with *E. arvense*-extract can compensate for the expected lack of efficiency between a basic substance and a conventional or chemical plant protection product.

In the case of hydrogen peroxide, phytotoxicity as an expected consequence of the foliar spray was already

described (Copes 2004, 2009). Eicher-Sodo et al. (2019) reported a damage-threshold above 25–50 mg/L hydrogen peroxide applied on young microgreens of the species *Brassica eruca*, *Helianthus annuus*, *Raphanus sativus* and *Lactuca sativa*. This is clearly below the concentration of 10 g/L, used in our study. To begin use of hydrogen peroxide, the grower has to consider the developmental stage and cultivar of the plant, while planning the spray application. In our case, fortunately, neither a severe leaf damage nor a significant increased amount of non-marketable flowers occurred during the experimental period.

We could show a significantly reduced disease severity in both cultivars and trials. This is in accordance with the results of Copes (2009) and Baysal-Gurel and Miller (2015), who identified a reduced infection of *P. hemerocallidis* in daylily and *Oidium neolycopersici* in tomato. However, these results are not necessarily applicable to different crop systems. The knowledge of the pathosystem and the pathogenesis is important for the use of hydrogen peroxide as a spray application. Additionally, Copes (2004) describes a strong dose-dependant response of *B. cinerea* spores applied on different substrates from hydrogen peroxide. Overall, very few data are available to assess the potential of hydrogen peroxide as a foliar application, which has to be investigated further. In addition, the disinfection effect on the leaf surface microbiome and the resulting effects on plant vigour are currently unclear.

Basic substances can contribute to the required and important reduction of chemical plant protectant use. However, they do not seem to be a panacea for the grower and we have to consider them as an additional building block within the overall crop protection strategy. In high pathogen pressure conditions, basic substances play a supportive role and may be combined with Biorationals or conventional plant protectants. Further studies are needed to implement the basic substances *E. arvense*-extract and hydrogen peroxide in a plant protection programme.

Acknowledgements We thank Joseph Cutler for English proofreading. This research was founded by the Ministry of Economy and Innovation, Free and Hanseatic City of Hamburg, Germany (project AZ 734.650.004/014B).

Author contributions FW and MB contributed to conceptualization; FW and JP contributed to methodology and investigation; FW contributed to formal analysis, data curation and visualization; FW and MB contributed to validation; FW and JP contributed to writing—original draft preparation; FW, JP, MB, MR, and CB contributed to writing—review and editing; CB contributed to funding acquisition and supervision; MR and CB contributed to project administration and resources.

Declarations

Conflict of interest The authors declare that they have no conflict of interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Baysal-Gurel F, Miller SA (2015) Management of powdery mildew in greenhouse tomato production with biorational products and fungicides. *Acta Hort* 1069:179–183. <https://doi.org/10.17660/ActaHort.2015.1069.25>
- Bowen P, Menzies J, Ehret D, Samuels L, Glass AD (1992) Soluble silicon sprays inhibit powdery mildew development on grape leaves. *J Am Soc for Horticult Sci* 117:906–912. <https://doi.org/10.21273/JASHS.117.6.906>
- Brzozowski L, Mazourek M (2018) A sustainable agricultural future relies on the transition to organic agroecological pest management. *Sustainability* 10:2023. <https://doi.org/10.3390/su10062023>
- BVL (2022) Verzeichnis zugelassener Pflanzenschutzmittel. Bundesamt für Verbraucherschutz und Lebensmittelsicherheit. Available on: <https://apps2.bvl.bund.de/psm/jsp/index.jsp>. Accessed 08 Feb 2022
- Čanadanović-Brunet JM, Četković GS, Djilas SM, Tumbas VT, Savatović SS, Mandić AI, Markov SL, Cvetković DD (2009) Radical scavenging and antimicrobial activity of horsetail (*Equisetum arvense* L.) extracts. *Int J Food Sci Technol* 44:269–278. <https://doi.org/10.1111/j.1365-2621.2007.01680.x>
- Carneiro DM, Jardim TV, Luciana A, Ymara C, Arantes AC, de Sousa AC, Barroso WKS, Sousa AL, Da Cunha LC, Cirilo HNC, Bara MTF, Jardim PCBV (2019) *Equisetum arvense*: new evidences supports medical use in daily clinic. *Pharmacogn Rev* 13:50–58. <https://doi.org/10.5530/phrev.2019.2.4>
- Carrasco G, Urrestarazu M (2010) Green chemistry in protected horticulture: the use of peroxyacetic acid as a sustainable strategy. *Int J Mol Sci* 11:1999–2009. <https://doi.org/10.3390/ijms11051999>
- Četojević-Simin DD, Čanadanović-Brunet JM, Bogdanović GM, Djilas SM, Četković GS, Tumbas VT, Stojiljković BT (2010) Antioxidative and antiproliferative activities of different horsetail (*Equisetum arvense* L.) extracts. *J Med Food* 13:452–459
- Copes WE (2004) Dose curves of disinfectants applied to plant production surfaces to control *Botrytis cinerea*. *Plant Dis* 88:509–515. <https://doi.org/10.1094/PDIS.2004.88.5.509>
- Copes WE (2009) Concentration and intervals of hydrogen dioxide applications to control *Puccinia hemerocallidis* on daylily. *Crop Prot* 28:24–29. <https://doi.org/10.1016/j.cropro.2008.08.003>
- Copes WE, Chastagner GA, Hummel RL (2003) Toxicity responses of herbaceous and woody ornamental plants to chlorine and hydrogen dioxides. *Plant Health Prog* 4:8. <https://doi.org/10.1094/PHP-2003-0311-01-RS>
- Đurić M, Mladenović J, Bošković-Rakočević L, Šekularac G, Brković D, Pavlović N (2019) Use of different types of extracts as biostimulators in organic agriculture. *Acta Agric Serbica* 24:27–39. <https://doi.org/10.5937/AASer1947027D>
- Eicher-Sodo M, Gordon R, Zheng Y (2019) Characterizing the phytotoxic effects of hydrogen peroxide on common microgreen species and lettuce cultivars. *Hort Technol* 29:283–289. <https://doi.org/10.21273/HORTTECH04255-18>
- Espinosa-Villarreal N, Chávez-Servín JL, Mercado-Luna A, La Torre-Carbot K, Aguilera-Barreyro A, Ferriz-Martínez RA, Malda-Barraera G, Serrano-Arellano J, Saldaña C, García-Gasca T (2017) Effect of foliar application of hydrogen peroxide on growth, yield, chemical composition and antioxidant compounds of amaranth leaf and seed. *Int J Agric Biol* 19:1541–1550. <https://doi.org/10.17957/IJAB/15.0461>
- EU (2009) Commission Regulation No 1107/2009. OJ L 309/1 of 24.11.2009: 1–50
- EU (2017a) Final review report for the basic substance hydrogen peroxide. SANTE/11900/2016 (rev. 1 of 24.01.2017a)
- EU (2017b) Final review report for the basic substance *Equisetum arvense* L. SANCO/12386/2013 (rev. 7 of 20.07.2017b)
- EU (2021) Commission Implementing Regulation (EU) 2021/1165 of 15 July 2021. OJ L 253 of 16.07.2021: 13–48
- EU (2022) European pesticide database. Available on: https://ec.europa.eu/food/plants/pesticides/eu-pesticides-database_en. Accessed 14 Dec 2021
- Fauteux F, Rémus-Borel W, Menzies JG, Bélanger RR (2005) Silicon and plant disease resistance against pathogenic fungi. *FEMS Microbiol Lett* 249:1–6. <https://doi.org/10.1016/j.femsle.2005.06.034>
- Fauteux F, Chain F, Belzile F, Menzies JG, Bélanger RR (2006) The protective role of silicon in the Arabidopsis–powdery mildew pathosystem. *Proc Natl Acad Sci USA* 103:17554–17559. <https://doi.org/10.1073/pnas.0606330103>
- Fawe A, Menzies JG, Chérif M, Bélanger RR (2001) Silicon and disease resistance in dicotyledons. In: Datnoff LE, Snyder GH, Korndörfer GH (eds) *Silicon in agriculture*, 1st edn. Elsevier, New York, pp 159–169
- García D, García-Cela E, Ramos AJ, Sanchis V, Marín S (2011) Mould growth and mycotoxin production as affected by *Equisetum arvense* and *Stevia rebaudiana* extracts. *Food Control* 22:1378–1384. <https://doi.org/10.1016/j.foodcont.2011.02.016>
- García-Gaytán V, Bojórquez-Quintal E, Hernández-Mendoza F, Tiwari DK, Corona-Morales N, Moradi-Shakoorian Z (2019) Polymerized Silicon (SiO₂-nH₂O) in *Equisetum arvense*: potential nanoparticle in crops. *J Chil Chem Soc* 64:4298–4302
- Godlewska K, Biesiada A, Michalak I, Pacyga P (2020) The effect of botanical extracts obtained through ultrasound-assisted extraction on white head cabbage (*Brassica oleracea* L. Var. Capitata L.) seedlings grown under controlled conditions. *Sustainability* 12:1871. <https://doi.org/10.3390/su12051871>
- Gomes FB, de Moraes JC, Santos CD, Goussain MM (2005) Resistance induction in wheat plants by silicon and aphids. *Sci Agric* 62:547–551. <https://doi.org/10.1590/S0103-90162005000600006>
- Goussain MM, Prado E, Moraes JC (2005) Effect of silicon applied to wheat plants on the biology and probing behaviour of the greenbug *Schizaphis graminum* (Rond.) (Hemiptera: Aphididae). *Neotrop Entomol* 34:807–813. <https://doi.org/10.1590/S1519-566X2005000500013>
- Guével M-H, Menzies JG, Bélanger RR (2007) Effect of root and foliar applications of soluble silicon on powdery mildew control and growth of wheat plants. *Eur J Plant Pathol* 119:429–436. <https://doi.org/10.1007/s10658-007-9181-1>
- Guntzer F, Keller C, Meunier J-D (2012) Benefits of plant silicon for crops: a review. *Agron Sustain Dev* 32:201–213. <https://doi.org/10.1007/s13593-011-0039-8>
- Jira-anunkul W, Pattanagul W (2021) Effects of hydrogen peroxide application on agronomic traits of rice (*Oryza sativa* L.) under drought stress. *Plant Soil Environ* 67:221–229. <https://doi.org/10.17221/628/2020-PSE>
- Laane H-M (2018) The effects of foliar Sprays with different silicon compounds. *Plants* 7:45. <https://doi.org/10.3390/plants7020045>

- Labun P, Grulova D, Salamon I, Šeršeň F (2013) Calculating the silicon in horsetail (*Equisetum arvense* L.) during the vegetation season. Food Nutr Sci 4:510–514. <https://doi.org/10.4236/fns.2013.45065>
- Langa-Lomba N, Buzón-Durán L, Martín-Ramos P, Casanova-Gascón J, Martín-Gil J, Sánchez-Hernández E, González-García V (2021) Assessment of conjugate complexes of chitosan and *Urtica dioica* or *Equisetum arvense* extracts for the control of grapevine trunk pathogens. Agronomy 11:976. <https://doi.org/10.3390/agronomy11050976>
- Lau V, Mattson N (2021) Effects of hydrogen peroxide on organically fertilized hydroponic Lettuce (*Lactuca sativa* L.). Horticulturae 7:106. <https://doi.org/10.3390/horticulturae7050106>
- Marchand PA (2015) Basic substances: an opportunity for approval of low-concern substances under EU pesticide regulation. Pest Manag Sci 71:1197–1200. <https://doi.org/10.1002/ps.3997>
- Marchand PA (2016) Basic substances under EC 1107/2009 phytochemical regulation: experience with non-biocide and food products as biorationals. J Plant Prot Res 56:312–318. <https://doi.org/10.1515/jppr-2016-0041>
- Marchand PA (2017) Basic substances under EU pesticide regulation: an opportunity for organic production? Organic Farm 3:16–19. <https://doi.org/10.12924/of2017.03010016>
- McAvoy RJ, Bible BB (1996) silica sprays reduce the incidence and severity of bract necrosis in poinsettia. HortScience 31:1146–1149. <https://doi.org/10.21273/HORTSCI.31.7.1146>
- Moraes JC, Goussain MM, Basagli MA, Carvalho GA, Ecole CC, Sampaio MV (2004) Silicon influence on the tritrophic interaction: wheat plants, the greenbug *Schizaphis graminum* (Rondani) (Hemiptera: Aphididae), and its natural enemies, *Chrysoperla externa* (Hagen) (Neuroptera: Chrysopidae) and *Aphidius colemani* viereck (Hymenoptera: Aphidiidae). Neotrop Entomol 33:619–624. <https://doi.org/10.1590/S1519-566X2004000500012>
- Oh H, Kim D-H, Cho J-H, Kim Y-C (2004) Hepatoprotective and free radical scavenging activities of phenolic petrosins and flavonoids isolated from *Equisetum arvense*. J Ethnopharmacol 95:421–424. <https://doi.org/10.1016/j.jep.2004.08.015>
- Pallag A, Filip GA, Olteanu D, Clichici S, Baldea I, Jurca T, Micle O, Vicaș L, Marian E, Sorițău O, Cenariu M, Mureșan M (2018) *Equisetum arvense* L. extract induces antibacterial activity and modulates oxidative stress, inflammation, and apoptosis in endothelial vascular cells exposed to hyperosmotic stress. Oxid Med Cell Longev. <https://doi.org/10.1155/2018/3060525>
- Pozza EA, Pozza AAA, Botelho DMdS (2015) Silicon in plant disease control. Revista Ceres 62:323–331. <https://doi.org/10.1590/0034-737X201562030013>
- Raudales RE, Parke JL, Guy CL, Fisher PR (2014) Control of waterborne microbes in irrigation: a review. Agric Water Manag 143:9–28. <https://doi.org/10.1016/j.agwat.2014.06.007>
- Richter E, Götte E, Hack G (2021) Zierpflanzenproduktion in Deutschland - mit alternativen Strategien im Pflanzenschutz zukunftsfähig? J Kult 73:333–352. <https://doi.org/10.5073/JFK.2021.11-12.01>
- Rogozhin EA, Vasilchenko AS, Barashkova AS, Smirnov AN, Zavriev SK, Demushkin VP (2020) Peptide extracts from seven medicinal plants discovered to inhibit oomycete *Phytophthora infestans*, a causative agent of potato late blight disease. Plants 9:1294. <https://doi.org/10.3390/plants9101294>
- Taylor A, Bonafos R, Chovelon M, Parvaud CE, Furet A, Aveline N, Bertrand C, Marchand PA (2022) *Equisetum arvense* (horsetail) extract: the first approved basic substance allowed for EU crop protection. Int J Bio-Resource Stress Manag 13:566–577. <https://doi.org/10.23910/1.2022.2757>
- Tebow JB, Houston LL, Dickson RW (2021) Silicon foliar spray and substrate drench effects on plant growth, morphology, and resistance to wilting with container-grown edible species. Horticulturae 7:263. <https://doi.org/10.3390/horticulturae7090263>
- Trebbi G, Negri L, Bosi S, Dinelli G, Cozzo R, Marotti I (2021) Evaluation of *Equisetum arvense* (Horsetail Macerate) as a copper substitute for pathogen management in field-grown organic tomato and Durum wheat cultivations. Agriculture 11:5. <https://doi.org/10.3390/agriculture11010005>
- Vargas-Hernández M, Torres-Pacheco I, Gautier F, Álvarez-Mayorga B, Cruz-Hernández A, García-Mier L, Jiménez-García SN, Ocampo-Velázquez RV, Feregrino-Perez AA, Guevara-Gonzalez RG (2016) Influence of hydrogen peroxide foliar applications on in vitro antimicrobial activity in *Capsicum chinense* Jacq. Plant Biosyst 151:269–275. <https://doi.org/10.1080/11263504.2016.1168494>
- Voogt W, Sonneveld C (2001) Silicon in horticultural crops grown in soilless culture. In: Datnoff LE, Snyder GH, Korndörfer GH (eds) Silicon in agriculture, 1st edn. Elsevier, New York, pp 115–131

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.