Pomegranate trees quality under drought conditions using potassium silicate, nanosilver, and selenium spray with valorization of peels as fungicide extracts

Walid F. A. Mosa1*, Said I. Behiry2, Hayssam M. Ali3, Ahmed Abdelkhalak4, Lidia Sas-Paszt5, Asma A. Al-Huqail3, Muhammad Moaaz Ali6 & Mohamed Z. M. Salem7*

The current study was performed on 8 years old "Succary" pomegranate cultivar (Punica granatum L.) during the 2019 and 2020 seasons. One hundred pomegranate trees were chosen and sprayed three times at the beginning of flowering, full bloom, and 1 month later with the following treatments: water as control, 0.025, 0.05 and 0.1 mg/L Se; 5 mL/L, 7.5 and 10 mL/L Ag NPs, and 0.5, 1 and 2 mg/L K2Si2O5. The results showed that spraying of SE, Ag NPs, and K2Si2O5 ameliorated the shoot length, diameter, leaf chlorophyll content, set of fruiting percentage, and fruit yield per tree and hectare compared to control through studying seasons. Moreover, they improved the fruit weight, length, and diameter, as well as total soluble solids, total, reduced, and non-reduced sugars percent, while they lessened the juice acidity percentage compared to control. The most obvious results were noticed with Se at 0.1 mg/L, Ag NPs at 10 mL/L, and K2Si2O5 at 2 mg/L in both experimental seasons over the other applied treatments. By HPLC analysis, peel extracts showed the presence of several bioactive compounds of catechol, syringic acid, p-coumaric acid, benzoic acid, caffeic acid, pyrogallol, gallic acid, ferulic acid, salicylic acid, cinnamic acid, and ellagic acid. The extracts applied to Melia azedarach wood showed promising antifungal activity against Rhizoctonia solani and were considered wood-biofungicides.

Pomegranate (Punica granatum L.) is a deciduous tree, which has been tamed for thousands of years, has a big range from cultivars and supplies opportunities for the consumers1,2. Its productivity can be boosted and enhanced by using numerous substances and elements. It was found that Se was enhanced greatly the development, yield and fruit quality of some fruit crops3–5, such as on grape, where it raised its content and the level of its nutrition, while diminishing the concentration of heavy metals particularly in European and American species6. Se exerts useful effects on plant growth and may works as quasi-fundamental micronutrient through change various physiological and biochemical features, therefore the plants differ greatly in their physiological and biochemical response to Se7. The Foliar application of Se at 0.017 g/L 6 times, with interval 10 days increased photosynthesis, yield of in pear, grape, and peach8.

*email: walidbreeder@yahoo.com; mohamed-salem@alexu.edu.eg
Using nano-fertilizers is differentiated by the possibility to use in small quantity compared with conventional fertilizers. In the recent years, a lot of interesting was given to nano fertilizers because their application promoted the development and yield of crops and lessened the chemical fertilizers usage. By prohibiting the leakage of nutrients, as usually occurs in the case of the usage of chemical fertilizers, nano-fertilizers can be more effective in reducing the soil pollution and other environmental hazards. Silver nanoparticles (Ag NPs), have strong biological activity. Ag NPs influence plants by different levels like germination promotion, growth activation, increasing the accumulation of biomass, improving shoot growth, and raising the pigment content.

Si implementation improved the employment of water, and dry matter increased, biotic and abiotic stresses’ tolerance like drought via maintaining the balance of water, improving photosynthesis process and the composition of xylem vessels during the high rates of transpiration. The application of Si on avocados reduced the respiration and the production rate of ethylene and consequently increased its growth, could adhere to the reverse activity of big quantities from boron. Moreover, spraying date palm with silicon raised the date development, yield and quality, “Hindy bisinara” mango trees, banana, pomegranates, and Flame seedless grapevines, “Washington” navel orange. Loquat tree (Eriobotrya japonica, Lind.) cv. Emanuel foliar treated with K₂SiO₅ at 1.0 and 2.0%, increased the percentages of fruit set and retention and thus the yield, fruit physical and chemical characteristics, and the concentration of 2% was better than 1%³. Moreover, it was noticed also that the pro harvest foliar spraying of K₂SiO₅ minimized the percentages of fruit decomposition, loss, and total acidity.

For waste valorization, peels from pomegranates have several benefits as for the extractions of bioactive compounds. Some compounds like ellagic acid derivatives, punicalalin isomers, and delphinidin, pelargonidin 3-glucosides and 3,5-diglucosides were isolated from pomegranate juice showing good antioxidant activity. Peel extract had markedly higher antioxidant capacity than the pulp extract. Hydrolyzable tannins such as punicalin, punicalagin, pedunculagin, gallic and ellagic acid were identified in peel extracts. Other phytochemicals identified from the pomegranate are organic and phenolic acids (gallic, ellagic and chlorogenic). So, this experiment was conducted to inspect the effectiveness of selenium, Ag NPs and silicon in alleviating the effect of drought and salinity and consequently increasing the vegetative development, yield and quality of pomegranate and their effects on phytochemical compositions by HPLC and their application as a wood-biofungicide.

Materials and methods
Experimental design. This study is complied with relevant institutional, national, and international guidelines and legislation. This study does not contain any studies with human participants or animals performed by any of the authors, where Pomegranate cv. Succary trees at the age of 8 years planted at 4 × 5 m at a private orchard at Rashid, Alexandria Governorate, Egypt through 2019 and 2020 in a sandy soil were irrigated with drip system. The collection of Pomegranate specimens has been done under the permission from the private land owner, at Rashid, Alexandria Governorate, Egypt. Physiochemical analysis for the soil of the experiment was listed in Table 1.

One hundred pomegranate trees were chosen and were similar in their growth and size as possible to apply the following treatments: Control (water only), Selenium (Se) (Alfa aesar®, Alfa Aesar, headquartered in Ward Hill, Massachusetts, United States) at 0.025, 0.05 and 0.1 mg/L; silver nanoparticles (Ag NPs) at 5, 7.5 and 10 mL/L; Potassium silicate (K₂SiO₅) (Alfa aesar®) at 0.5, 1, and 2 mg/L. The chosen trees were foliar treated at the first of flowering, full bloom and 1 month later and were received the same horticultural treatments applied at the orchard. The aforementioned treatments were ordered in Randomized Complete Block Design, where each one of them contained ten replicates/trees. The influence of the aforementioned treatments was evaluated by measuring their impacts on the following:

Vegetative parameters. Four main vegetative shoots around the trees from each side were labelled at the start of the vegetative season, and their tallness and diameter were assessed first in April and second at October. Leaf chlorophyll content in fresh leaves was assessed by chlorophyll meter (SPAD-502; Konica Minolta, Osaka, Japan) and the results were expressed in SPAD units. Fruit set percentage was assessed according to this equation:

\[
\text{Fruit set}(\%) = \frac{\text{No. of fruitlets}}{\text{No. of opened flowers}} \times 100
\]

Fruit drop percentage was estimated by accounting dropping fruits number from the middle of June till fruit harvesting time conditions of the experiment, then expressed as a percentage according to this formula:

\[
\text{Fruit drop}(\%) = \frac{\text{No. of dropped fruits}}{\text{No. of set fruits}} \times 100
\]

Fruit cracking percent was measured according to the following equation:

\[
\text{Fruit cracking}(\%) = \frac{\text{Number of cracking fruits}}{\text{total number of fruits on tree}} \times 100
\]

Fruit sun burn proportion by accounting the sunburned fruit with the respect of total number of fruits on each tree before the picking time.
At the time of picking up (October), the number and weight of fruits per tree were counted. Physical and chemical fruit characteristics. At the time of picking up, the sample of six fruits from every tree was picked up by random way to assess the fruit weight (g), tallness, diameter, volume. Fruit firmness was determined by using Magness and Taylor pressure tester (mod. FT 327 (3–27 Ibs. Made in Italy). Total soluble solids (TSS) percent was measured by using a hand refractometer (ATAGO Co. LTD., Tokyo, Japan). Total and reducing sugars were determined by Nelson arsenate—molybdate colorimetric method. Non-reducing sugars were by the difference between total sugars and reducing sugars. Fruit Titratable acidity percent was determined by AOAC method, where it was expressed as citric acid in g/100 ml fruit juice. TSS/acid ratio was counted. Vitamin C mg/100 ml juice was by titration with 2,6 dichloro phenol-indo-phenol and calculated as mg/100 mL of juice. Anthocyanin content was determined.

Preparation of pomegranate extracts. Peels from treated fruit with Se, Ag NPs, and K$_2$Si$_2$O$_5$ in April 2020 were air-dried at room temperature for 2 weeks. The dried peels from pomegranate fruits were ground to a fine powder using a small laboratory mill. About 50 g from each of the dried powder peels were extracted by the soaking method with 100 mL of acetone solvent (99%) with stirring for 6 h at room temperature. After the extraction process was finished, the extract filtered through a cotton plug and then with Whatman No. 1 filter paper. The filtered extract was concentrated by evaporating the acetone solvent to have the dried peel extracts. To prepare the concentrations, the extracts were dissolved in dimethyl sulfoxide (10% DMSO), and the concentrations levels of 2%, 4%, and 6% were obtained

HPLC analysis of phenolic compounds. The phenolic compounds from the acetone extracts of each of the pomegranate peels were identified by HPLC (Agilent 1100) was composed of binary LC pump, a UV/Vis detector, and C18 column (125 mm × 4.60 mm, 5 µm particle size). Chromatograms were obtained and analyzed using the Agilent ChemStation. The separation and identification conditions can be found in the previous work.

Antifungal property of wood treated with extracts. Wood samples of Melia azedarach tree were air-dried and be ready at about 0.5 × 1 × 1 cm. Designed wood samples were autoclaved for 20 min at 121 °C, and then left to cool. Rhizoctonia solani (acc# MH352450) was used for the antifungal bioassay. Three wood samples were utilized for each concentration, as well as for hesta (2.5 g/L), the positive (thiophanate-methyl 70 wp) and negative (10% DMSO) controls. The antifungal action of the extracts wood-treated in terms of the inhibition percentage of fungal linear growth (IPFLG) was measured following our last works.

Table 1. Physiochemical analysis of the experimental soil.

| Parameters          | 0–30 | 30–60 | Unit |
|---------------------|------|-------|------|
| **Mechanical analysis** |      |       |      |
| Sand                | 94   | 94    | %    |
| Silt                | 0    | 0     | %    |
| Clay                | 6    | 6     | %    |
| Textural class      | Sandy| Sandy |       |
| pH (1:2)            | 7.2  | 7.3   | –    |
| EC (1:1, water extract) | 1.95 | 2.04  | dS/m |
| O.M                 | 0.7  | 0.7   | %    |
| CaCO$_3$            | 0.28 | 0.28  | %    |
| **Soluble cations** |      |       |      |
| Ca$^{2+}$           | 8    | 9     | meq/L|
| Mg$^{2+}$           | 3.4  | 8.2   | meq/L|
| Na$^+$              | 3.4  | 3.7   | meq/L|
| K$^+$               | 1.3  | 1.4   | meq/L|
| **Soluble anions**  |      |       |      |
| HCO$_3^-$           | 0.5  | 0.5   | meq/L|
| Cl                  | 7.2  | 6.4   | meq/L|
| SO$_4^{2-}$         | 10.44| 14.05 | meq/L|
| **Micronutrients**  |      |       |      |
| Nitrogen (N)        | 49   | 55.05 | mg/kg|
| Phosphorus (P)      | 97   | 780   | mg/kg|
| Potassium (K)       | 197  | 246   | mg/kg|

\[
\text{Sunburn}(% ) = \frac{\text{No. of fruit sunburnt}}{\text{total No. of fruits on tree}} \times 100
\]
processes and in improving the growth parameters of orange trees. Reported in several studies, foliar spraying of "Washing capabile of raising the resistance of plants to biotic and abiotic exertion64,65, and lessen the oxidation stress in both studying seasons.

nutrient elements70. Foliar application of orange trees by Se at 0, 20, 40, 80 and 160 ppm raised the growth, yield, induces the growth of plant, increases the process of photosynthesis and helps in the balance of the necessary and shoot lengths71. K2Si2O5 at 2 mg/L compared with the other applied concentrations, and K2Si2O5 was the superior treatment in vegetative growth parameters were greatly improved particularly with Se at 0.1 mg/L, Ag NPs at 10 mL/L and the foliar application of Ag NPs at 10, 12.5, and 15 mL/L. positively increased the diameter of shoots, leaf surface area, leaf total chlorophyll in 'Florida prince' peach cultivar82. Additionally, the foliar application of Ag NPs at 10, 12.5, and 15 mL/L, positively increased the diameter of shoots, leaf surface area, leaf total chlorophyll as compared to control in the two seasons41. Moreover, the exogenous application formula; IPFLG (%) = [(GC − GT)/GC] × 100, where GC and GT ready the average diameters of the fungal colony of control and treatment, respectively.

Statistical analysis. Obtained data were analyzed by one-way analysis of variance69. A least significant difference at 0.05% was used to compare between the means of the treatments and measured with CoHort Software (Pacific Grove, CA, USA).

Results and discussions Vegetative and fruit parameters. Table 2 showed that length and thickness of shoots, leaf chlorophyll, were greatly enhanced by spraying Se, Ag NPs, and K2Si2O5 with respect to control. Besides, the same measured vegetative growth parameters were greatly improved particularly with Se at 0.1 mg/L, Ag NPs at 10 mL/L and K2Si2O5 at 2 mg/L compared with the other applied concentrations, and K2Si2O5 was the superior treatment in both studying seasons.

These results are in parallel with the reported results of a lot of authors, who mentioned that spraying Se is capable of raising the resistance of plants to biotic and abiotic exertion64,65, and lessen the oxidation stress in chloroplast66, thus it can enhance the development of plants67. Selenium plays a crucial role in physiological processes and in improving the growth parameters of orange trees. Reported that the foliar spraying of "Washington" navel orange by selenium at 0, 20, 40, 80 and 160 ppm improved significantly the shoot number, length, secondary shoots, leaf number per shoot and leaf area surface compared with control69. Small dose of Se can induces the growth of plant, increases the process of photosynthesis and helps in the balance of the necessary nutrient elements68. Foliar application of orange trees by Se at 0, 20, 40, 80 and 160 ppm raised the growth, yield, fruit quality attributes, leaf mineral content and enzymes activity, and the concentration of 40 ppm was the best results compared with the rest applied treatments69. The application of selenium at five different concentrations at 0, 10, 20, 40, and 80 mg L−1 on four different olive cultivars: "San Felice", "Canino", "Frantoio", and "Moraiolo". It was noticed that Se concentration between 10 and 40 mg L−1 increased fresh and dry weight of the explants and shoot lengths71.

With the same trend, it was reported by many authors that Ag NPs had a good influence on growth, root-shoot ratio, and root prolongation72–75. Spraying of saffron corms with Ag NPs at 20–60 mg/L increased significantly the number of roots, dry weight of leaves 4, and also the growth of plants, the surface area, length of roots and shoots as well as chlorophyll content76. Photosynthesis, chlorophyll content, fresh weight, root and shoot length, as well as developing of seedlings in Brassica juncea seedlings were enhanced by Ag NPs compared with control77. Spraying cucumber with Ag NPs raised the number of leaves per plant and plant height78. Ag NPs raised leaf area, shoots and growth of plants at 1, 4, 8, 16, and 32 mg/L, content of pigments79, and the accumulation of biomass80 and improved shoot induction and proliferation. Ag NPs-foliar spraying increased plant growth attributes in terms of length of shoot, and root, and leaf area as well as leaf total chlorophyll81. The foliar spraying of onion with Ag NPs at 20 ppm increased plant height, total leaf and leaf content from total chlorophyll81. Additionally, the foliar application of Ag NPs at 10, 12.5, and 15 mL/L, positively increased the diameter of shoots, leaf surface area, leaf total chlorophyll in leaves in 'Florida prince' peach cultivar82.

Silicon plays a great role in increasing photosynthetic rate, cell division, number of pigments, the absorption and transferring of water, and root growth as well as the tolerance against biotic and abiotic exertion73,74,75,76,77,78,79,80. Spraying 250 ppm K2Si2O5 on 'Flame seedless' grapevines increased the leaf area and the length of main shoot as well as leaf total chlorophyll as compared to control in the two seasons81. Moreover, the exogenous application of K2Si2O5 at 0.05–0.1% on 'Keitte' mango trees at the start of growth,
just after fruit setting and 1 month later increased shoot length, leaf number per shoot, leaf area and total chlorophylls. The spraying of orange cv. Olinda Valencia with $K_2Si_2O_5$ increased shoot length, and diameter, leaf number per shoot, leaf area surface, as well as the height, volume and diameter of tree with respect with untreated plants. $K_2Si_2O_5$ plays an important role in minimizing the production of ethylene and chlorophyll degeneration. Spraying orange trees with $K_2Si_2O_5$ at 0.1, 0.2 and 0.3% induced an obvious improving of shoot length and thickness, leaf area, leaf nutrient, pigment contents and total chlorophyll and the utilization of 0.2% was the superior treatment compared with control and the rest applied treatments.

Table 3 clearly showed that fruit set percentage as well as fruit number were statistically enhanced by the spray of Se, Ag NPs and $K_2Si_2O_5$, while they lessened obviously the fruit drop proportion with the respect of untreated trees. Besides, spraying 0.1 mg/L Se, 10 mL/L Ag NPs and 2 mg/L $K_2Si_2O_5$ extremely increased fruit set percentage and fruit number, and minimized the fruit drop percentage compared with the other applied treatments or control in the two seasons. Spraying of Se, Ag NPs and $K_2Si_2O_5$ reduced statistically the fruit cracking and sunburn proportion, while they increased significantly the fruit yield (Table 4). The most clear results were accompanied with the foliar application of $K_2Si_2O_5$ at 2 mg/L compared with the rest applied treatments and control in both experimental seasons.

These results are in the same trend with the prior results, where the application of selenium increased efficiently the yield in horticultural crops. Besides, it was found that Se raised the yield in “Valencia” orange, ’Zaghlol’ date palm and in ‘Starking Delicious’ apple cultivar. Additionally, Se acts as an anti-senescent and has the ability to improve growth and developing of plants. Furthermore, it was found that the foliar spraying...
Table 5. Influence of the foliar spraying of Se, Ag NPs and K₂Si₂O₅ on weight, volume, length, and diameter of “Succary” pomegranate fruit during 2019 and 2020 seasons. Means not sharing the same letter(s) within each column are significantly different according to LSD at 0.05 level of significance.

| Treatments | 2019 (g) | 2020 (g) | 2019 (cm³) | 2020 (cm³) | 2019 (cm) | 2020 (cm) | 2019 (cm) | 2020 (cm) |
|------------|---------|---------|-----------|-----------|---------|---------|---------|---------|
| Control    | 359.75g | 373.25g | 395.00f   | 410.50g   | 6.15b   | 6.25h   | 6.78b   | 6.95g   |
| 0.025 mg/L Se | 377.25f | 388.75f | 413.50e   | 427.25f   | 7.27g   | 7.42g   | 8.21g   | 8.40f   |
| 0.05 mg/L Se  | 398.25d | 410.5d  | 435.00c   | 448.75b   | 7.44f   | 7.88e   | 8.43e   | 8.63e   |
| 0.1 mg/L Se   | 433.25c | 445.75b | 468.25c   | 483.75b   | 8.18c   | 8.52c   | 9.02c   | 9.38c   |
| 5 mL/L Ag NPs | 375.75f | 387.25f | 411.25e   | 423.75f   | 7.30g   | 7.60f   | 8.29g   | 8.41f   |
| 7.5 mL/L Ag NPs | 405.25e | 417.00d | 441.25c   | 455.00b   | 7.57e   | 7.88e   | 8.44e   | 8.64e   |
| 10 mL/L Ag NPs | 437.75b | 451.00b | 475.00b   | 489.25b   | 9.31b   | 9.72b   | 10.13b  | 10.44b  |
| 0.5 mg/L K₂Si₂O₅ | 386.75e | 405.00c | 425.00d   | 442.75e   | 7.47f   | 7.69f   | 8.28f   | 8.41f   |
| 1 mg/L K₂Si₂O₅ | 408.25c | 421.25c | 443.75c   | 459.25c   | 7.99e   | 8.15d   | 8.90d   | 9.17d   |
| 2 mg/L K₂Si₂O₅ | 490.25a | 504.00a | 527.00a   | 542.75a   | 9.49a   | 9.89a   | 10.24a  | 10.57a  |
| LSD₀.₀₅     | 8.14    | 6.56    | 8.99      | 6.89      | 0.07    | 0.13    | 0.06    | 0.08    |

of 0, 20, 40, 80 and 160 ppm Se on 'Washington Navel' orange trees improved significantly the obtained yield, and the best results were noticed with the usage of 40 ppm.

Spraying Ag ions reduced the abscission of flowers and the flowering buds in 'Alstroemeria' and in orchid. Ag NP from 20 to 60 ppm raised the yield in Borage. The foliar applications of Ag NPs on cucumber increased number and weight of fruit per plant. Ag NP exogenous spraying at 60 ppm increased the leaf area, length of shoots and roots of Phaseolus vulgaris and Zea mays. It was shown that NPs significantly raised the uptaking and transferring of NPK, thus consequently they could improve the plant growth, chlorophyll content, and grain yield. Spray of Onion with 20 mg/L Ag NPs raised the yield, and with 10, 12.5 and 15 mL/L, pollen viability and flowers percentages of peach cv. Florida prince were improved, and thus the fruit yield.

Silicon plays an important role in rising photosynthesis rate, cell division, pigments in the plants, absorption of water, tolerance of biotic and abiotic stresses and thus the final yield. Exogenous spraying of K₂Si₂O₅ at 250 ppm raised number of clusters per vine and therefore increased the final obtained yield compared with control in the two experimental seasons. The exogenous spraying of 'Grandnaine' banana with 0.05 and 0.1% K₂Si₂O₅ raised obviously the weight of bunch and hands, number of hands per bunch, number of fingers, thus consequently it improved the final yield compared with control. Spraying K₂Si₂O₅ at 0.05, 0.1 and 0.2% on 'Keitte' mango trees at the start of growth, just after fruit setting and 1 month later increased the percentages of initial fruit setting, fruit retention, fruit weight and subsequently the yield. Spray orange cv. Olinda Valencia with K₂Si₂O₅ boosted the fruit yield and 2% was the eminent treatment in the two seasons. Spraying loquat trees with K₂Si₂O₅ at 1 or 2% improved the percentages of fruit retention, fruit weight, number of fruits per cluster and thus the final yield. K₂Si₂O₅ sprayer at 5000 ppm enhanced the fruit weight, depleted the fruit cracking with improving the yield in 'Wonderful' and 'Manfalouty' pomegranates with the respect of untreated trees. Spraying of “Washington Navel” orange trees (by 0.1, 0.2 and 0.3% K₂Si₂O₅) increased clearly number of fruits per plant. Ag NPs enlarge weight, diameter and length of fruit of cucumber, 20 ppm Ag NPs on onion increased its bulb weight, and peach trees with 10, 12.5, and 15 mL/L. Ag NP on peach improved greatly fruit weight, volume, length, and diameter, flesh weight as well as fruit firmness.
These results are in the same trend with previous results\cite{102}, where treating grapevines cv. Flame seedless with K$_2$Si$_2$O$_5$ at 250 ppm increased weight of berry and cluster over control. Spraying potassium silicate increased the fruit firmness in “Amal” apricot cultivar\cite{103}, “Anna” apple\cite{104} and orange\cite{105} as compared to untreated trees. Additionally, the exogenous sprinkle of K$_2$Si$_2$O$_5$ on banana cv. Grandnaine at 0.05–0.1% increased weight, length, and diameter of finger\cite{38}. The foliar application of K$_2$Si$_2$O$_5$ at 0.05, 0.1 and 0.2% on ‘Keitte’ mango trees at the start of growth, just after fruit setting and 1 month later increased fruit length, width, firmness, and the percentage of seeds and peel\cite{87}. The average of fruit weight, volume, dimensions, shape index and juice weight as well as fruit firmness of sprayed orange trees cvs. Washington with potassium silicate were increased\cite{106} and Olinda Valencia\cite{88}. With the same trend, the foliar spray of loquat trees with K$_2$Si$_2$O$_5$ at 1 or 2% raised the fruit weight, size, length, diameter and firmness, pulp percentage, thickness, and weight\cite{43}. Moreover, K$_2$Si$_2$O$_5$ sprayed at 5000 ppm increased the fruit weight in pomegranate cvs. Wonderful\cite{97} and Manfalouty\cite{98} compared with untreated trees. The exogenous sprinkle of K$_2$Si$_2$O$_5$ at 0.1, 0.2 and 0.3% boosted the fruit weight, diameters, height, volume and Fruit peel thickness in orange cv. Washington Navel\cite{89}.

The percent of fruit total soluble solids, TSS/acidity ratio, and fruit content from vitamin C were significantly boosted by the foliar application of Se at and, Ag NPs and K$_2$Si$_2$O$_5$, while they reduced that fruit acidity percentage compared to control (Table 7). The best results were statistically resulted from the spraying of K$_2$Si$_2$O$_5$ followed by Ag NPs at Ag NPs at 10 mL/L.

The proportions of total, reduced and non-reduced sugars, fruit content from anthocyanin were markedly raised by the external application of Se at 0.025, 0.05 and 0.1 mg/L. Ag NPs at 5, 7.5 or 10 mL/L and K$_2$Si$_2$O$_5$ at 0.5, 1 and 2 mg/L, with the respect of control (Table 8). The highest increments in the previous measurements were accompanying to the foliar spraying of Se at 0.1 mg/L, Ag NPs at 10 mL/L and K$_2$Si$_2$O$_5$ at 1 or 2 mg/L over the other applied treatments and control. Additionally, the current results exhibited that K$_2$Si$_2$O$_5$ at 2 mg/L was

### Table 6. Influence of the foliar spraying of Se, Ag NPS and K$_2$Si$_2$O$_5$ on fruit firmness, grain weight and juice volume in “Succary” pomegranate fruit during 2019 and 2020 seasons. Means not sharing the same letter(s) within each column are significantly different according to LSD at 0.05 level of significance.

| Treatments   | Fruit firmness (lb/inch$^2$) 2019 | Fruit firmness (lb/inch$^2$) 2020 | Grain weight (g) 2019 | Grain weight (g) 2020 | Juice volume (mL) 2019 | Juice volume (mL) 2020 |
|--------------|-----------------------------------|-----------------------------------|-----------------------|-----------------------|------------------------|------------------------|
| Control      | 20.50e                            | 22.00f                            | 207.50f               | 211.00h               | 40.50f                 | 44.00e                 |
| 0.025 mg/L Se| 22.00de                           | 23.50f                            | 217.5e                | 225.25g               | 42.75f                 | 45.00f                 |
| 0.05 mg/L Se | 23.75bcd                          | 27.25cde                          | 225.50d               | 231.75e               | 48.75de                | 50.50bcd               |
| 0.1 mg/L Se  | 25.75abc                          | 30.50c                            | 239.00c               | 250.00c               | 52.00bc                | 53.00bc                |
| 5 mL/L Ag NPs| 22.75de                           | 24.25ef                           | 218.25e               | 226.5g                | 47.00e                 | 47.5de                 |
| 7.5 mL/L Ag NPs| 24.00bcd                         | 27.75cde                          | 232.75c               | 240.50d               | 50.00cd                | 51.25bcd               |
| 10 mL/L Ag NPs| 25.87ab                          | 34.00e                            | 246.25b               | 254.75s               | 53.00b                 | 54.50b                 |
| 0.5 mg/L K$_2$Si$_2$O$_5$ | 23.00cde                         | 24.50f                            | 219.00c               | 230.25e               | 48.75de                | 50.25cd                |
| 1 mL/L K$_2$Si$_2$O$_5$ | 24.25bcd                         | 28.75c                            | 233.00c               | 240.75d               | 52.25bc                | 52.00bc                |
| 2 mL/L K$_2$Si$_2$O$_5$ | 28.12a                           | 38.00a                            | 272.75c               | 279.00a               | 57.75a                 | 59.25a                 |
| LSD$_{0.05}$ | 2.56                              | 3.24                              | 6.04                  | 4.65                  | 2.36                   | 3.73                   |

### Table 7. Influence of the foliar spraying of Se, Ag NPS and K$_2$Si$_2$O$_5$ on fruit content from TSS, acidity, TSS/acidity ratio, and V.C. of pomegranate cv. Succary during 2019 and 2020 season. Means not sharing the same letter(s) within each column are significantly different at 0.05 level of significance.

| Treatments   | TSS % 2019 | TSS % 2020 | Acidity % 2019 | Acidity % 2020 | TSS/Acidity 2019 | TSS/Acidity 2020 | V.C. (mg/100 mL) 2019 | V.C. (mg/100 mL) 2020 |
|--------------|------------|------------|----------------|----------------|-----------------|-----------------|-----------------------|-----------------------|
| Control      | 12.09f     | 12.67f     | 1.11a          | 1.03a          | 10.89g          | 12.28g          | 11.21f                | 11.46f                |
| 0.025 mg/L Se| 12.91e     | 13.52e     | 0.99b          | 0.87b          | 13.03f          | 15.44f          | 13.57e                | 13.33e                |
| 0.05 mg/L Se | 14.15d     | 15.10d     | 0.96c          | 0.8cd          | 14.74e          | 18.87d          | 15.73c                | 15.00c                |
| 0.1 mg/L Se  | 15.67c     | 16.22bc    | 0.89c          | 0.77e          | 17.56c          | 21.12c          | 16.78a                | 15.86a                |
| 5 mL/L Ag NPs| 13.17e     | 13.02ef    | 0.97bc         | 0.81c          | 13.45f          | 16.15f          | 15.07d                | 13.33e                |
| 7.5 mL/L Ag NPs| 14.22d    | 15.21d     | 0.95d          | 0.78de         | 14.92e          | 19.41d          | 15.93c                | 15.21bc               |
| 10 mL/L Ag NPs| 16.48b    | 16.73ab    | 0.84e          | 0.73f          | 19.59b          | 22.89b          | 16.86a                | 15.86a                |
| 0.5 mg/L K$_2$Si$_2$O$_5$ | 13.96d | 14.67d | 0.96cd | 0.81c | 14.48e | 18.09e | 15.56c | 13.63d |
| 1 mL/L K$_2$Si$_2$O$_5$ | 15.31c | 15.90c | 0.91e | 0.77e | 16.85d | 20.59c | 16.14b | 15.36b |
| 2 mL/L K$_2$Si$_2$O$_5$ | 17.29a | 17.20a | 0.83f | 0.70g | 20.78a | 24.54a | 16.86a | 15.89a |
| LSD$_{0.05}$ | 0.44       | 0.56       | 0.02           | 0.02           | 0.58            | 0.81            | 0.41                  | 0.24                  |
the superior treatment compared with the rest applied treatments. These results are in agreement with the past results of [80], where the external spraying of selenium increased the content from vitamin C in tea. As Se increases the fruit content from TSS which contains acids, salts, vitamins, amino acids, sugars so, it can improve the taste of pear fruits [81]. Treating grape with Se boosted markedly the percentages of soluble sugar, soluble protein, soluble solid, as well as vitamin C, while it minimized organic acid percentage [82]. Selenium application on apple cv. Starking Delicious at 0.5, 1, and 1.5 mg/L twice during the enlargement fruit period improved remarkably soluble solid content [83].

Low concentrations of Ag NP caused increasing of soluble sugar [84,85]. The foliar applications of Ag NPs on cucumber increased TSS of fruit [86]. Sprinkle of Ag NPs on sunflower at 50 mL/L increased the leaf content from carbohydrate as compared to control [87]. The external application of Ag NPs at 20 ppm on onion increased total soluble solids [88]. Ag NPs improved greatly the percentages of TSS, TSS/acid ratio, total, reduced and non-reduced sugars as well as fruit content from anthocyanin, while they reduced the fruit acidity percentage [89].

The exogenous sprinkle of grapevines cv. Flame seedless with 250 ppm potassium silicate increased statistically the percentages of TSS, as well as total and reducing sugars compared with control [90]. Spraying of potassium silicate on ‘Grandnaine’ banana at 0.05 to 0.1% improved the percentages of TSS and total sugars, while it reduced the fruit acidity percentage compared to control [91]. Silicon application improved fruit content from total soluble solids, TSS/acid ratio and vitamin C in “Anna” apple [92], and in orange cv. Olinda Valencia [93]. The external application of K2Si2O5 at 0.05, 0.1 and 0.2% on ‘Keitte’ mango trees at the start of growth, just after fruit setting and 1 month later increased the percentages of TSS, total, reducing, non-reducing, Vitamin C content, SSC/acidity ratio, while reduced the total fruit acidity % [94]. Silicon application improved fruit content from total soluble solids, TSS/acid ratio and vitamin C in “Anna” apple [95], and in orange cv. Olinda Valencia [96]. The external application of Ag NPs at 20 ppm on onion increased total soluble solids [97], while reduced the fruit acidity percentage compared to control [98]. Silicon application improved fruit content from total soluble solids, TSS/acid ratio and vitamin C in “Anna” apple [99], and in orange cv. Olinda Valencia [100]. The external application of K2Si2O5 at 0.05, 0.1 and 0.2% on ‘Keitte’ mango trees at the start of growth, just after fruit setting and 1 month later increased the percentages of TSS, total, reducing, non-reducing, Vitamin C content, while it reduced the fruit acidity % [101]. Treating of loquat trees with K2Si2O5 at 1 or 2% improved the percentages of TSS, TSS/acid ratio, total sugars, vitamin C, while they lessened total fruit acidity proportion [102]. The external application of K2Si2O5 at 5000 ppm boosted the fruit chemical characteristics in terms of ascorbic acid, anthocyanin and total soluble solids percentages, while reduced the fruit acidity in pomegranate cvs. Wonderful [103] and Manafalouty [104] compared with untreated trees. External application of “Washington Navel” orange trees with and K2Si2O5 at 0.2 and 0.3% boosted markedly the fruit content from the percentages of SSC, reducing, total, non-reduced, Vitamin C content, SSC/acidity ratio, while reduced the total fruit acidity % [105].

The results listed in Table 9 showed that the foliar application of Se, Ag NPs and K2Si2O5 improved significantly the leaf mineral composition from N, P, and K macronutrients compared with the control during the two seasons. Additionally, the foliar application of 0.1 mg/L Se, 10 mL/L Ag NPs and 1 and 2 mg/L K2Si2O5 exhibited the high percentages from N, P and K compared with the other applied treatments in both experimental seasons. Moreover, the superior treatment was the application of K2Si2O5 at 2 mg/L. Low dose of Se can help in the balance of the necessary nutrient elements in the plants [106]. Spraying Citrus Sinensis with Se at 20, 40, 80 and 160 ppm improved obviously potassium, nitrogen and phosphorus concentration in the leaves with the respect of control and 40 ppm was the supreme one [107]. The application of nano fertilizers can help the translocation process of nutrients to the desired parts of plant [108]. Nano fertilizers greatly enhanced the uptake of NPK nutrients, which play an important role in increasing the growth, chlorophyll content and yield of wheat [109]. Therefore, seaweed extracts and Se spray can improve the growth and yield of the studied plants [110].

Table 9. Influence of the foliar spraying of Se, Ag NPS and K2Si2O5 on fruit content from total, reduced and non-reduced sugars, and anthocyanin of pomegranate cv. Succary during 2019 and 2020 seasons. Means not sharing the same letter(s) within each column are significantly different at 0.05 level of significance.

| Treatments | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 | 2019 | 2020 |
|------------|------|------|------|------|------|------|------|------|
| Control    | 8.98b| 9.24b| 6.59g| 6.82h| 2.40f| 2.42e| 0.32g| 0.35g|
| 0.025 mg/L Se | 9.78g| 10.22g| 7.30f| 7.49g| 2.48f| 2.73d| 0.35f| 0.38g|
| 0.05 mg/L Se | 11.00e| 11.11e| 8.21e| 8.21e| 2.79d| 2.90d| 0.45d| 0.44f|
| 0.1 mg/L Se | 13.04c| 13.97b| 9.74c| 10.11b| 3.3b| 3.86a| 0.49c| 0.53c|
| 5 mL/L Ag NPs | 10.02g| 10.71f| 7.47f| 7.88f| 2.55ef| 2.83f| 0.36f| 0.39g|
| 7.5 mL/L Ag NPs | 11.28e| 11.76d| 8.47d| 8.56d| 2.81d| 3.20bc| 0.45d| 0.48de|
| 10 mL/L Ag NPs | 13.68b| 14.05b| 10.12b| 10.33b| 3.56a| 3.73a| 0.56b| 0.59b|
| 0.5 mg/L K2Si2O5 | 10.62f| 10.80f| 7.89e| 7.85f| 2.72de| 2.95cd| 0.46e| 0.46ef|
| 1 mg/L K2Si2O5 | 12.54d| 13.21c| 9.46c| 9.79c| 3.08e| 3.42b| 0.46cd| 0.51cd|
| 2 mg/L K2Si2O5 | 14.23a| 14.55a| 10.61a| 10.64a| 3.62a| 3.91a| 0.66a| 0.69a|
| LSD0.05 | 0.36 | 0.21 | 0.33 | 0.27 | 0.21 | 0.27 | 0.03 | 0.03 |

Antifungal activity. Figure 1 shows the visual observation of the antifungal activity of wood-treated with peels’ acetone extracts from fruits of pomegranate as sprayed with numerous nanoparticles. Antifungal action of wood-treated with numerous acetone extracts from peels of pomegranate fruits as treated with variant nano-
Table 9. Influence of the foliar spraying of Se, Ag NPs and K$_2$Si$_2$O$_5$ on the leaf composition from nitrogen, phosphorus, and potassium percentages of “Succary” pomegranate during 2019 and 2020 seasons. Means not sharing the same letter(s) within each column are significantly different at 0.05 level of significance.

| Treatments   | N %     | P %     | K %     |
|--------------|---------|---------|---------|
|              | 2019    | 2020    | 2019    | 2020    | 2019    | 2020    |
| Control      | 1.44e   | 1.47g   | 0.45f   | 0.55e   | 1.21e   | 1.36e   |
| 0.025 mg/L Se| 1.75d   | 1.73f   | 0.49ef  | 0.56e   | 1.24e   | 1.39e   |
| 0.05 mg/L Se | 1.80bcd | 1.84de  | 0.59d   | 0.73cd  | 1.29cd  | 1.61cd  |
| 0.1 mg/L Se  | 1.85ab  | 1.92c   | 0.89c   | 0.84bc  | 1.41b   | 1.66c   |
| 5 mL/L Ag NPs| 1.76cd  | 1.78ef  | 0.56de  | 0.60de  | 1.27de  | 1.50d   |
| 7.5 mL/L Ag NPs| 1.82abc | 1.86d   | 0.61d   | 0.83bc  | 1.36bcd | 1.64c   |
| 10 mL/L Ag NPs| 1.87a   | 1.98b   | 1.07b   | 0.91b   | 1.44b   | 1.79b   |
| 0.5 mg/L K$_2$Si$_2$O$_5$ | 1.79bcd | 1.79ef  | 0.58de  | 0.63de  | 1.28de  | 1.59cd  |
| 1 mg/L K$_2$Si$_2$O$_5$ | 1.84ab  | 1.89cd  | 0.81c   | 0.84bc  | 1.40bc  | 1.65c   |
| 2 mg/L K$_2$Si$_2$O$_5$ | 1.88a   | 2.06a   | 1.23a   | 1.19a   | 1.61a   | 1.90a   |
| LSD$_{0.05}$ | 0.06    | 0.05    | 0.09    | 0.14    | 0.10    | 0.10    |

Figure 1. The visual observation of antifungal activity of wood-treated with acetone extracts from pomegranate peels collected from trees sprayed with different doses of Se1: 0.025 mg/L; Se2: 0.05 mg/L; Se3: 0.1 mg/L; Ag1: 5 mL/L; Ag2: 7.5 mL/L; Ag3: 10 mL/L; Si1: 0.5 mg/L; Si2: 1 mg/L; Si3: 2 mg/L, and untreated trees (C1, C2, C3).
materials in terms of inhibition percentages is shown in Table 1. The results cleared that the acetone extracts at the concentration of 6% from peels sprayed with 1 mg/L K\textsubscript{2}Si\textsubscript{2}O\textsubscript{5}, 0.025 mg/L Se, 2 mg/L K\textsubscript{2}Si\textsubscript{2}O\textsubscript{5}, 0.05 mg/L Se, 0.1 mg/L Se, 0.5 mg/L K\textsubscript{2}Si\textsubscript{2}O\textsubscript{5} and 5 mL/L Ag NP, with inhibition 63.70, 51.48, 50.37, 48.14, 48.14, and 47.03, and 45.92%, respectively, opposed to \textit{R. solani} compared to the positive control used (hesta 2.5 g/L) which noticed prevention values of 32.96%. Also, it can be shown from Table 10 that at the concentration of 4%, the acetone extracts from peels of fruits collected from trees treated with 0.025 mg/L Se, 1 mg/L K\textsubscript{2}Si\textsubscript{2}O\textsubscript{5}, and 0.05 mg/L Se showed inhibition proportions of 45.92, 44.81, and 43.70%, respectively, opposed to the growth of \textit{R. solani}.

**Phenolic compounds analysis of peel extracts.** Data in Table 11 demonstrate that the greatest abundant concentration of catechol was found in acetone extract from peels of fruits treated with 0.025 mg/L Se (12.30 µg/mL) and 5 mL/L Ag NP (8.22 µg/mL) but not noticed in other treatments. Syringic acid was found with high quantity in acetone extract peels of fruits treated with 7.5 mL/L Ag NP, with inhibition 63.70, 51.48, 50.37, 48.14, 48.14, and 47.03, and 45.92%, respectively, opposed to \textit{R. solani} compared to the positive control used (hesta 2.5 g/L) which noticed prevention values of 32.96%. Also, it can be shown from Table 10 that at the concentration of 4%, the acetone extracts from peels of fruits collected from trees treated with 0.025 mg/L Se, 1 mg/L K\textsubscript{2}Si\textsubscript{2}O\textsubscript{5}, and 0.05 mg/L Se showed inhibition proportions of 45.92, 44.81, and 43.70%, respectively, opposed to the growth of \textit{R. solani}.

### Table 10. Antifungal activity of acetone extracts from peels of pomegranate fruits collected from trees sprayed with different nanomaterials against the growth of \textit{R. solani}

| Acetone extract from peel of fruits treated with | Extract concentration (%) | \textit{R. solani} fungal inhibition percentage |
|-----------------------------------------------|---------------------------|-----------------------------------------------|
| Untreated                                     | 2%                        | 35.18 ± 0.64                                  |
|                                               | 4%                        | 36.66                                         |
|                                               | 6%                        | 39.25 ± 0.64                                  |
| 5 mL/L Ag                                     | 2%                        | 32.96 ± 0.64                                  |
|                                               | 4%                        | 39.25 ± 0.64                                  |
|                                               | 6%                        | 45.82 ± 0.64                                  |
| 7.5 mL/L Ag                                   | 2%                        | 32.96 ± 0.64                                  |
|                                               | 4%                        | 32.59 ± 0.64                                  |
|                                               | 6%                        | 40.37 ± 0.64                                  |
| 10 mL/L Ag                                    | 2%                        | 37.03 ± 0.64                                  |
|                                               | 4%                        | 38.51 ± 0.64                                  |
|                                               | 6%                        | 40                                           |
| 0.025 mg/L Se                                 | 2%                        | 42.59 ± 1.69                                  |
|                                               | 4%                        | 45.92 ± 0.64                                  |
|                                               | 6%                        | 51.48 ± 0.64                                  |
| 0.05 mg/L Se                                  | 2%                        | 39.25 ± 0.64                                  |
|                                               | 4%                        | 43.70 ± 1.28                                  |
|                                               | 6%                        | 48.14 ± 0.64                                  |
| 0.1 mg/L Se                                   | 2%                        | 38.14 ± 0.64                                  |
|                                               | 4%                        | 41.11                                         |
|                                               | 6%                        | 48.14 ± 0.64                                  |
| 0.5 mg/L K\textsubscript{2}Si\textsubscript{2}O\textsubscript{5} | 2%                        | 33.33                                         |
|                                               | 4%                        | 40.74 ± 0.64                                  |
|                                               | 6%                        | 47.03 ± 0.64                                  |
| 1 mg/L K\textsubscript{2}Si\textsubscript{2}O\textsubscript{5} | 2%                        | 40.37 ± 0.64                                  |
|                                               | 4%                        | 44.81 ± 0.64                                  |
|                                               | 6%                        | 63.70 ± 0.64                                  |
| 2 mg/L K\textsubscript{2}Si\textsubscript{2}O\textsubscript{5} | 2%                        | 37.03 ± 0.64                                  |
|                                               | 4%                        | 39.25 ± 0.64                                  |
|                                               | 6%                        | 50.37 ± 0.64                                  |
| Positive control*                             | 2.5 g/L                   | 32.96 ± 0.64                                  |
| Negative Control                              | 0                         | 0.00                                          |
| \(P\)-value                                   |                           | <0.0001                                       |
compound showed the highest abundant concentrations in acetone extract from peels of fruits collected from trees sprayed with 0.1 mg/L Se (12.39 µg/mL) and 1 mg/L K$_2$Si$_2$O$_5$ (12.69 µg/mL) and in untreated (10.23 µg/mL). Gallic acid with high amount was observed in acetone extract from peels of fruits treated with 10 mL/L Ag NP (12.44 µg/mL) and in untreated (9.44 µg/mL). The highest amount of ferulic acid was identified in acetone extract from peels of fruits treated with 0.025 mg/L Se (13.09 µg/mL), 0.1 mg/L K$_2$Si$_2$O$_5$ (11.97 µg/mL) and 7.5 mg/L Ag NP (6.12 µg/mL). Salicylic acid was found at high quantity in acetone extracts from peels of fruits treated with 0.5 mg/L K$_2$Si$_2$O$_5$ (12.44 µg/mL) and 0.05 mg/L Se (11.45 µg/mL). Cinnamic acid showed the highest amount in acetone extracts from fruit peels of trees treated with 5 mL/L Ag NP (14.33 µg/mL) and untreated trees (19.36 µg/mL). The highest concentration of ellagic acid was observed in acetone extracts from peels of treated trees with 0.05 mg/L Se (18.33 µg/mL) and 0.1 mg/L Se (7.69 µg/mL). The full HPLC chromatograms of the isolated and identified phenolic compounds are shown in Fig. 2.

Therefore, the bioactivities of acetone treated-wood are linked to the existence of bioactive phenolic compounds. Peel extract has been reported to contain more phenolics than seed or pulp extracts. The predominant compounds were gallic acid, ellagic acid, quercetin, caffeic acid, p-coumaric acid, and vanillic acid were found in peel extract. Gallic and ellagic acids were presented in the methanolic extract of pomegranate peel. Peel extracts demonstrated power antifungal activity against Aspergillus niger and Trichoderma reesei. Peel extract showed markedly antifungal activity against A. parasiticus and A. parasiticus. Peel extract noticed high activity against A. parasiticus and no activity against A. flavus. The development levels of Alternaria alternata, Stemphylium botryosum, and Fusarium spp. growth rates were significantly inhibited by the peel extracts. The development levels of Fusarium, Penicillium chrysogenum, and Rhizoctonia solani, and the HPLC showed the presence of benzoic acid, caffeine, and o-coumaric acid as most abundant compounds.

### Conclusion
Spraying Se, Ag NPs and K$_2$Si$_2$O$_5$ raised the shoot length, diameter, leaf chlorophyll, fruit set proportion, and fruit yield, fruit weight, length and diameter, total soluble solids, total, reduced and non-reduced sugars, while they minimized the juice acidity percent with the respect to control during our study. Fruit cracking and fruit sunburn were lessened markedly by the application of Se, Ag NPs and K$_2$Si$_2$O$_5$ with respect to control. The application of 0.1 Se mg/L, 10 mL/L Ag NPs and 2 mg/L K$_2$Si$_2$O$_5$ was more effective than 0.025 or 0.05 mg/L Se, 5 or 7.5 mL/L Ag NPs and 0.5 or 1 mg/L K$_2$Si$_2$O$_5$ in improving the developing performance, yield and yielding components through studying times. The supreme treatments, which achieved the best results, was the application of 2 mg/L K$_2$Si$_2$O$_5$ over the other applied treatments during our study seasons. Additionally, the extracts from fruit peels identified several bioactive phenolic compounds and the extracts observed good wood-biofungicide.

### Data availability
All data generated or analyzed during this study are included in this published article.

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**Table 11.** HPLC analysis of phenolic compounds in acetone extract of pomegranate fruit peels treated with different treatments. *ND not detected.
Figure 2. HPLC chromatograms of phenolic compounds from acetone extracts of pomegranate peels fruits treated with Ag1: 5 mL/L Ag NPs; Ag2: 7.5 mL/L Ag NPs; Ag3: 10 mL/L Ag NPs; Se1: 0.025 mg/L Se; Se2: 0.05 mg/L Se; Se3: 0.1 mg/L Se; Si1: 0.5 mg/L K₂Si₂O₅; Si2: 1 mg/L K₂Si₂O₅; Si3: 2 mg/L K₂Si₂O₅.
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Author contributions
W.F.A.M., S.I.B., A.A., and M.Z.M.S. wrote the main manuscript text, and W.F.A.M., S.I.B., H.M.A., L.S.-P., M.M.A., and M.Z.M.S. prepared figures, and W.F.A.M., S.I.B., A.A. A.A.A.-H., and M.Z.M.S. carried out the methodology, W.F.A.M., S.I.B., H.M.A., L.S.-P., M.M.A., A.A.A.-H. and M.Z.M.S. investigated the results. All authors reviewed the manuscript.

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Competing interests
The authors declare no competing interests.

Additional information
Correspondence and requests for materials should be addressed to W.F.A.M. or M.Z.M.S.

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