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Effectiveness of Peroxy Acetic Aacid (PAA), Perbicarbonate (PB) and Potassium Silicate (PS) on Okra Growth, Yield and Resistance to Powdery Mildew

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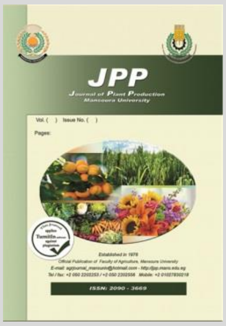

ABSTRACT

Attempts are being made to minimize the use of synthetic chemicals such as fungicides. There is an interest toward the use of environmentally-friendly products to minimize impact of toxic residuals on human, animals, and environment. Two-season field experiments were conducted in 2018 and 2019to investigate the effectiveness of foliar sprayings of three products [potassium silicate (PS), perbicarbonate (PB), and peroxyacetic acid (PAA)] as singular or sequential treatments (totaling 10 treatment combinations) on growth (plant height, number of leaves, number of branches, leaf area), yield, yield attributes (number of pods plant $^{-1}$, pod length, pod weight), chlorophyll a, b, and carotene contents, and resistance of okra plants (cv. Baladi) to powdery mildew disease. All treatments were significantly reduced powdery mildew infection with highest resistance observed with PAA+PS or PAA+PB, or PB+PAA treatments. Growth characteristics were enhanced by most treatments with the highest increases detected with singular PS or PAA treatments and with sequential PB+PS treatment. PS was superior in increasing the number of leaves, branching number, and leaf areas. The only treatments that significantly increased total yield were PAA+PB, PAA, PS, PS+PAA, and PAA+PS with the former two treatments giving the highest total yield. In conclusion, foliar spraying of okra with singular or sequential treatments with PS, PAA, and PB significantly improved plant resistance to powdery mildew infection. Nevertheless, singular PS or PAA treatments as well as sequential PB+PS, PAA+PS, PS+PAA, and PAA+PB treatments were the most effective in improving growth and yield while controlling powdery mildew disease.

Keywords: Okra yield, potassium silicate, peroxyacetic acid, perbicarbonate, powdery mildew.

INTRODUCTION

Okra (*Abelmoschus esculentus* L.) is one of the most important vegetable crops grown in tropical and subtropical areas of the world due to its nutritional, industrial and medicinal values. The tender immature pods of okra are considered an affordable source of carbohydrates, proteins, fibers, vitamins, and minerals. Okra has several health benefits such as reducing blood cholesterol, promoting skin health, and stabilizing blood sugar level (Gemede *et al.*, 2014; Haryati, 2019; Ardestani *et al.*, 2020).

The area harvested of okra worldwide has increased to 2 million hectares including 4.621 ha in Egypt, giving a total yield of approximately 10 million tons including 55609 tons in Egypt (FAOSTAT 2018). Okra plants can be attacked by fungal, viral, and bacterial diseases throughout its growth period. Powdery mildew, a widely-distributed and severely-destructive plant disease, is caused by air-borne fungus (*Erysiphe cichoracearum*) (Ale-agha *et al.*, 2008; Moharam and Obiadalla Ali, 2012). It can infect okra leaves, stems, or pods causing major (up to 17-86.6%) economic losses due to the reduction in pod quality and yield (Sridhar and Sinha, 1989; El Kot and Hamza, 2011 and Moharam, 2013; Kakade *et al.*, 2020).

Synthetic chemicals, particularly fungicides, are extensively used to control powdery mildew disease (Mmbaga and Sauvé, 2004; Khalikar *et al.*, 2011; Gogoi *et al.*, 2013; Sharma *et al.*, 2017). As okra needs continuous and prolonged harvests throughout the growing season, there is a valid concern about the toxic residues of fungicides on plants and the harvested pods. Extensive use of fungicides will also result in environmental pollution in addition to development of new resistant strains of powdery mildew (Mcgrath, 2007; Kakade *et al.*, 2020). In the light of the growing public concern and awareness about the negative effects of using fungicides, there is an obvious need to find eco-friendly, effective, and safe products to control powdery mildew (Fallik *et al.*, 1997; El Kot and Hamza, 2011; Kakade *et al.*, 2020). To control powdery mildew in okra and other plant species, several alternatives to fungicides such as oils, plant extracts, bio-agents, and salts have been studied (Pasini *et al.*, 1997; Casulli, Santomauro and Faretra, 2000; Liang *et al.*, 2005; Praveen and Dhandapani, 2008; Khalikar *et al.*, 2011; Moharam and Obiadalla Ali, 2012; Tesfagiorgis *et al.*, 2014).

Bicarbonate salts are commonly used in food industry for food preservation, enhancing taste and texture, and for pH control. According to the United States Environmental Protection Agency (USEPA), bicarbonates are safe for human health and for the environment (Palmer *et al.*, 1997 and Olivier *et al.*, 1998). Bicarbonates were also

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found to inhibit the activity of a broad spectrum of microbes (Pasini *et al.*, 1997) and its salts, including potassium bicarbonate, have an antifungal activity, hence, they were suggested to be used to augment the effect of fungicides (Fallik *et al.*, 1997; Mitre *et al.*, 2009; Ordóñez-Valencia *et al.*, 2009 and Ferrera-Cerrato *et al.*, 2011). Only a few studies, however, that were conducted to investigate the effects of potassium bicarbonates on powdery mildew infection on vegetable crops (Fallik *et al.*, 1997; Pace *et al.*, 2016 and Soliman and El-Mohamedy, 2017).

The peroxyacetic acid (PAA) is a mixture of hydrogen peroxide (H_2O_2) and acetic acid (AA, CH_3CO_2H). PAA is a biodegradable product (degradation products are acetic acid, hydrogen peroxide, water, and oxygen), very effective biocide, not pollutant during manufacturing process, and non-toxic to environment after use and, therefore, it meets all the green chemistry principles (Carrasco and Urrestarazu, 2010; Ayoub *et al.*, 2017 and Jo *et al.*, 2019; Kakade *et al.*, 2020). In addition to its excellent antimicrobial activity (Baldry, 1983), PAA has proven its effectiveness in a wide range of agricultural applications such as protecting the surface of fruits and vegetables and extending their postharvest life (Alvaro *et al.*, 2009). PAA reduced *412 Listeria monocytogenes* populations in lettuce (Beuchat *et al.*, 2004), suppressed bacterial wilt in tomato (Hong *et al.*, 2018), and showed antimicrobial activity against bacterial leaf blight and fungal sheath blight in rice (Jo *et al.*, 2019). PAA also enhanced the growth and yield of watercress plants without yielding any harmful compounds when it breaks down (Carrasco *et al.*, 2011). In a previous study, foliar PAA application was found beneficial in controlling powdery mildew in okra and sunflower plants but plant growth performance was not monitored in that study (Galal, 2017).

Silicon is considered the second most abundant element in the earth's crust (Rodrigues and Datnoff, 2007), however, it is always combined with other elements which render most of its sources insoluble. Moreover, the residual plant-available form of silicone is continuously lost in the leaching process in soils of tropical and subtropical areas (Richmond and Sussman, 2003). Therefore, plants would benefit from fertilization or foliar applications of silicon. However, data on the effect of PS, PAA, and bicarbonates on growth and yield of okra plants and their efficiency in controlling powdery mildew is still insufficient. Therefore, the aim of the present study is to investigate the effects of PS, PAA, or bicarbonates (whether as singular or sequenced) treatments on okra growth characteristics, chlorophyll content, yield, and yield attributes, while testing their efficacy on controlling powdery mildew disease infection in okra plants.

MATERIALS AND METHODS

Growth conditions and design of experiment

Two field experiments were carried out during two growing summer seasons of 2018 and 2019 at the experimental field of plant pathology department in Faculty of Agriculture, Minia University, EL- Minia governorate (28° 07′N; 30° 43′E), Egypt. Okra (*Abelmoschus esculentus L.*) seeds (cv. Baladi) were sown in June of 2018 and 2019. The soil texture of the experimental site was clay with an average pH of 7.56. To keep a source of powdery mildew infection, borders were planted with okra seeds two weeks before planting time of experiment. The experiments were laid out in a randomized block design with three replications and ten tested treatments. Each replicate had one plot 4 x 5m (5 rows/plot, two lines for each row). Each row was 5m long X 0.8m width. Seeds were planted on both sides of each row with one plant per hill. Adjacent hills were 50 cm apart providing 10 plants/row and 50 plants/plot. Agricultural practices were applied as recommended for okra production under Minia governorate growing conditions.

Preparations of test solutions and treatments

Three main compounds (g/liter distilled water) were used in this experiment. Two of them are H_2O_2-based compounds: 1) Peroxyacetic acid mixture (PAA), which is formed of a mixture of 2.0 g/l hydrogen peroxide (H_2O_2) and 0.2 g/l acetic acid (AA), as described by (Galal, 2017); 2) Perbicarbonate (PB), which is formed of 0.2 g/l potassium bicarbonate + 2.0 g/l H_2O_2. Potassium silicate (PS) 0.2 g/l is the third investigated compound used in this study.

Out of the mentioned three compounds, ten different treatments were used in this experiment as follows in Table (1)

Table 1. Foliar treatments used in the current experiment and their description

Treatment name	Treatment description
Control	Three foliar sprays of distilled water
3PS	Three PS sprays
3PAA	Three PAA sprays
3PB	Three PB sprays
1PS2PAA	One PS spray + two PAA sprays
1PS2PB	One PS spray + two PB sprays
1PA2PS	One PAA spray + two PS sprays
1PA2PB	One PAA spray + two PB sprays
1PB2PS	One PB spray + two PS sprays
1PB2PAA	One PB sprays +two PAA sprays

Foliar singular or sequential applications were sprayed on okra plant leaves to runoff. Treatments were applied 50 days (the beginning of powdery mildew infection), 65, and 80 days after sowing (DAS). Throughout the experiment, no fungicides were used to control powdery mildew disease in okra. Ten plants from each treatment in each plot were randomly chosen and marked for subsequent observations.

Plant growth and leaf area measurements

Plant height, number of leaves, and number of branches were measured. Plant height (cm) was measured at 75 and 90 DAS. Using a measuring tape, height was taken from the soil surface to the highest leaf tip. Number of leaves plants $^{-1}$ was recorded at 75 and 90 DAS. Number of branches plants $^{-1}$ was recorded 90 and 150 DAS during each season. Average weights of collected leaves of five plants from each treatment were recorded to calculate leaf area using leaf area-leaf weight relationship following the methodology of (Wallace and Munger, 1965).

Chlorophyll a, b, and carotene contents determination

Leaf chlorophyll a, b, and carotene contents were measured on the fifth fully developed leaf counted from the top of the ten marked plants (After 90 days of planting). Fresh leaf samples (0.5 g) were extracted using 95% methanol and were determined spectrophotometrically according to (Nagata and Yamashita, 1992). The supernatant absorbance of chlorophyll a, b, and carotene were determined at wavelengths of 662, 645, and 470 nm, respectively. Leaf chlorophyll a, b, and carotene contents were calculated in mg/L according to the following formulas, (Nagata and Yamashita, 1992; Dinu *et al.*, 2018)

$$\text{Chlorophyll a} = 11.75\ A662 - 2.350\ A645$$

$$\text{Chlorophyll b} = 18.61\ A645 - 3.960\ A662$$

$$\text{Carotene} = Cx + c = 1000\ A470 - 2.270\ Ca - 81.4\ Cb / 227$$

Ca = Chlorophyll a; Cb = Chlorophyll b; Cx + c = Total carotene

Yield and yield components

Number of pods per plant in each treatment was recorded two times a week from the marked plants in both seasons. Total number of pods per plant and mean weight of pod (g) were calculated from all the collected harvests. In both seasons, length of all green pods/plant in each treatment was individually measured from the marked plants using a measuring tape.

All collected harvests of green okra pods weights were used to calculate the total fresh yield (ton/feddan).

Okra powdery mildew disease assessment

Disease severity of powdery mildew was rated weekly beginning at 2 weeks after the last foliar spraying. Each plant was visually rated for disease severity based on estimation of the percentage of the leaf surfaces covered with powdery mildew lesions on five fully expanded leaves (from leaf number 4 to leaf number 8) in each plant. Values of area under powdery mildew progress curve (AUPMPC) were calculated based on the following formula:

$$\Sigma[\{(xi + xi{-}1)/2d\}+(ti - ti{-}1)]$$

Where

xi is the rating at each evaluation time and (ti – ti–1) is the time between evaluations as described by (Zhang *et al.*, 2016).

Statistical analysis

Mean values of three replications of each treatment were calculated. Data was compared with the control or among treatments by appropriate analysis of variance to distinguish significant differences at $P \leq 0.05$ followed by least significant difference tests (LSD) according to (Gomez and Gomez, 1984). Data was analyzed using the MSTAT-C computer software program (Bricker, 1991).

RESULTS AND DISCUSSION

Effects on growth characteristics

Most treatments, particularly at 90 DAS, significantly increased plant height as compared to the control in both seasons (Table 2). At 75 DAS in both seasons, the highest plants were those treated with 1PS2PA (93.94 cm in 2018 and 89.77 cm in 2019), 3PA (94.01 cm in 2018 and 87.16 in 2019) and 3PS (88.81 cm in 2018 and 90.76 cm in 2019), as compared to the control (72.48 cm in 2018 and 70.54 cm in 2019), while those treated with 3PB (64.43 cm in 2018 and 65.31 cm in 2019) and 1PB2PA (69.74 cm in 2018 and 66.28 cm in 2019) were shorter than the control. The highest plants at 90 DAS in both seasons were also those treated with 3PA (135.83 cm in 2018 and 140.06 cm in 2019) followed by those treated with 3PS (132.70 cm in 2018 and 138.60 cm in 2019) or 1PB2PS (130.32 cm in 2018 and 136.32 cm in 2019) as compared to the control (100.52 cm in 2018 and 95.01 cm in 2019, Table 2).

At 75 and 90 DAS in both seasons, the number of leaves was significantly increased by 3PS, 3PA, 1PS2PA, 1PS2PB, and 1PB2PS as compared to the control and without significant differences between those treatments (Table 2). At 75 DAS in both seasons, 1PB2PS plants had the highest number of leaves (10.12 in 2018 and 10.74 in 2019) followed by 3PS (9.37 in 2018 and 10.58 in 2019) and 3PA (9.87 in 2018 and 9.15 in 2019). At 90 DAS in both seasons, 3PS gave the highest number of leaves (16.57 in 2018 and 14.78 in 2019), followed by 1PB2PS (15.07 in 2018 and 14.64 in 2019) and 3PA (14.28 in 2018 and 14.69 in 2019, Table 2). At 90 DAS in both seasons, plants sprayed with 1PB2PA had the lowest number of leaves per plant (Table 2).

Table 2. Effect of investigated foliar treatments on growth characteristics (Plant height (cm) and Number of leaves/plants) of okra plants cv. 'Baladi' during 2018 and 2019 growing seasons.

	Plant height (cm)						Number of leaves/plants					
	75 DAS			90 DAS			75 DAS			90 DAS		
Treatment	**2018**	**2019**	**Means**	**2018**	**2019**	**Means**	**2018**	**2019**	**Means**	**2018**	**2019**	**Means**
Control	72.48	70.54	71.51	100.52	95.01	97.77	7.38	7.18	7.28	10.40	9.52	9.96
3PS	88.81	90.76	89.79	132.70	138.60	135.65	9.37	10.58	9.98	16.57	14.78	15.68
3PA	94.01	87.16	90.59	135.83	140.06	137.95	9.87	9.15	9.51	14.28	14.69	14.49
3PB	64.43	65.31	64.87	110.71	115.72	113.22	6.85	7.88	7.37	11.68	11.11	11.40
1PS2PA	93.94	89.77	91.86	120.01	122.21	121.11	9.61	8.46	9.04	12.02	11.11	11.57
1PS2PB	78.71	73.55	76.13	113.38	130.57	121.98	8.08	7.81	7.95	11.58	11.03	11.31
1PA2PS	72.74	71.87	72.31	115.70	127.11	121.41	7.67	6.83	7.25	12.00	11.58	11.79
1PA2PB	73.95	71.58	72.77	103.51	115.67	109.59	6.83	8.36	7.60	10.98	11.13	11.06
1PB2PS	88.71	90.20	89.46	130.32	136.32	133.32	10.12	10.74	10.43	15.07	14.64	14.86
1PB2PA	69.74	66.28	68.01	120.88	131.60	126.24	7.51	8.39	7.95	10.77	10.64	10.71
L.S.D at 0.05	3.5	3.2	3.35	4.1	5.1	4.6	0.602	0.60	0.601	0.98	1.13	1.055

DAS, days after sowing; 3PS, 3 sprays of potassium silicate; 3PA, 3 sprays of peroxyacetic acid; 3PB, 3 sprays of perbicarbonate; 1PS2PA, 1 PS spray + 2 PAA sprays; 1PS2PB, 1 PS spray + 2 PB sprays; 1PA2PS, 1 PAA spray + 2 PS sprays; 1PA2PB, 1 PAA spray + 2 PB sprays; 1PB2PS, 1 PB spray + 2 PS sprays; 1PB2PA, 1 PB sprays + 2 PAA sprays.

Okra branching varied with treatments and growing seasons (Table 3). At 90 DAS, treatments with 3PS, 1PS2PA, and 1PB2PS gave significantly the highest mean number of branching (2.75, 2.93, 2.49 in 2018 and 2.89, 2.81 2.95 in 2019, respectively, Table 3). At 150 DAS, the highest number of branching was found in plants treated with 3PS, 3PA, and 1PB2PS (6.47, 6.07, 6.73 in 2018 and 4.32, 4.22, 3.99 in 2019, respectively, Table 3). In general, the number of branching taken at 150 DAS was higher in 2018 than in 2019 growing season (Table 3). Plants treated with 1PB2PA had the lowest number of branching in the whole experiment except at 90 DAS in 2018 (Table 3).

All treatments, except 3PA, significantly increased plant leaf areas as compared to the control in both seasons

(Table 3). In both seasons, the highest means for leaf areas were obtained in plants treated with 3PS (170.33 cm^2 in 2018 and 166 cm^2 in 2019), followed by 1PA2PS (143.3 cm^2 in 2018 and 140 cm^2 in 2019) and 3PB (131 cm^2 in 2018 and 130 cm^2 in 2019) as compared to the control (101.3 cm^2 in 2018 and 100 cm^2 in 2019, Table 3). The narrowest leaf areas were found in plants treated with 3PA (84.67 cm2 in 2018 and 89.6 cm2 in 2019) as compared to the control (Table 3).

Table 3. Effect of investigated foliar treatments on growth characteristics (Branches per plant and leaf area) of okra plants cv. 'Baladi' during 2018 and 2019 growing seasons.

	Number of branches						Leaf area		
	90 DAS			150 DAS			2018	2019	
Treatment	**2018**	**2019**	**Means**	**2018**	**2019**	**Means**			**Means**
Control	1.12	1.40	1.26	3.98	3.90	3.94	101.3	100.0	100.6
3PS	2.75	2.89	2.82	6.47	4.32	5.40	170.3	166.0	168.1
3PA	2.47	2.11	2.29	6.07	4.22	5.15	84.7	89.6	87.2
3PB	1.78	1.78	1.78	5.33	3.39	4.36	131.0	130.0	130.5
1PS2PA	2.93	2.81	2.87	5.13	3.14	4.14	112.0	110.0	111.0
1PS2PB	2.15	2.20	2.17	3.92	2.69	3.31	118.0	115.0	116.5
1PA2PS	1.53	2.15	1.84	4.81	2.91	3.86	143.3	140.0	141.6
1PA2PB	1.50	1.56	1.53	4.94	2.47	3.71	123.0	121.0	122.0
1PB2PS	2.49	2.95	2.72	6.73	3.99	5.36	106.3	105.6	105.9
1PB2PA	1.58	1.53	1.55	3.66	3.06	3.36	121.0	120.0	120.5
L.S.D at 0.05	0.29	0.26	0.275	0.72	0.58	0.65	3.8	3.71	----

DAS, days after sowing; 3PS, 3 sprays of potassium silicate; 3PA, 3 sprays of peroxyacetic acid; 3PB, 3 sprays of perbicarbonate; 1PS2PA, 1 PS spray + 2 PAA sprays; 1PS2PB, 1 PS spray + 2 PB sprays; 1PA2PS, 1 PAA spray + 2 PS sprays; 1PA2PB, 1 PAA spray + 2 PB sprays; 1PB2PS, 1 PB spray + 2 PS sprays; 1PB2PA, 1 PB sprays + 2 PAA sprays.

Effects on leaf chlorophyll a, b, and carotene contents

As compared to the control treatment, all studied treatments significantly increased leaf content of Chl a, with the highest content in 1PB2PS-treated plants (15.71 mg/100g in 2018 and 15.74 mg/100g in 2019), followed by 1PS2PA (13.88 mg/100g in 2018 and 13.90 mg/100g in 2019), 1PB2PA (13.47 mg/100g in 2018 and 13.50 mg/100g in 2019), and 1PA2PS (13.18 mg/100g in 2018 and 13.23 mg/100g in 2019) (Table 4). Leaf content of Chl b was significantly increased only in plants treated with 1PS2PA (9.27 mg/100g in 2018 and 9.31 mg/100g in 2019) and 1PA2PB (7.40 mg/100g in 2018 and 7.43 mg/100g in 2019) as compared to the control (6.85 mg/100g and 6.90 mg/100g in 2019, Table 4); all other treatments gave lower Chl b content than the control (Table 4). The total leaf Chl contents (Chl a + Chl b), however, were increased with all treatments as compared to the control (Table 4). Regarding carotene content, insignificant differences were noted among all treatments (Table 4).

In the present study, most studied treatments significantly improved plant height, whereas branching number was increased by 3PS, 3PA, and 1PB2PS, at most of the time points of measurements. Number of leaves was significantly improved by 3PS, 3PA, 1PS2PA, 1PS2PB, and 1PB2PS only while leaf area was significantly increased by all treatments (except 3 PA). The results of our study show that the highest increases in most okra growth characteristics was achieved by 3PS treatment (followed by 3PA and 1PB2PS) with 3PS being superior in increasing the number of leaves, branching number, and leaf areas. As regard to the yield and yield attributes results, 3PS, 1PA2PB, 3PA, 1PB2PS, and 1PS2PB improved most characteristics, with 1PA2PB achieving the highest total yield.

Table 4. Effect of investigated foliar treatments on mean values of chlorophyll a, b, total, and carotene contents (mg/100 g) in okra plants cv. 'Baladi' grown during 2018 and 2019 seasons.

Treatments	**Chl a**	**Chl b**	**Total**	**Carotene**	**Chl a**	**Chl b**	**Total**	**Carotene**
	2018				**2019**			
Control	10.30	6.85	17.15	6.21	10.33	6.90	17.23	6.23
3PS	12.02	6.79	18.87	7.54	12.11	6.81	18.92	7.56
3PA	11.88	6.70	18.58	6.13	11.85	6.72	18.57	6.11
PB3	11.69	6.20	18.56	6.62	11.72	6.23	17.95	6.60
1PS2PA	13.88	9.27	23.15	6.10	13.90	9.31	23.21	6.12
1PS2PB	12.58	6.71	19.49	6.73	12.61	6.82	19.43	6.75
1PA2PS	13.18	7.04	20.22	7.78	13.23	7.12	20.35	7.75
1PA2PB	12.76	7.40	20.16	6.64	12.80	7.43	20.23	6.62
1PB2PS	15.71	6.13	21.84	6.23	15.74	6.16	21.9	6.20
1PB2PA	13.47	6.86	20.33	6.54	13.50	6.88	20.38	6.56
L.S.D at 0.05	0.840	0.45	----	0.863	0.843	0.47	----	0.866

3PS, 3 sprays of potassium silicate; 3PA, 3 sprays of peroxyacetic acid; 3PB, 3 sprays of perbicarbonate; 1PS2PA, 1 PS spray + 2 PAA sprays; 1PS2PB, 1 PS spray + 2 PB sprays; 1PA2PS, 1 PAA spray + 2 PS sprays; 1PA2PB, 1 PAA spray + 2 PB sprays; 1PB2PS, 1 PB spray + 2 PS sprays; 1PB2PA, 1 PB sprays + 2 PAA sprays; Chl a, chlorophyll a, Chl b, chlorophyll b.

Achieved the best growth and yield results. Silicon has been known with its several benefits including the increased resistance to pests and pathogens and the improved quality and yield of crops (Richmond and Sussman, 2003). Application of foliar soluble silicon was found to increase leaf area of potato plants, which is in accordance with the results of this study (Pilon, Soratto and Moreno, 2013). Zhao *et al.*, 2019 suggsted that soluble PS can be an alternative option to conventional fertilization particularly with the wide problem of limited potassium resources in the world (Zhao *et al.*, 2019). The same study also proposed that PS can sustain plant growth and yield and enhance pH of the soil to solve soil acidification problem (Zhao *et al.*, 2019). In agreement to our findings, other researchers have reported that PS foliar application has improved plants growth by producing more aerial and root dry weight than the control plants (Wang and Galletta, 1998). On the other hand, a study by Guével, Menzies and Bélanger, 2007 has reported that wheat growth (including height and weight) was not improved by foliar PS application (Guével, Menzies and Bélanger, 2007). Souza *et al.*, 2017 found that PS treatment of lettuce did not improve plants growth characters including the total fresh matter, commercial fresh matter, and number of leaves (Souza *et al.*, 2017).

Effects on yield and its components

The studied treatments showed variable effects on the number of pods/plant (Table 5). In 2018, only plants treated with 3PB, 1PS2PA, and 1PS2PB that had significantly higher number of pods/plant than the control plants (Table 5). In 2019, all treatments (except 3PS and 1PB2PS) significantly increased number of pods/plant as compared to the control (Table 5). Mean values of both seasons showed that the highest and the lowest numbers of pods/plant were those treated with 1PS2PB and 3PS, respectively (Table 5). Regarding the pod length, 1PA2PB, 3PS, and 1PB2PS treatments gave the longest pods (5.93, 5.87, 5.33 cm, respectively) in 2018 as compared to the control (3.87 cm, Table 5). In 2019, however, plants treated with 3PS and 1PB2PS had the longest pods (5.70 and 5.50 cm, respectively) as compared to the control (3.47 cm, Table 5). Mean values of both seasons showed that the longest pods were noted in plants treated with 3PS (5.78 cm) and 1PB2PS (5.41 cm, Table 5).

Table 5. Effect of investigated foliar treatments on mean number of pods/plant and average pod length (cm) of okra plants cv. 'Baladi' during 2018 and 2019 growing seasons.

Treatments	Number of okra pods/plant			Average pod length (cm)		
	2018	2019	Means	2018	2019	Means
Control	128.70	112.50	120.6	3.87	3.47	3.67
3PS	102.21	108.06	105.13	5.87	5.70	5.78
3PA	113.45	138.51	125.77	4.10	4.13	4.11
PB3	140.96	139.86	140.41	4.07	4.17	4.12
1PS2PA	146.92	151.06	148.99	3.93	4.23	4.08
1PS2PB	156.65	141.46	149.05	4.93	5.27	5.1
PA2PS1	120.33	175.00	147.66	4.17	4.67	4.42
1PA2PB	125.86	135.86	130.86	5.93	3.90	4.91
1PB2PS	110.16	114.81	112.48	5.33	5.50	5.41
1PB2PA	107.52	127.02	117.27	3.93	4.00	3.96
L.S.D at 0.05	0	2.8	---	0.36	0.45	----

3PS, 3 sprays of potassium silicate; 3PA, 3 sprays of peroxyacetic acid; 3PB, 3 sprays of perbicarbonate; 1PS2PA, 1 PS spray + 2 PAA sprays; 1PS2PB, 1 PS spray + 2 PB sprays; 1PA2PS, 1 PAA spray + 2 PS sprays; 1PA2PB, 1 PAA spray + 2 PB sprays; 1PB2PS, 1 PB spray + 2 PS sprays; 1PB2PA, 1 PB sprays + 2 PAA sprays.

For the pod weight, only 3PS, 3PA, 1PA2PB, and 1PB2PS treatments that significantly increased pod weight in the two growing seasons as compared to the control (Table 6) with mean values of 5.85, 5.72, 5.66, and 5.65g, respectively).

Table 6. Effect of investigated foliar treatments on mean pod weight (gm) and yield (ton /feddan) of okra plants cv. 'Baladi' during 2018 and 2019 growing seasons.

Treatments	Pod weight (gm)			Yield (ton/feddan)		
	2018	2019	Means	2018	2019	Means
Control	4.27	4.80	4.53	6.600	6.480	6.54
3PS	5.87	5.83	5.85	7.200	7.560	7.38
3PA	6.17	5.27	5.72	8.400	8.760	8.58
PB3	4.54	4.29	4.41	7.680	7.200	7.44
1PS2PA	4.65	4.70	4.67	8.040	8.520	8.28
1PS2PB	3.83	4.10	3.96	7.200	6.960	6.98
PA2PS1	5.90	4.00	4.2	8.520	8.400	8.46
1PA2PB	5.80	5.52	5.66	8.760	9.000	8.88
1PB2PS	5.90	5.40	5.65	7.800	7.440	7.62
1PB2PA	4.65	4.33	4.49	6.000	6.600	6.30
L.S.D at0.05	0.45	0.39	----	0.36	0.98	---

3PS, 3 sprays of potassium silicate; 3PA, 3 sprays of peroxyacetic acid; 3PB, 3 sprays of perbicarbonate; 1PS2PA, 1 PS spray + 2 PAA sprays; 1PS2PB, 1 PS spray + 2 PB sprays; 1PA2PS, 1 PAA spray + 2 PS sprays; 1PA2PB, 1 PAA spray + 2 PB sprays; 1PB2PS, 1 PB spray + 2 PS sprays; 1PB2PA, 1 PB sprays + 2 PAA sprays.

In both growing seasons, only 3PS, 3PA, 1PS2PA, 1PA2PS, and 1PA2PB treatments that significantly increased the total yield as compared to the control (Table 6) with the highest total yield produced by 1PA2PB (8.760 ton/feddan in 2018 and 9.000 ton/feddan in 2019). 1PB2PA, however, resulted in lower mean values of the two seasons than the control (6.30 vs 6.54 ton/feddan, Table 6). Other treatments (3PB, 1PS2PA, 1PA2PS, and 1PB2PS) showed comparable yield results to those obtained from the control treatment (Table 6).

Disease assessment

All tested treatments significantly reduced AUDPC incidence as compared to the untreated plants in both growing seasons (Table 7). The least AUDPC values were found in plants sprayed with 1PA2PS (166.33 and 173.33 in 2018 and 2019, respectively). In both growing seasons, the highest protection percentage was found in plants treated with 1PA2PS (68.97% and 74.90%, respectively), followed by 1PA2PB (68.37 and 74.30, respectively), 1PB2PA (68.75 and 72.22, respectively), 3PS (201.67 and 202.43), respectively.

Table 7. Effect of singular and investigated foliar treatments on area under powdery mildew progress curve (AUPMPC) and percentage of protection to okra plants cv. 'Baladi' during 2018 and 2019 growing seasons.

Treatments	AUPMPC			Protection %		
	2018	2019	Means	2018	2019	Means
Control	558.67	647.33	603	0	0	0
3PS	201.67	202.43	202.05	63.90	68.72	66.31
3PA	233.00	193.27	213.135	58.29	70.14	64.215
PB3	234.67	242.10	238.385	57.99	62.60	60.295
1PS2PA	208.00	249.83	228.915	62.76	61.40	62.08
1PS2PB	206.67	224.90	215.785	63.00	65.25	64.125
PA2PS1	173.33	166.33	169.83	68.97	74.30	71.635
1PA2PB	176.67	183.97	180.32	68.37	71.58	69.975
1PB2PS	208.00	206.00	207	62.76	68.17	65.465
1PB2PA	186.33	179.80	183.065	68.75	72.22	70.485
L.S.D at 0.05	19.12	13.4	----	----	----	----

3PS, 3 sprays of potassium silicate; 3PA, 3 sprays of peroxyacetic acid; 3PB, 3 sprays of perbicarbonate; 1PS2PA, 1 PS spray + 2 PAA sprays; 1PS2PB, 1 PS spray + 2 PB sprays; 1PA2PS, 1 PAA spray + 2 PS sprays; 1PA2PB, 1 PAA spray + 2 PB sprays; 1PB2PS, 1 PB spray + 2 PS sprays; 1PB2PA, 1 PB sprays + 2 PAA sprays.

Development of synthetic chemicals such as pesticides and fungicides has definitely protected horticultural products and saved it from the prevalent damaging diseases. However, they also raised the global challenge toward the safety of products used in the agricultural industry. Growers are required to use safe agricultural practices to assure that produce meets quality and safety standards including generating new antifungal products that have minimal impact on the environment and human and animal health (Kakade *et al.*, 2020). Silicon has several agronomic and horticultural benefits including reducing severity of many plant diseases, and was, therefore, suggested to be used in integrated disease management strategies (Rodrigues and Datnoff, 2007). Bicarbonates, such as potassium bicarbonates, have antifungal activity and were also suggested to be used in organic production (Mitre *et al.*, 2010; Soliman and El-Mohamedy, 2017; Türkkan *et al.*, 2018). PAA is considered an environment-friendly product with a reported antifungal activity against *Rhizoctonia solani* and *Botrytis cinerea* (Narciso *et al.*, 2007; Ayoub *et al.*, 2017; Jo *et al.*, 2019).

The results of the present study show that the highest chlorophyll contents were achieved when PS was accompanied by other treatments sprayings such as 1PB2PS and 1PS2PA. In agreement to our results, application of foliar soluble silicon increased leaf area, Chl a, and caretonoids of potato plants (Pilon, Soratto and Moreno, 2013). Also, Chl a, b, and total chlorophyll were increased with PS fertilization of rice plants (Gerami, Fallah and Moghadam, 2012) and with foliar spraying of rose leaves (Locarno, Fochi and de Oliveira Paiva, 2011).Wang and Galletta, 1998, observed that strawberry plants sprayed with PS produced more dry matter and contained more total chlorophyll content (Wang and Galletta, 1998). The authors attributed the increase in growth to the increased membrane lipid unsaturation level that helped preserve its fluidity and functions, and maintained the physiological bilayer phase. Those enhancements may have induced cell expansion and consequently improved growth of plants (Wang and Galletta, 1998). On the contrary, Dehghanipoodeh *et al.*, 2016 found no significant differences in chlorophyll content in strawberry plants treated with silicon and the control (Dehghanipoodeh *et al.*, 2016).

Most growth characteristics and yield attributes in the present study were improved by 1PB2PS, 3PB, or 1PS2PB treatments while the highest yield was achieved by 1PA2PB treatment. In accordance with our results, a study by Soliman and El-Mohamedy, 2017, reported that okra plants treated with foliar spraying with bicarbonate alone or mixed with other salts significantly increased plant height, number of branches, pod weight, and yield. In contradiction of our results, Soliman and El-Mohamedy, 2017 reported that bicarbonate did not affect the pod number per plant (Soliman and El-Mohamedy, 2017), which were significantly increased by our 3PB treatments.

In our study, PAA, particularly as a singular treatment, enhanced all growth characteristics (except leaf area), mean pod weight, and total yield of okra plants. In agreement with our results, PAA increased watercress plant height, leaf length, and improved the yield (Carrasco *et al.*, 2011). In another study on hydroponically-grown, 1-week-old tomato seedlings, treatment with PAA showed a concentration-dependent reduction in the growth of all vegetative organs (Vines *et al.*, 2003). The authors also reported that PAA was less toxic to older plants and to those grown on solid substrates (Vines *et al.*, 2003). Generally, there is insufficient information on the effects of PAA on the plant growth.

As regard to powdery mildew control, all studied treatments significantly decreased AUDPC. The highest percentage of disease prevention was found in plants treated with 1PA2PS, followed by 1PA2PB, 1PB2PA, and 3PS. PAA sprayed before PS or PB, or after PB showed the highest protection against powdery mildew infection on plants (1PA2PS, 1PA2PB, and 1PB2PA). To our knowledge, studies on the effects of PAA on powdery mildew are very limited. One study found that foliar application of PAA decreased powdery mildew infection of okra and sunflower plants (Galal, 2017). In another study, PAA mixture also showed antifungal activity to other fungal diseases and inhibited mycelial growth of *Rhizoctonia solani* in rice plants (Jo *et al.*, 2019). In in-vitro studies, PAA inhibited growth of *Botrytis cinerea* and minimized the use of fungicides (with their harmful effects on human and environment) by 95% (Ayoub *et al.*, 2017).

In our experiment, PB (whether a singular or sequenced treatment) was effective against powdery mildew infection especially when sequenced with PAA (1PA2PB and 1PB2PA). In earlier studies, potassium bicarbonate suppressed conidia formation of *Helminthosporium solani* fungi on potato tubers (Olivier *et al.*, 1998) and inhibited *Botrytis cinerea* growth (Bombelli and Wright, 2006). In agreement with our results, spraying okra plants with bicarbonates (3.0%) decreased severity of powdery mildew and enhanced defense resistance proteins, total phenol content, polyphenol oxidase, peroxidases, chitinase, and protein content (Soliman and El-Mohamedy, 2017). Similarly, potassium or sodium bicarbonate treatment significantly reduced severity of powdery mildew in sweet red pepper (Fallik *et al.*, 1997) and in tomato plants (Pace, Vrapi and Gixhari, 2016). Earlier reports recommended potassium bicarbonates to be used in organic agriculture because of its eco-friendly features (Mitre, Mitre and Sestras, 2009; Pace, Vrapi and Gixhari, 2016). The antifungal effects of bicarbonates were found to come from their role in changing the pH of the medium (DePasquale and Montville, 1990), affecting membranes permeability, impeding oxidative phosphorylation reactions (DePasquale and Montville, 1990; Olivier *et al.*, 1998), and suppressing conidia formation and fungal growth (Olivier *et al.*, 1998; Bombelli and Wright, 2006).

The means by which silicon increases resistance to powdery mildew is still unclear (Pozza *et al.*, 2015). Suggested mechanisms include formation of a mechanical barrier, acting as a modulator of host resistance (Heath and Stumpf, 1986; Rodrigues and Datnoff, 2007), formation of higher penetration resistance, or its role in lowering the interchange of materials between fungus and host plant because of the silicified cell walls (Heath and Stumpf, 1986). A recent study suggested that silicone-treated plants form fungistatic phenolic compounds that increase cell wall resistance by increasing the middle lamella thickness causing physical and/or chemical barriers (Pozza *et al.*, 2015). It was also noted that treating infected plants by *Pythium* spp. with soluble silicon stimulated a cascade of biochemical changes such as increased activity of chitinases, peroxidases, polyphenoloxidases, and increased β-glucosidase activity) which lead to rapid defense reactions (Cherif *et al.*, 1994).

Soluble silicon increased resistance of cucumber plants to powdery mildew by the presence of low molecular-weight metabolites such as phytoalexins which enhanced antifungal activity of infected leaves (Fawe *et al.*, 1998). In another study on cucumber plants, foliar application of potassium silicate was effective in controlling powdery mildew infection caused by *Podosphaera xanthii* by making a physical barrier deposit on the leaf surface and/or by the osmotic effect of the applied silicate, however, it did not improve systemic acquired resistance induced by inoculation (Liang *et al.*, 2005). The reduction of powdery mildew incidence in wheat plants following foliar applications of PS was thought to be a direct effect on the fungus rather than inducing resistance (Guével *et al.*, 2007). In strawberry, drenching the soil with liquid potassium silicate strongly suppressed mildew before it appeared

(Kanto *et al.*, 2006). In contrast, PS did not decrease the severity of powdery mildew in gerbra daisy plants which was explained by the low accumulation of silicon by gerbra leaves (Moyer *et al.*, 2008).

CONCLUSION

Singular or sequential ten treatments of PAA, PB, and PS were evaluated for their effectiveness in powdery mildew disease resistance in okra plants along with their effects on plant growth, chlorophyll a, b, and carotene contents, and yield and its attributes. All studied treatments significantly reduced powdery mildew infection with highest resistance observed with 1PA2PS, followed by 1PA2PB, 1PB2PA, and 3PS. Most studied treatments significantly improved plant height, whereas branching number was increased by 3PS, 3PA, and 1PB2PS. Number of leaves was significantly improved by 3PS, 3PA, 1PS2PA, 1PS2PB, and 1PB2PS only, while leaf area was significantly increased by all treatments (except 3 PA). Yield and yield attributes were improved by 3PS, 1PA2PB, 3PA, 1PB2PS, and 1PS2PB, with 1PA2PB achieving the best total yield. In conclusion, singular treatments of PS or PAA and sequential treatments of 1PB2PS, 1PAA2PS, 1PS2PAA, or 1PA2PB are the most effective treatments in controlling powdery mildew disease in okra plants while improving its growth, chlorophyll content, and yield.

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تأثير فاعلية بيروكسي حمض الخليك والبيربيكربونات البوتاسيوم وسيليكات البوتاسيوم على النمو والمحصول ومقاومة البياض الدقيقي في الباميا

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أجريت هذه التجربة بمزرعة قسم أمراض النبات كلية الزراعة جامعة المنيا لدراسة الغرض من تأثير بيروكسي حمض الخليك (PAA) ، البيربيكربونات البوتاسيوم (PB) ، وسيليكات البوتاسيوم (PS) كمركبات فردية و متبادلة رشأ علي نبات الباميا في مواعيد مختلفة وتم قياس العديد من الصفات على النمو (ارتفاع النبات ، عدد الأوراق ، عدد الفروع ، مساحة الورقة) ، المحصول (عدد القرون النباتية ، طول القرون ، وزن القرون) ، الكلوروفيل أ ، ب ، ومحتويات الكاروتين ومقاومة نباتات البامية (صنف بلدي) لمرض البياض الدقيقي. وتبين أن المعاملات PAA + PS أو PAA + PB أو PB + PAA لها تأثير إيجابي في مقاومة البياض الدقيقي بالإضافة الي تحسين خصائص النمو من خلال معظم المعاملات مع أعلى تأثير لـ PS أو PAA المستخدم بصورة فردية ومع المعاملة PB + PS. ولوحظ تفوق PS في زيادة عدد الأوراق وعدد الأفرع ومساحة سطح الورقة. كانت المعاملة الوحيدة التي زادت بشكل كبير من متوسط وزن القرون هي PS و PAA و PAA + PB و PB + PS. كما ان المعاملة الوحيدة التي زادت بشكل كبير من المحصول الكلي هي PAA + PB و PAA و PS و PS + PAA و PAA + PS مع المعاملتين السابقتين اللتين أعطتا أعلى إنتاجية. في الختام، أدى الرش الورقي للباميا بمعاملات مفردة أو متبادلة باستخدام PS و PAA و PB إلى تحسين مقاومة النبات لعدوى البياض الدقيقي بشكل ملحوظ. ومع ذلك، كانت معاملات PS أو PAA بصورة فردية بالإضافة إلى المعاملات PB + PS و PAA + PS و PS + PAA و PAA + PB هي الأكثر فعالية في تحسين النمو والمحصول والسيطرة علي انتشار مرض البياض الدقيقي.

الكلمات المفتاحية: محصول الباميا، بوتاسيوم سليكات، بيروكسي حمض الخليك، البيربيكربونات، البياض الدقيقي.