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Efficiency of potassium and calcium compounds in gel formula to control early blight disease, improve productivity, and shelf life of potato

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Abstract

The efficiency of foliar spray with potassium sulphate, potassium silicate, calcium chloride and calcium citrate gel formula was evaluated in controlling early blight disease (caused by Alternaria solani), improving growth and yield quality of potato (cv. Lady Rosetta). A field experiment was performed during two successive seasons, 2018/2019 and 2019/2020. Foliar applications of potassium and calcium compounds were compared to Copperal Max (8 % copper as a positive control) and water as a control treatment. All treatments were sprayed twice on the plants at 45 and 60 days post-planting. The results proved that all foliar spraying treatments significantly decreased the disease incidence and severity of early blight, improved vegetative growth parameters and nutrients content (N, P and K) of potato plants as well as increased yield and tuber quality of potato compared with untreated plants. In this respect, the lowest disease severity was achieved by Copperal Max (9 and 11.05%) followed by potassium silicate (9.95 and 12.77%) and calcium chloride (9.66 and 12.92%), finally, untreated control recorded the highest disease severity (22.07 and 26.71 %) respectively at both tested seasons. On the other hand, potassium silicate and calcium chloride in gel formula was superior to other treatments in increasing the total and marketable yield of potato tubers, also reducing the weight loss and decay of tubers stored on a shelf. These results suggest that one of the main alternatives to controlling potato early blight is using potassium silicate or calcium chloride.

Keywords: Potato, Early blight, Potassium silicate, Potassium sulphate, Calcium chloride, Calcium citrate.

INTRODUCTION

Potato (Solanum tuberosum L.) is one of the important strategic crops for the production of global food, planted with 19.303 million hectares and producing 388.191 million tons. In Egypt, potato is the second-largest horticultural crop exported after citrus, planted with a total area of 415 thousand feddans (feddan = 0.42 hectare), produced about 4.841 million tons **(Anon., 2017)**. The export of Egyptian potatoes reached 737 thousand tons worth 211 million

US$, European Union countries are considered the most important markets for imported Egyptian potatoes **(**Anon., 2018).

Early blight caused by *Alternaria solani* (Ellis and Martin), Jones and Grout is one of the most important diseases attacking potato plants and occurs in most potato production areas every year, causing huge losses in potato yield, especially with high humidity around plants, leading to the speedy development of symptoms and death of the plants (Abd-El-Kareem *et al.,* 2002).

Symptoms usually appear on the old leaves first as small irregular spots of dark brown to black color. There is often a tight yellow halo around each spot. When the incidence is more severe, the spots interfere together, thus the leaves become yellow and die (Sikora, 2004). Symptoms of the stems appear in the form of rectangular and sunken spots that may also form concentric rings. The incidence in tubers appears to be slightly sunken irregular patches with raised borders; dry rot forms under the skin inside the tuber (Schultz and French, 2009).

Copper has been used in agriculture to control fungi and bacteria for over a century. It plays an important role in integrated pest management when sprayed before infection with full coverage of plants, but copper is essential in organic farming, where disease management depends almost exclusively on its use. However, the use of this heavy metal may have long-term consequences due to its accumulation in the soil, which appears incompatible with organic farming's objectives (La Torre *et al*., 2018).

Potassium salts increase the resistance of plants to stress conditions and induce the natural defenses of plants against pathogens in addition to the accumulation of polyphenols that works as major action implicated in the neutralization of charges and as osmotic active substances (Wang *et al.,* 2013). It also positively effects synthesis, transformation and storage of carbohydrates as well as potato tuber quality (Ebert, 2009; Marschner, 2012).

Liquid potassium silicate is used as a silicon source and contains small amounts of potassium that help improve yield quality (Tarabih, *et al.*, 2014). Potassium silicate can improve environmental stress tolerance and increase crop productivity (Talebi *et al.*, 2015). Silicon enhancing plant resistance to fungal diseases occurs in one of two ways. The first is depositing silicon in cell walls to form a physical barrier that impairs the penetration of pathogens into plant tissues (physical defense). The second relates to the biologically active use of silicon to induce the natural defense mechanism of plants to resist pathogens (Van Bockhaven *et al.*, 2013; Sakr, 2016).

Spraying plants with various sources of potassium such as potassium sulfate and potassium silicate may improve yield and tuber quality, in heavy clay or in sandy soils where K is not available for the plants (Marchand and Bourrie, 1999; Abay and Sheleme, 2011). These compounds improved the growth parameters, yield and mineral content in potato plants (El-Zohiri and Asfour, 2011; Pilon *et al.*, 2014; Salim *et al.*, 2014).

Calcium is an essential plant nutrient, which plays a structural role in maintaining cell wall firmness, membrane stability and cell integrity (Marschner, 2012). The role of calcium in disease resistance may be due to interference with the activity of hydrolytic enzymes and reduction of cell wall softness by polygalacturonase (Conway *et al.* 1992). As well as calcium ion stimulates the accumulation of phytoalexin, known to be implicated in the defense mechanisms of plants against fungal attacks (Zook *et al*., 1987). Using calcium chloride against early blight pathogen of potato plays a role in increasing the thickness of the cell wall and cuticle layer, so it protects the plant from an invasion of pathogens (Mendez *et al.*, 1994).

Increment of calcium content in potato plants increased plant resistance to infection with early blight and reduced internal defects of potato tubers, resulting in increased yield, storage life and quality of tubers (El-Mougy and Abdel-Kader, 2009).

Calcium citrate is calcium salt of citric acid and one of the important organic acids for the respiration of plant cells. The protective effect of citrate against plant diseases is indirectly attributable by an increase in phenolic compounds and the activity of their associated enzymes (Ibrahim et al., 2015). Several studies have evaluated the effect of spraying potassium and calcium salts on the growth, yield and quality of potatoes (El-Mougy and Abdel-Kader, 2009; Palta, 2010; Salim *et al.*, 2014; Talebi *et al.*, 2015; Seifu and Deneke, 2017).
Formula type plays a significant role in determining the final efficacy of potassium and calcium salts based product. The nutrients in a gel formula help with quick and easy absorption of these nutrients by leaves, where it provides thickens the layer of spraying material on treated leaves and improves adhesion between treated surfaces and spraying materials (Powell and Faull, 1989). Therefore the main objective of this study finds alternatives to copper compounds inducing plants to resist early blight disease and improving the productivity of potato without causing toxicity such as, potassium and calcium compounds which formulated in gel form to increase adhesive capacity and improve the distribution of compounds on the surface of treated plants for increasing the effectiveness of these compounds.

MATERIALS AND METHODS

A field experiment was performed during the two successive seasons 2018/2019 and 2019/2020 at the experimental farm of Agricultural Research Center, Ministry of Agriculture and Land Reclamation, Giza, Egypt. The experiment was conducted to evaluate the effect of foliar spraying using some compounds (potassium sulphate, potassium silicate, calcium chloride and calcium citrate) in gel formula on the incidence of early blight disease and the productivity of potato plants. The commercial potato tubers of Lady Rosetta cultivar were planted during the first week of October in both seasons of study in clay loam soil. The field was prepared according to the recommendations of the Ministry of Agriculture, then divided into plots of 12.6 m^2 (4.5 m length and 2.8 m width), each plot contained 4 ridges (70 cm width). The tubers were planted at a dpth of 15 cm and a distance of 25 cm on one side of a ridge, each experimental plot contained 72 plants. The plants were irrigated using a surface irrigation system.
This experiment included six treatments as follows:

1. Potassium sulphate (K_2SO_4)
2. Potassium silicate (K_2SiO_3)
3. Calcium chloride ($CaCl_2$)
4. Calcium citrate ($Ca_3(C_6H_5O_7)_2$)
5. Copperal Max (8% $CuSO_4$) as a positive control
6. Water as a control treatment

Concentrated solutions of potassium sulphate and potassium silicate were prepared at a concentration of 15 % potassium, while concentrated solutions of calcium chloride and calcium citrate were prepared at a concentration of 10% calcium according to a percentage of potassium or calcium in each compound. All compounds of potassium sulphate, potassium silicate, calcium chloride and calcium citrate were prepared in gel formula by adding 10% carboxymethyl cellulose to concentrated solutions. Copperal Max is produced by the Central Laboratory of Organic Agriculture from copper sulfate (8% copper). All treatments were sprayed twice on the plants at a rate of 1L / 200 L of water after 45 and 60 days post-planting. A group of potato plants were sprayed with water at the same time as a control.

A completly randomized block design was used to arrange the treatments and three replicates were allocated for each treatment. All agricultural practices (cultivation, irrigation, fertilization and insect control) were followed according to the Ministry of Agriculture for the production of potatoes in clay soils.

Disease incidence and severity of early blight

Disease incidence was recorded after the appearance of natural disease symptoms in control plants (at both seasons as a percentage of infected plants. Disease incidence percentage (DI) was calculated and expressed by the following formula:

DI = (n/N) X 100

Where n = Number of diseased plants, N= Total number of plants.

The reduction % in disease incidence (DI %) and the reduction % in disease severity were calculated according to (Atia, 2005) as follows:

Reduction = C-T/C X100

C = percentage of disease incidence and/ or severity in untreated plants (control).

T = percentage of disease incidence and/ or severity in treated plants.

Disease severity was recorded using a disease scale of 0-7 according to Chirst (1991) as follow:

0 = no infected, 1 = trace to 1%, 2 = 2-5%, 3 = 6-10%, 4 = 11-25%, 5 = 26-50%, 6 = 51-75% and 7 = 76-100% of the leaflet infected. The disease severity was calculated using the following formula:

% Severity = (sum of n x v) x100/ 7N

Where n= number of leave-in each symptom's category; v = numerical value of each category; N = total number of leaves

Growth characteristics and nutritional status

Five plants from each experimental plot were taken randomly after 80 days from planting date in both seasons to measure growth characteristics and nutritional status of potato plants. Fresh shoot weight and leaf numbers per plant were measured. The chlorophyll reading was also measured in the third upper leaf using Minolta Chlorophyll Meter SPAD 502. The nutrient content (N, P and K) of potato plants was determined in the most recent fully developed leaf after drying at 70 °C according to Cottenie *et al.* (1982). Total nitrogen, phosphorus and potassium were determined by Micro Kjeldahl, Spectrophotometer and Flame photometer, respectively according to FAO (1980). All chemical analyses of soil and plants were carried out at the Laboratory of Arid Land Agricultural Research and Service Center, Faculty of Agriculture, Ain Shams University.

Yield component and tuber properties

At the maturity stage, 110 days after the planting date, potato tubers were harvested. The total yield per plot was recorded and divided into marketable and unmarketable tubers (tuber diameter < 2.5 cm) yield. Ten tubers from each replicate were randomly taken to measure tuber firmness using Pressure Tester (1.5 mm diameter), percentage of total soluble solids using Digital Refractometer and dry matter in tubers. The percentage of dry matter was calculated by the following equation:

$$\% \text{ Dry matter} = (\text{dry weight} / \text{fresh weight}) \times 100$$

Tubers shelf life

A representative sample of each treatment, consisting of 60 healthy tubers was selected and arranged in 3 replicates to be stored under room conditions for two months (February and March). The percentage of weight loss and decayed tubers were calculated at the end storage period according to the following equations:

$$\text{Weight loss} = \frac{(\text{weight at start of storage period} - \text{weight at end storage period}) \times 100}{\text{Weight at start storage period}}$$

$$\text{Decay} = \frac{\text{Number of decayed tubers} \times 100}{\text{Total number of tubers}}$$

The obtained data were subjected to statistical analysis of variance according to procedures outlined by (**Snedecor and Cochran, 1980**) using SAS software, version 2004. The means of treatment was compared by Duncan's test at ≤ 0.05 level of probability.

RESULTS AND DISCUSSION

Disease incidence and severity of early blight in a field experiment

The efficacy of the tested compounds, as well as Copperal Max, under natural field infection by *A. solani* were determined at two seasons 2018/2019 and 2019/2020. Data in Table (1) showed that disease incidence was more severe during the first season than the second season. This might be attributed to the variable factors of the environmental conditions such as temperatures, relative humidity (fog dew and rains) as reported by Waals *et al.* (2003). Data also showed that all treatments significantly reduced the disease incidence and severity of early blight compared with controlled treatment in both seasons. In this respect, Copperal Max as a positive control was the most effective treatment on reducing disease incidence and severity in the two seasons followed by calcium chloride in the first season and potassium silicate in the second season. Potassium sulphate was the lowest treatment in controlling early blight disease during the two seasons (Table 1). Data showed that the different treatments varied in their effect on controlling early blight disease. Disease severity (D.S) was also recorded, the lowest disease severity was achieved by Copperal Max (9% and 11.05%), potassium silicate (9.95% and 12.77) and calcium chloride (9.66% and 12.92) compare with 22.07 % and 26.71 in control treatment at fires and second seasons respectively.

The effect of copper sulfate may be due to that the ability of copper ions to penetrate plant tissue and effect on pathogenesis fungi by denaturing their cellular proteins. Moreover, copper sulphate causes induction of plant defense responses (Kowalska *et al.*, 2015). While, using calcium chloride against early blight pathogens depends on its role in increasing the thickness of the cell wall and cuticle layer, so it protects the plant from invasion by fungal pathogens (Mendez *et al.*, 1994; Wickeramaarchchi *et al*., 2003). On the other hand, potassium silicate could increase the concentration of antifungal compounds such as increase the concentration of phenolic compounds which lead to decrease disease incidence mechanisms (Van Bockhaven *et al.*, 2013 and Sakr, 2016). However, Silicon has offered protection against fungal diseases by strengthening cell walls which makes it difficult to penetrate and colonize the plant by pathogens. Where, the effectiveness of silicon is due to the physical barrier formed by the deposition of silicon under the cuticle (Keller *et al*., 2015).

The effectiveness of gel formula with all compounds may be due to their slow evaporation, which prolongs their existence and their ability to cover the leaf surface besides breaking the surface tension caused by waxes and creating a film on the surfaces that carries moisture (Burges, 1998).

Table (1): Efficacy of potassium and calcium compounds in gel formula on reducing early blight disease incidence and severity of potato plants during 2018/2019 and 2019/ 2020 seasons.

Treatments	% Disease Incidence (DI)		% Reduction in DI		% Disease Severity (DS)		% Reduction in DS	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
K sulphate	34.23 b	29.93 b	34.06	27.93	13.30 b	16.68 b	39.73	37.56
K silicate	24.09 c	18.50 cd	53.59	55.46	9.95 cd	12.77 d	54.92	52.21
Ca chloride	23.11 c	18.82 cd	55.48	54.68	9.66 cd	12.92 cd	56.22	51.63
Ca citrate	29.60 b	21.95 c	42.98	47.15	12.39 bc	15.66 bc	43.87	41.39
Copperal Max	21.13 c	16.03 d	59.30	61.39	9.00 d	11.05 d	59.21	58.65
Control	51.91 a	41.53 a			22.07 a	26.71 a		

In column means followed by the same letters are not statistically different at ($p \leq 0.05$) level according to Duncan's multiple range test.
Copperal Max = Copper sulphate as a positive control
Control = water as a negative control

Growth characteristics

All compounds in a gel formula and Copperal Max increased growth characteristics. This might be due to their effect on potato pathogens and have a profound effect on crop health. Calcium chloride was the most treatments in increasing shoot fresh weight and number of leaves (570 g and 62.67 leaves) in the first season, whereas potassium silicate was the most effective treatment (600.51 g and 64.98 leaves) in the second season without significant differences between them and Copperal Max (Table 2). The improvement of growth characteristics with calcium chloride and potassium silicate treatments may be attributed to the positive effect of these treatments on reducing the incidence and severity of early blight on plants as shown in Table 1. Besides the direct positive effect of the treatments of calcium chloride and potassium silicate in improving the growth characteristics where calcium plays a structural role in maintaining cell wall firmness, membrane stability and cell integrity (Marschner 2012), thus improved growth parameters of potato plants. This result was consistent with the results obtained by **Seifu and Deneke (2017),** where spraying potato plants with calcium chloride revealed the best plant growth than unsprayed plants. While, improving the growth of plants that were treated with potassium silicate can be attributed to the role of potassium in many metabolic processes and acts as a catalyst or activator of certain enzymes into the plant, thus improving growth parameters of plants. This is in harmony with Abay and Sheleme (2011), they reported that the potassium silicate application increases growth parameters of the potato plants.

Table (2): Effect of foliar spraying with potassium and calcium compounds in gel formula on vegetative growth characteristics of potato plants during 2018/2019 and 2019/ 2020 seasons

Treatments	Shoot fresh weight g		Leaf No		Chlorophyll SPAD	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
K sulphate	473.33 c	493.69 b	50.33 c	53.51 b	38.00 b	40.00 bc
K silicate	563.33 a	600.51 a	60.00 a	64.98 a	42.00 a	43.51 a
Ca chloride	570.00 a	591.66 a	62.67 a	64.90 a	40.67 ab	42.67 ab
Ca citrate	516.67 b	531.13 b	54.67 bc	56.20 b	37.67 b	38.83 c
Copperal Max	560.00 a	578.48 a	59.00 ab	60.64 ab	40.33 ab	43.00 ab
Control	410.00 d	419.02 c	43.67 d	44.63 c	33.00 c	33.47 d

In column means followed by the same letters are not statistically different at ($p \leq 0.05$) level according to Duncan's multiple range test.
Copperal Max = Copper sulphate as a positive control
Control = water as a negative control

Concerning chlorophyll reading of potato leaves, results show that in both seasons a significant increment in chlorophyll reading was obtained in all tested treatments compared with control. Potassium silicate formulated with gel showed the highest values of chlorophyll reading in both seasons (42 and 43.51). No significant differences were detected between the treatments of calcium chloride in a gel formula and Copperal Max. This may be due to the active role of potassium in a variety of physiological processes, i.e. photosynthesis, protein synthesis and maintenance of water status in plant tissues (Ebert, 2009; Marschner, 2012). Also, silicon has a role in improving the chain of photosynthesis and preventing the deterioration of chlorophyll, where the action of silica bodies as windows allowed the light transmission to mesophyll area (Epstein, 1999; Pilon *et al.*, 2014). In this respect, Salim *et al.* (2014) and Abd El-Gawad *et al.* (2017) demonstrated that foliar application of potassium silicate improved the vegetative growth parameters of potato plants.

Nutritional status of potato plants (N, P and K content of leaves)

Uptake of N, P and K by plants depends on the overall health of the plants, as well as the availability of these nutrients in the soil and growth stage. All treatments show a significant increase in N, P and K concentration in potato leaves as compared to control at two seasons (Table 3). The highest concentration of N and P in potato leaves were obtained by foliar spraying of potassium silicate in gel formula followed by Ca chloride in a gel formula and then Copperal Max treatments without significant differences between them in the two seasons. The maximum value of K concentrations was also recorded by foliar applications of potassium silicate in gel formula followed by insignificant differences for K sulphate in gel formula during both seasons. Whereas the lowest values of N, P and K were recorded by control treatment in both seasons of study. The affirmative effect of potassium silicate on N, P and K uptake may be because potassium silicate is a good source of potassium. Since potassium has an essential role in the absorption of nutrients through the process of osmoregulation, stomata movement and phloem loading, subsequently, enhancing the nutritional content of plant (Wang *et al.,* 2013). Besides the foliar application of potassium silicate works to deposit silica in the required key points that keep hair roots healthy, allowing better absorption of water and nutrients (Salim *et al.,* 2014). These results are in harmony with those obtained by Pilon *et al.* (2014) and Abd El-Gawad *et al.* (2017), and they stated that foliar application of potassium silicate gave higher values for leaf macronutrient as compared to control treatment.

Table (3): Effect of foliar spraying with potassium and calcium compounds in gel formula on the nutritional status of potato plants during 2018/2019 and 2019/ 2020 seasons.

Treatments	N		P		K	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
K sulphate	3.710 b	3.940 c	0.317 bc	0.333 b	5.637 a	5.620 a
K silicate	4.303 a	4.530 a	0.358 a	0.373 a	5.703 a	5.683 a
Ca chloride	4.290 a	4.507 a	0.350 ab	0.370 ab	5.487 b	5.460 b
Ca citrate	3.757 b	3.947 c	0.313 c	0.330 b	5.377 c	5.355 c
Copperal Max	4.023 ab	4.363 b	0.347 ab	0.364 ab	5.497 b	5.473 b
Control	3.070 c	3.250 d	0.237 d	0.248 c	4.817 d	4.806 d

In column means followed by the same letters are not statistically different at ($p \leq 0.05$) level according to Duncan's multiple range test.
Copperal Max = Copper sulphate as a positive control
Control = water as a negative control

Yield and its Components

Data in Table (4) illustrate that all the compounds in gel form, as well as the Copperal Max treatment, increased the total and marketable yield of potato tubers compared to control treatment. Foliar application of potassium silicate in gel formula recorded the highest total yield (45.483 and 47.667 kg) and marketable yield (42.530 and 43.633 kg) per plot in two seasons, respectively. Calcium chloride in gel formula ranked second-order insignificant differences compared to potassium silicate treatment. Copperal Max treatment ranked in the third order in terms of the total and marketable yield, while calcium citrate in gel formula ranked in the fourth-order followed by the potassium sulfate in a gel formula, finally the control treatment recorded the lowest total and marketable yield. Potassium silicate produced the lowest unmarketable yield (2.950 and 4.030 kg) of potato tubers in both seasons, respectively, without significant differences compared to calcium chloride, which produced 3.777 and 4.680 kg as unmarketable yield. The treatment of potassium sulfate came in the second order in terms of reducing the unmarketable yield without significant differences compared to the treatments of calcium citrate and Copperal Max. The positive effect of potassium silicate and calcium chloride treatments on total and marketable yield may be due to increasing the uptake of N, P and K by these plants as shown in Table 3, which improved of vegetative growth characteristics as shown in Table 2. This resulted in more stimulation of photosynthesis and metabolic processes of organic compounds in the plant that transport from the leaves to accumulate in the tubers, thus increase the weight and quality of potato tubers. These results are confirmed by Salim *et al.*, (2014) and Talebi *et al.* (2015), stated that potassium silicate can help to grow plants more resistant to fungal diseases and improve environmental stress tolerance as well as increase crop productivity. This finding is also agrees with Ozgen and Palta (2004) and El-Mougy and Abdel-Kader (2009) suggested that application of calcium chloride on potato plants resulted in greater resistance of the plant against early blight and decreased potato tuber internal defects, led to an increase in weight of tubers and marketable yield.

Table (4): Effect of foliar spraying with potassium and calcium compounds in gel formula on yield component of potato during 2018/2019 and 2019/ 2020 seasons

Treatments	Total yield kg/plot (12.8 m^2)		Marketable yield kg/plot (12.8 m^2)		Unmarketable yield kg/plot (12.8 m^2)	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
K sulphate	36.713 d	38.877 d	30.157 c	31.830 c	6.557 b	7.047 b
K silicate	45.483 a	47.667 a	42.530 a	43.633 a	2.950 c	4.030 c
Ca chloride	44.417 ab	46.460 ab	40.640 a	41.777 a	3.777 c	4.680 c
Ca citrate	40.320 c	41.853 c	32.720 c	33.940 c	7.600 b	7.913 b
Copperal Max	42.497 b	44.933 b	35.687 b	37.193 b	6.810 b	7.733 b
Control	29.120 e	29.760 e	19.217 d	19.770 d	9.900 a	9.990 a

In column means followed by the same letters are not statistically different at ($p \leq 0.05$) level according to Duncan's multiple range test.
Copperal Max = Copper sulphate as a positive control
Control = water as a negative control

Tuber properties at harvest

All K and Ca compounds in gel form applied as foliar spraying, as well as the Copperal Max treatment, increased the firmness, percent of TSS and dry matter in potato tubers compared to control treatment (Table 5). Treatments of potassium silicate and calcium chloride recorded the highest firmness of tubers in both seasons. The increment in tuber firmness with potassium silicate treatment may be caused by the deposition of silicon in the cell walls, which increases the strength and stiffness of cell walls (Jayawardana *et al.,* 2014; Khan *et al.,* 2017). While improving the firmness of the tuber with calcium chloride may be due to integrating of calcium with pectic acid to form calcium pectate in the cell walls, which is a useful compound for maintaining the structure of the tubers (Siddiqui and Bangerth, 1995). In this respect, Saure (2005) reported that calcium may prevent physiological disorders attributed to its deficiency by stabilizing cell membranes. Treatments of potassium silicate and potassium sulphate recorded the highest percentage of TSS and dry matter in potato tubers in both seasons. This meant that potassium applications had a positive correlation with TSS and dry matter. These results might be due to the presence of potassium in these compounds which plays an essential role in promoting photosynthesis products and transporting them from the leaves to the tubers (Ebert, 2009; Marschner, 2012).

Table (5): Effect of foliar spraying with potassium and calcium compounds in gel formula on tuber firmness, TSS and dry matter contents of potato tubers during 2018/2019 and 2019/ 2020 seasons

Treatments	Firmness (kg/cm^2)		% TSS		% Dry matter	
	1st season	2nd season	1st season	2nd season	1st season	2nd season
K sulphate	7.500 b	7.340 bc	7.267 a	7.097 a	22.843 a	22.873 a
K silicate	7.977 a	7.847 a	7.367 a	7.177 a	22.927 a	22.980 a
Ca chloride	7.907 a	7.817 a	6.467 b	6.197 b	22.517 ab	22.547 ab
Ca citrate	7.683 ab	7.603 ab	6.433 b	6.187 b	22.500 ab	22.530 ab
Copperal Max	7.457 b	7.297 bc	6.433 b	6.163 b	22.540 ab	22.560 ab
Control	7.407 c	7.257 c	6.300 b	6.170 b	22.063 b	22.177 b

In column means followed by the same letters are not statistically different at ($p \leq 0.05$) level according to Duncan's multiple range test.
Copperal Max = Copper sulphate as a positive control
Control = water as a negative control

Tubers shelf life

Data presented in Table (6) shown the effect of spraying potato plants with K and Ca compounds in gel formula on weight loss and decay of potato tubers after storage for two months on the shelf. All K and Ca compounds in a gel formula, as well as the Copperal Max treatment, reduced weight loss in tubers compared to control treatment. Application of Ca chloride and K silicate gave the lowest weight loss and decay percentage of potato tubers. The reduction of weight loss in tubers associated with the treatments of calcium chloride and potassium silicate can be attributed to the effect of these treatments on increasing the hardness of the cell walls, which reduces the loss of water from the cells and consequently reduces weight loss. These results were confirmed by Palta (2010) who explained that calcium reduces weight loss of tubers by developing the membranes and strengthening cell walls for skin layer, thereby reducing water evaporation. These results were also corroborated by Imas (1999), who reported that potassium silicate helps in slowing down senescence and reducing the physiological disorders during storage, thus increasing shelf life of potato tubers and reducing post-harvest weight losses from the tubers. Concerning the reduction of decay in potato tuber using calcium chloride and potassium silicate, it can be explained by the effect of calcium and silicon on increasing the hardness of cell walls for tubers, which reduces the ability of pathogens causing decay to penetrate tuber tissues, thus reducing the percentage of decay in tubers. These results were corroborated by Conway *et al.* (1992) and Miles *et al.* (2009), who indicated that calcium plays a role in defense against postharvest pathogens by increasing the hardness of cell walls, making them more resistant to deleterious enzymes produced by fungi and also delaying decay of tubers. These results were confirmed by Van Bockhaven *et al.* (2013) and Sakr (2016). They confirmed the role of silicon in increasing the ability of fungal diseases control.

Table (6): Effect of foliar spraying with potassium and calcium compounds in gel formula on weight loss and decay of potato tubers after stored for two months on a shelf during 2018/2019 and 2019/ 2020 seasons

Treatments	% Weight loss		% Decay	
	1st season	2nd season	1st season	2nd season
K sulphate	14.367 b	7.367 b	5.733 b	4.200 b
K silicate	7.233 d	5.200 d	2.400 d	1.117 d
Ca chloride	6.733 d	4.333 d	2.200 d	1.063 d
Ca citrate	11.167 c	6.400 c	4.500 bc	2.600 c
Copperal Max	10.033 c	6.433 c	4.067 c	2.667 c
Control	20.467 a	17.733 a	10.400 a	8.833 a

In column means followed by the same letters are not statistically different at ($p \leq 0.05$) level according to Duncan's multiple range test.
Copperal Max = Copper sulphate as a positive control
Control = water as a negative control

CONCLUSION

In conclusion, application of potassium silicate and calcium chloride in gel formula reduced the disease incidence and severity of early blight, improved plant growth, crop yield and quality of potato tubers, as well as decreased the weight loss and decay of tubers stored on the shelf for two months.

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كفاءة مركبات البوتاسيوم والكالسيوم فى تركيبة الجل على مكافحة اللفحة المبكرة وتحسين إنتاجية نباتات البطاطس

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تم تقييم كفاءة الرش الورقي بكبريتات البوتاسيوم ، سيليكات البوتاسيوم ، كلوريد الكالسيوم وسيترات الكالسيوم التي تم تركيبها فى صورة جل على مكافحة مرض اللفحة المبكرة الناتج عن الفطر *Alternaria solani* و تحسين النمو وجودة انتاجية البطاطس صنف ليدى روزيتا. أجريت تجربة حقلية خلال الموسمين المتتاليين 2019/2018 و 2020/2019. تمت مقارنة بين الرش بمركبات البوتاسيوم و الكالسيوم و الرش بمركب كوبرال ماكس (8% نحاس كعنصر مقارنة ايجابى) و الماء كمعاملة مقارنة. تم رش جميع المعالملات مرتين بعد 45 و 60 يومًا من الزراعة. أثبتت النتائج أن جميع معاملات الرش الورقي أدت بشكل كبيرالى الخفض من نسبة حدوث وشدة مرض اللفحة المبكرة وزيادة النمو الخضري ومحتوى العناصر الغذائية (N و P و K) لنباتات البطاطس وكذلك زيادة المحصول وجودة درنات البطاطس مقارنة بالنباتات غير المعاملة. أقل نسبة شدة مرضية تم تسجيلها عند استخدام مركب كوبرال ماكس (9 و 11.05 ٪) ، يليها سيليكات البوتاسيوم (9.95 و 12.77٪) وكلوريد الكالسيوم (9.66 و 12.92٪)، أخيرًا سجلت المقارنة غير المعاملة أعلى شدة للمرض (22.07 و 26.71٪) خلال الموسم الاول و الثانى على التوالي. تفوق كلا من سيليكات البوتاسيوم وكلوريد الكالسيوم في تركيبة الجل على المعاملات الأخرى في زيادة المحصول الكلي والقابل للتسويق لدرنات البطاطس، وكذلك في تقليل فقدان الوزن وتعفن الدرنات المخزنة على الرف. تشير هذه النتائج إلى أن أحد البدائل الرئيسية في مكافحة اللفحة المبكرة للبطاطس هو استخدام سيليكات البوتاسيوم أو كلوريد الكالسيوم.