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Research Article
Green Chemicals for Controlling Soil-Borne Fungi Attacking Potato Plants and Produce Quality Tubers

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Abstract

Background and Objectives: Potato (*Solanum tuberosum* L.) established as the fourth main food crop worldwide. Based upon the accumulated data, the objective of this research was planned to study the possible effect of using antioxidants or formulated antioxidant (GAWDA®) on accelerating systemic acquired resistance in potato plants to overcome colonization and invasion of the common pathogenic fungi attacking the plants and tubers. This approach, if succeeded, it may be recommended to the potato growers as an innovative tactic to produce higher yield and quality tubers. **Methodology:** Potato tubers raised from wilted plants, grown in different locations presenting Dakahlia Governorate of Egypt were collected to isolate the common phytopathogenic fungi. *In vitro* studies were carried out to select the efficient concentration of the antioxidants tests for reducing the growth of the target fungi. *In vivo* studies were applied in the field plots at Mansoura University Campus. The growth parameters as well as the tubers weight and their quality characters were recorded. Data was statistically analyzed using CoStat 6.311 software of analysis of variance. The means were compared using least significant difference (LSD) at $p \leq 0.05$ as outlined by Duncan. **Results:** Soaking tubers in 3.5 g L^{-1} of GAWDA® formulation for half an hour before planting followed by three times of spraying with the same concentration started on 30 days old plants followed by 15 days interval spray declined the diseases incidence and increased their production. **Conclusion:** Results address a strong correlation between the enhancing systemic acquired resistances of potato plants by green chemicals (Antioxidants) and controlling the soil-borne fungi attacking potato plants to produce quality tubers and higher yield.

Key words: Green chemicals, antioxidants, potato production, quality tubers, Fusarium wilt, disease management, GAWDA® formulation, systemic acquired resistance

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Potato (*Solanum tuberosum* L.) established as the fourth main food crop worldwide. It is a highly specialized business in 245 countries[1]. The potential yield of potato is determined by 18 specific factories affecting yield and quality including: Pests, diseases and weeds[2]. As Egypt a unique growing area for potato due to its wide range of growing condition, it is at a high risk of diseases attack. So that understanding of basic potato physiology and characteristics would help managing the diseases incidence including, Rhizoctonia canker, black dot, potato early dying, Verticillium wilt, common scab, powdery scab, pink rot, leak, black dot, black scurf and Fusarium dry rot[3]. Despite, nearly 40 soil-borne pathogens significantly affect the potato growth causing outbreak in diseases incidence[4,5]. In this context, a case study by Gashgari and Gherbawy[6] showed that both *Fusarium* and *Rhizoctonia* species attack the plants and their tubers resulting in a significant damage in forms of wilting or/and tuber dry rot.

However, Rhizoctonia disease, caused by *Rhizoctonia solani* (Kühn), is the most serious disease of potato especially in the cool regions of the world[7,8] and the possibility of yield loss nearly 30%[9].

Fusarium dry rot of potato is a devastating postharvest disease worldwide. It is caused by several *Fusarium* species[10-13]. The symptoms are usually shown as internal light to dark brown or blank rot[14,15]. Their incidence is common in most types of soil where potatoes are grown. Its species have potential to survive in the soil for some years and show their impact as a devastating postharvest disease[10,11]. Loss associated with the dry rot was estimated by 25-60%[16,11]. Other studies showed that crop losses attributed to this disease in England has been estimated by 95%[14,15].

Since the commercially grown potato cultivars are resistant to dry rot in North America[17], the disease has been managed primarily by reducing tuber bruising, providing conditions for rapid wound healing[11,18] as well as by applying the fungicides.

The black scarf disease of potato caused by *Rhizoctonia solani* Kühn[19-21] shows different symptoms on the tubers including malformed tubers, increased proportion of small and overlarge tubers which reduce their economic value especially when sclerotia on the tubers are present[22-24]. This disease reveals nearly 30% loss in potato production[23].

Application of green chemicals of potential to control potato diseases: A predictive modeling for using friendly environmental chemicals (Green Chemicals) were applied on peanut[25], cotton[26], cucumber[27] and broad bean[28] resulting in quality seeds and high yield. Application of these chemical on potato was taken in consideration in the ongoing project.

This trend of using the green chemicals for controlling plant diseases was shown by others i.e.: (Halliwell and Gutteridge[29], Olivier and Loria[30], Olivier *et al.*[31], Hervieux *et al.*[32] and Mecteau *et al.*[33].

Salicylic acid, as a green chemical[34] was involved in controlling the damage caused by a number of pathogens including bacteria, fungi and viruses due to its effects in improving the plant systemic acquired resistance[35].

It was also reported that citric acid (CA) are used to improve the growth and yield of a number of plants. In this respect, Abd-Allah *et al.*[36], indicated that plant height, yield and its components as well as protein content in bean, pea and faba bean increased as a result of citric acid application. Sheteawi[37], stated that a mixture of ascorbic and citric acids promote the antioxidant defense system, rather than solitary effects of each. Fawy and Atyia[38], show that yield of wheat increased with increasing foliar application rates of citric acid ranged from 100-300 ppm. Maleki *et al.*[39] revealed that foliar spray of citric acid significantly increased shoot fresh weight, shoot dry weight, root fresh weight and root dry weight of sweet basil.

So far, the objective of this research was planned to study the possible effect of using green chemicals in forms of antioxidants or formulated antioxidant (GAWDA®) for managing the two common fungi attacking potato in Egypt along with possible thrives yield.

In this regard, Egypt export nearly 351,000 t of potato to European countries in 2016/2017 and the ongoing project may meets the standard of quality for fresh fruit and vegetables recommended by Economic Commission for Europe FFV-52, 2011 Edition. Further, maximizing the production of tubers is the 2nd approach of the project. On the other, hand, the impact of using friendly environmental chemicals on potato may minimize the application of hazards chemicals used for controlling such diseases, save the environment clean and improve the production of higher quality.

MATERIALS AND METHODS

Isolation and identification: Potato tubers raised from wilted plants grown in different locations presenting Dakahlia Governorate of Egypt (Kotama-Batra-Altawila) were collected to isolate the common phytopathogenic fungi and this study was carried out at the Seed Pathology Lab, Department of

Plant Pathology, Mansoura University, Egypt during three successive seasons (2013-2016), while tubers were thoroughly rinsed in tap water and small pieces of the vascular tissues were surface sterilized for 1 min in 0.5% sodium hypochlorite solution, then washed 3 times in sterilized distilled water and distributed onto moist blotter papers containing petri-dishes. Plates were incubated at 22°C for 7 days in the dark. The growing fungi were identified depends on the morphological characteristics of the growth, conidia, growth ratio, colony pigment, size and shape of conidia and other morphological structures[40-45].

Pathogenicity test: Pots of 30 cm diameter each, filled with clay sandy soil at a rate of 5 kg/pot were inculcated with the fungus suspension prepared by growing each isolate in glass bottles containing sterilized sorghum grain medium. The autoclaved medium consisted 100 g of sorghum seeds mixed with sand at a ratio of 2:1 and moist with water. Cultures were incubated at 25±2°C for 15 days, while soil was infested by mixing the inoculum of each fungus in the upper 5 cm layer of the soil surface at a rate of 2% (w/w) for *R. solani* and 4% (w/w) for each of *F. oxysporum* and *F. solani*. They irrigated every 2 days for a period of a week to insure the fungal adaptation. Two cuts of healthy looking tubers from a previously tested lot were sown in each pot. Five pots presented 1 replicate of each fungus, while 5 uninfested pots were used as a check. The treatments were irrigated when necessary. All pots were kept in a net house under natural conditions while the temperature was fluctuated between 20-30°C and the humidity between 55-75%.

Antioxidants: The following antioxidants were selected to test their possible effect on retarding the growth of the pathogenic fungi under investigation viz.: Salicylic acid, tartaric acid, citric acid and GAWDA® formulation (Tri-Sodium Orthophosphate 1 mM+Tartaric acid 2 mM+Hydroxyquinoline 1 mM+Calcium Chloride 6 mM+Magnesium Chloride 5 mM+Calcium Borate 5 mM).

Effect of antioxidants on the fungal linear growth: Salicylic acid, tartaric acid, citric acid and GAWDA® formulation each were dissolved in distilled water to obtain concentrations of (0.5,1 and 1.5 g L^{-1}), (2.5, 3 and 3.5 g L^{-1}), (2, 2.5 and 3 g L^{-1}) and (2.5, 3 and 3.5 g L^{-1}), respectively. Disks of each fungal growth (0.6 cm diameter) from 7 days old cultures were transferred onto the centers of PDA plates supplemented with the different concentrations of selected antioxidants. The possible inhibitory effects of these antioxidants on the tested fungi were recorded. Three replicates were used to present one treatment. All cultures were incubated at 25±2°C for 7 days in the dark. Linear growth of each fungus was measured and recorded.

Source of tubers: Tubers of potato cv. Spunta produced by HZPC Holland B.V. were used in the research.

Pot experiments: Four hundred forty four plastic pots (30 cm in diameter), filled with clay sandy soil at a rate of 5 kg/pot were inoculated with the tested fungi prepared by growing each fungal isolate the same way as indicated before in pathogenicity section. Pieces of potato tubers were separately soaked for few minutes in one of the following antioxidants: Salicylic acid at the concentration of (0.5, 1.0 and 1.5 g L^{-1}), tartaric acid at the concentration of (2.5, 3 and 3.5 g L^{-1}), citric acid at the concentration of (2, 2.5 and 3 g L^{-1}) and GAWDA® at the concentration of (2.5, 3 and 3.5 g L^{-1}). Two tuber pieces of 3 different treatments were sown in each pot while three pots were used as one replicate. Three pots of untreated seeds were used as a check. All the other agricultural practices were carried out. Assessing the occurrence of damping-off were recorded in 15, 25 and 35 days old plants. Chlorophyll a, b, total chlorophyll, carotenoids and total phenols were recorded in 30 days old plants. On 90 and 120 old plants, the growth parameters including plant weight (g), plant height (cm), shoot weight (g), shoot length (cm), root weight (g), root length (cm) as well as yield and yield components i.e., weight of tubers/plant and yield/fed were recorded.

Field application: A small experimental plot area at the campus of Mansoura University was used to carry out the field application in two successive seasons (2014-2015). Data was subjected to split-split plot design of 6 replicates. Pieces of potato tubers cv. Spunta were sown in the 1st of February, in ridges of 200 cm in hills spaced 25 cm apart on one side of the ridge. Percentage of damping-off occurrence was recorded on 15, 25 and 35 days old plants.

Physiological characters

Assay of photosynthetic pigments in plant leaves: Third upper leaves of a number of potato plants were collected to determine the quantities of the photosynthetic pigments (mg g^{-1} fresh weight) while the method described by Mackinney[46] was followed. Ten mL methanol 90% was used to extract of the pigments of 0.05g fresh leaves. The remaining tissues were thrown out while the extracted pigment was calorimetrically measured at wave length of 452.5, 650 and

665 nm using the colorimeter (SPEKOL11). The total contents of chlorophyll a, b and carotenoids in each treatment were calculated as mg/1 g.

Total phenols content: As shown above a number of the 3rd upper leaves were used to assess their contents of total phenols using Foline-Ciocalteau reagent[47]. Samples of 2 g/each homogenized in 80% ethanol were spin down using a cooling centrifuge rotates at 10000 rpm for 15 min. The residue was re-extracted twice in 80% ethanol and all supernatants were collected, transferred to evaporating dishes at room temperature and kept until a complete dryness. The solid residue was dissolved in 5 mL distilled water while 100 µL of the extract was rediluted in 3 mL of distilled water followed by adding 0.5 mL of Foline-Ciocalteau reagent and kept for 3 min followed by adding 2 mL of 20% sodium carbonate, mixed thoroughly and left for 1 h. The formed color was measured photometrically at 650 nm length while Catechol presented the standard solution. Data were expressed as milligram (mg) catechol/100 g of fresh weight.

Total soluble solids (TSS): The total soluble solids was estimated by using Refractometer (ATAGO-MANUAL, Japan). The method was described by Ranganna[48]. A drop of potato juice was placed on the prism of the refractometer and the percentage of total soluble solids was recorded.

Estimation of starch: The method decreased by Thayumanavan and Sadasivam[49] was followed, while (0.1-0.5 g) of dry tissues was homogenized in 80% ethanol to remove the soluble sugar, centrifuged at 2000 rpm and the residue was retained. The residue washed thoroughly in 80% ethanol until no color was shown when the anthrone reagent was added. The residue was dried in a water bath followed by its dissolving in 5.0 mL of cooled distilled water at 0°C, then 6.5 mL of 52% perchloric acid were added at 0°C and maintained at room temperature for 20 min and centrifuged at 200 rpm. The supernatant was kept while the extraction was repeated using fresh perchloric acid, centrifuged again for 5 min and the supernatant was refrigerated. The volume was completed to 100 mL using distilled water. A size of 0.1 mL of the supernatant was pipetted and completed to one mL using distilled water. Four mililiter of the anthrone reagent were added to each sample. The mixture was incubated for 8 min. in boiled water, followed by cooling it down rapidly in ice. The intensity of the form green color was measured spectrophotometrically at 630 nm. Starch content was calculated with the aid of the standard curve of glucose.

Total K: Samples of dried potato at 70°C were grinding, digested in sulfuric acid and kept overnight. The mixture then heated at 350°C until complete digestion. The digested samples then mixed with a combination of sulfuric and perchloric acids until no color was shown then diluted with distilled water and completed to 100 mL. The dilute then was subjected to the flame photometer and the reading was recorded[50].

Total carotenoids: Carotenoids were determined spectrophotometrically followed the method of Horvath *et al.*[51], while 5 g of fresh tuber tissue was put in a cold porcelain mortar containing some quartz sand and several of $MgCO_3$ powder to reduce acidification. Tubers were grained in 80% acetone for 5 min, then transferred to centrifuge tubes. The volume of the extract was completed with acetone up to 8 mL and mixed well. The tubes sealed with parafilm to retard acetone evaporation. The samples were centrifuged for 3 min at 1000 rpm. After centrifugation the formed color was directly measured spectrophotometrically at a wave length of 480 nm against a blank of pure 80% aqueous acetone. The concentration of carotenoids was calculated as µg/mL using the following equation: Carotenoids = 5.02 E480 = mg/mL.

Statistical analysis: The collected data were statistically analyzed using CoStat 6.311[52] software of analysis of variance[53]. The means were compared using least significant difference (LSD) at $p \leq 0.05$ as outlined by Duncan[54].

RESULTS

Pathogenicity test: Results in Table 1 illustrate the degrees of variance in pre, post-damping-off and stunted seedlings caused by *F. oxysporum* (3 isolates), *F. solani* (2 isolates) and *R. solani* (2 isolates). *F. oxysporum* (3 isolate) shows its syndrome at percentage of 20, 20 and 30%, respectively, *F. solani* (isolate 1) at 40, 20 and 20%, respectively, *R. solani* (isolate 2) at 30, 28 and 28%, respectively while the check presented the fungal syndrome at 10, 0 and 10%, respectively. The percentage of survived plants grown under the stress of *F. oxysporum* (isolate 3) was 30 and 20% under the stress of *F. solani* (1 isolate) while it was 14% under the stress of *R. solani* (2 isolate). In the check treatment, the survived plants reached 80% of the total growing plants.

Table 1: Pre and post emergence damping off and stunted seedlings in soil infested with *F. oxysporum*, *F. solani* and *R. solani*

Fungi	Pre-emergence	Post-emergence	Stunting seedlings	Survival seedlings
Fusarium solani 1	40[a]	20[a]	20[ab]	20[d]
Fusarium solani 2	20[bc]	20[a]	20[ab]	40[bc]
Rhizoctonia solani 1	30[ab]	20[a]	20[ab]	30[cd]
Rhizoctonia solani 2	30[ab]	28[a]	28[a]	14[d]
Fusarium oxysporum 1	20[bc]	10[b]	20[ab]	50[b]
Fusarium oxysporum 2	20[bc]	10[b]	30[a]	40[bc]
Fusarium oxysporum 3	20[bc]	20[a]	30[a]	30[cd]
Control	10[c]	0[c]	10[b]	80[a]

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05

Table 2: Effect of different concentrations of the antioxidants on linear growth of the tested fungi isolated from potato plants

Treatments	Concentrations	*Fusarium oxysporum*	*Fusarium solani*	*Rhizoctonia solani*
GAWDA®	2	6.47[c]	3.63[de]	2.13[fg]
	2.5	4.43[f]	2.50[f]	1.23[h]
	3	4.33[f]	1.07[g]	0.00[j]
	3.5	0.00[i]	0.00[h]	0.00[j]
Salicylic acid	0.5	4.43[f]	3.17[ef]	2.47[fg]
	1	1.27[h]	0.90[g]	0.67[i]
	1.5	0.00[i]	0.00[h]	0.00[j]
	2	0.00[i]	0.00[h]	0.00[j]
Citric acid	2	5.03[e]	7.00[b]	3.57[e]
	2.5	4.37[f]	6.00[c]	3.10[e]
	3	1.87[g]	4.33[d]	2.53[f]
	3.5	0.00[i]	2.50[f]	0.00[j]
Tartaric acid	2	8.40[b]	4.33[d]	6.93[b]
	2.5	6.57[c]	3.77[de]	5.37[c]
	3	5.93[d]	3.10[ef]	4.10[d]
	3.5	4.53[ef]	1.53[g]	2.00[g]
Check		9.00[a]	9.00[a]	9.00[a]

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05

Table 3: Effect of antioxidants and methods of application on retarding damping-off syndromes on potato plants under the natural condition

	Damping-off (%)			
Treatments	Pre-emergence	Post-emergence	Stunt seedlings	Normal seedlings
Antioxidants				
GAWDA®	6.30[e]	5.07[e]	7.74[e]	80.74[a]
Tartaric	9.60[d]	7.78[d]	14.15[d]	68.33[b]
Citric	10.89[c]	8.89[c]	16.26[c]	63.96[c]
Salicylic	12.41[b]	10.11[b]	18.41[b]	59.00[d]
Check	19.22[a]	14.67[a]	26.67[a]	39.70[e]
Concentrations				
1	13.49[a]	10.56[a]	18.64[a]	57.22[c]
2	11.82[b]	9.40[b]	16.58[b]	62.13[b]
3	9.73[c]	7.96[c]	14.71[c]	57.22[a]
Methods				
So	14.44[a]	10.24[a]	18.04[a]	57.22[c]
Sp	10.96[b]	9.27[b]	16.20[b]	63.71[b]
So+SP	9.64[c]	8.40[c]	15.69[c]	66.11[a]

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Effect of the selective antioxidants on the fungal growth (*in vitro* study): Data in Table 2 show that salicylic acid at the concentrations of (0.5, 1, 1.5 and 2 g L^{-1}), tartaric acid, citric acid and GAWDA® formulation at concentrations (2, 2.5, 3 and 3.5 g L^{-1}) significantly reduced the *in vitro* growth of *F. oxysporum*, *F. solani* and *R. solani* isolated from potato tubers. It was also noticed that the reduction in the fungal growth was correlated to the increase in concentration of the tested antioxidants.

Effect of antioxidants on retarding damping-off syndromes on potato plants grown under natural condition: Data in Table 3 and 4 show that soaking tubers in 3.5 g L^{-1} of GAWDA® formulation for half an hour before planting followed by

Table 4: Alliance between the selective antioxidants and methods of application for retarding damping-off syndromes of potato plants under natural conditions

Treatments	Damping-off (%)		Stunt seedlings	Normal seedlings
	Pre-emergence	Post-emergence		
GAWDA®				
2.5 (g L^{-1})				
So	10.000^{i-m}	7.333^{f-k}	12.667^{f-j}	69.667^{e-k}
Sp	9.000^{j-n}	8.000^{e-j}	15.000^{e-h}	68.333^{f-l}
So+Sp	5.000^{o-q}	5.000^{j-l}	7.000^{j-l}	82.000^{b-e}
3.0 (g L^{-1})				
So	7.667^{k-o}	5.333^{j-l}	10.000^{h-l}	77.000^{b-g}
Sp	6.667^{m-p}	4.667^{j-l}	7.333^{j-l}	81.333^{b-e}
So+Sp	6.000^{n-p}	6.000^{h-l}	5.333^{lm}	82.667^{b-d}
3.5 (g L^{-1})				
So	8.667^{j-n}	6.000^{h-l}	6.000^{l}	79.000^{b-f}
Sp	3.667^{pq}	3.333^{lm}	6.333^{kl}	86.667^{b}
So+Sp	0.000^{r}	0.000^{m}	0.000^{m}	100.000^{a}
Tartaric acid				
2.5 (g L^{-1})				
So	13.000^{e-i}	10.000^{e-i}	18.000^{c-f}	58.667^{k-q}
Sp	12.000^{f-j}	8.000^{e-j}	14.000^{f-h}	65.667^{g-n}
So+Sp	10.000^{i-m}	9.000^{d-i}	16.000^{d-g}	64.667^{g-o}
3.0 (g L^{-1})				
So	12.000^{f-j}	9.000^{d-i}	16.000^{d-g}	63.333^{h-o}
Sp	9.000^{j-n}	8.000^{e-j}	14.000^{f-h}	68.667^{f-l}
So+Sp	8.000^{k-o}	7.000^{g-l}	12.000^{g-k}	72.333^{c-i}
3.5 (g L^{-1})				
So	13.667^{d-h}	9.000^{d-i}	16.000^{d-g}	61.667^{i-p}
Sp	7.000^{l-p}	6.667^{g-l}	11.000^{g-l}	75.333^{b-h}
So+Sp	1.667^{qr}	3.333^{lm}	10.333^{g-l}	84.667^{bc}
Citric acid				
2.0 (g L^{-1})				
So	15.000^{e-i}	12.000^{b-d}	20.667^{c-e}	52.667^{o-s}
Sp	13.667^{d-h}	9.333^{c-h}	16.000^{d-g}	61.333^{i-p}
So+Sp	11.667^{g-j}	10.000^{e-i}	18.333^{c-f}	59.667^{j-p}
2.5 (g L^{-1})				
So	13.000^{e-i}	10.000^{e-i}	18.333^{c-f}	58.333^{k-q}
Sp	10.333^{h-l}	9.000^{d-i}	16.000^{d-g}	64.333^{h-o}
So+Sp	9.333^{j-n}	8.000^{e-j}	14.000^{f-h}	68.667^{f-l}
3.0 (g L^{-1})				
So	15.333^{c-f}	10.000^{e-i}	18.000^{c-f}	56.333^{l-r}
Sp	7.667^{k-o}	8.000^{e-j}	13.000^{f-i}	72.000^{d-j}
So+Sp	2.000^{qr}	3.667^{k-m}	12.000^{g-k}	82.333^{b-d}
Salicylic acid				
0.5 (g L^{-1})				
So	17.000^{b-d}	13.000^{a-c}	23.333^{bc}	46.333^{q-s}
Sp	15.333^{c-f}	11.000^{b-f}	18.000^{c-f}	55.667^{m-r}
So+Sp	13.000^{e-i}	11.667^{b-e}	21.000^{b-d}	54.333^{n-s}
1 (g L^{-1})				
So	15.000^{e-i}	11.000^{b-f}	21.000^{b-d}	52.667^{o-s}
Sp	12.000^{f-j}	10.000^{e-i}	18.333^{c-f}	59.333^{k-p}
So+Sp	10.667^{h-k}	9.000^{d-i}	16.000^{d-g}	64.333^{h-o}
1.5 (g L^{-1})				
So	17.333^{bc}	12.000^{b-d}	20.667^{c-e}	50.333^{p-s}
Sp	9.000^{j-n}	9.000^{d-i}	14.000^{f-h}	68.000^{f-m}
So+Sp	2.333^{qr}	4.333^{j-l}	13.333^{f-h}	80.000^{b-f}
Check				
So	19.667^{ab}	13.000^{a-c}	23.000^{bc}	44.333^{r-t}
Sp	16.333^{b-e}	14.667^{ab}	26.667^{ab}	43.000st
So+Sp	21.667^{a}	16.333^{a}	30.000^{a}	32.000^{t}

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Table 5: Effect of antioxidants along with the methods of application on growth parameters of potato plants grown under the natural condition

Treatments	Plant height (cm)	Root length (cm)	Shoot Length (cm)	Plant weight (g)	Root weight (g)	Shoot weight (g)
Antioxidants						
GAWDA®	122.37[a]	23.07[a]	99.48[a]	1398[a]	37.30[a]	463.44[a]
Tartaric	113.00[b]	21.30[b]	91.67[b]	1300[b]	34.67[b]	431.04[b]
Citric	105.44[c]	19.85[c]	85.56[c]	1213[c]	32.33[c]	402.04[c]
Salicylic	79.85[d]	15.00[d]	64.89[d]	918[d]	24.48[d]	304.44[d]
Check	72.63[e]	13.70[e]	58.74[e]	834[e]	22.15[e]	276.56[e]
Concentrations						
1	93.64[c]	17.60[c]	76.02[c]	1076[c]	28.67[c]	356.89[c]
2	98.13[b]	18.51[b]	79.60[b]	1128[b]	30.07[b]	374.09[b]
3	104.20[a]	19.64[a]	84.58[a]	1193[a]	31.82[a]	395.53[a]
Methods						
So	97.02[b]	18.29[b]	78.87[b]	1116[b]	29.71[b]	369.93[b]
Sp	93.33[c]	17.58[c]	75.69[c]	1073[c]	28.64[c]	355.89[c]
So+SP	105.62[a]	19.89[a]	85.64[a]	1209[a]	32.20[a]	400.69[a]

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

3 times of spraying with the same concentration started on 30 days old plants and 15 days interval spray showed a positive effect on decreasing the pre, post-emergence damping-off and stunted seedlings as well as scale up the percentage of normal seedlings in compare to the check treatment.

Also, it was found that GAWDA® formulation at the concentration (3.5 g L^{-1}) significantly decreased pre, post-emergence damping-off and stunted seedlings to record 6.30, 5.07 and 7.74%, respectively compared to the check, which recorded 19.22, 14.67 and 26.67%, respectively, On the other hand, an increase in normal seedlings was observed to record 80.74%, respectively when compared to the check (39.70% recovery).

The combination of soaking+spraying GAWDA® formulation on potato plants significantly decreased pre, post-emergence damping-off and stunted seedlings to record 9.64, 8.40 and 15.69%, respectively while normal seedlings recorded 66.11%.

The formulation at concentration of 3.5 g L^{-1} in form of soaking+spraying application inhibited the pre, post-emergence damping-off and stunted seedlings down to zero level, compared with the check, which recorded 21.67, 16.33 and 30.00%, respectively. On the other hand, an increase in normal seedlings was observed to record 100%, respectively while the check recorded was 32.00%.

Effect of the selective antioxidants on the growth parameters and yield components of potato plants: Data in Table 5-8 illustrate the effect of the selected antioxidants on growth parameters and yield components i.e. plant height, root length, shoot length, plant weight, root weight, shoot weight, weight of tubers/plant and weight of tubers/feddan of potato plants. The application methods were carried out in form of tuber soaking, 3 times of spraying started on 30 days old plants with 15 days interval period and soaking followed by 3 times of spraying started on 30 days old plants with a period of 15 days intervally and showed that GAWDA® formulation at the concentration (3.5 g L^{-1}) significantly increased the plant height, root length, shoot length, plant weight, root weight, shoot weight, weight of tubers/plant and weight of tubers/feddan of potato plants to record 122.37 cm, 23.07 cm and 99.48 cm, 1398 g, 37.30 g, 463.44 g, 897.04 g and 28.767 t/feddan, respectively in compare with other methods, while the non-infected one (check) recorded 72.63cm, 13.70 cm, 85.74 cm, 834 g, 22.15 g, 276.56 g, 535.26 g and 18.398 t/feddan, respectively.

When soaking+spraying treatment of the formulation were applied, a significantly increases in the plant height, root length, shoot length, plant weight, root weight, shoot weight, weight of tubers/plant and weight of tubers/feddan of potato plants were shown to record 105.62 cm, 19.89 cm, 85.64 cm, 1209 g, 32.20 g, 400.69 g, 775.6 g and 27.974 t/fed., respectively.

Data from field plots show that GAWDA® formulation at a concentration of 3.5 g L^{-1} when applied as Soaking+spraying increased growth parameters and yield components i.e. plant height, root length, shoot length, plant weight, root weight, shoot weight, weight of tubers/plant and weight of tubers/feddan to record 142 cm, 26.67 cm, 115 cm, 1550 g, 41.33 g, 514 g, 995.00 g and the calculation presents 20.76 ton/feddan, respectively while the check recorded 84.66 cm, 16 cm, 69 cm, 972 g, 26 g, 322 g, 624.00 g and 15.61 ton/feddan, respectively.

Photosynthetic pigments

Effect of the selected antioxidants on chlorophyll a content of potato plants grown under field conditions: Data presented in Table 9 and 10 show the effect of the selected antioxidants on chlorophyll a content in potato plants. The

Table 6: The of interaction between antioxidants effect and methods of application on growth parameters of potato plants grown under the natural conditions

Treatments	Plant height (cm)	Root length (cm)	Shoot Length (cm)	Plant weight (g)	Root weight (g)	Shoot weight (g)
GAWDA®						
2.5 (g L^{-1})						
So	113^{e-i}	21.33^{c-f}	92.00^{c-f}	1300^{e-i}	34.67^{e-i}	431.00^{e-i}
Sp	95.66^{h-j}	18.00^{g-i}	78.00^{g-j}	1100^{h-k}	29.33^{h-j}	365.00^{h-k}
So+Sp	116.6^{b-f}	22.00^{b-e}	94.67^{b-e}	1340^{b-f}	35.67^{b-f}	444.00^{b-f}
3.0 (g L^{-1})						
So	118.6^{b-e}	22.67^{b-e}	96.67^{b-e}	1367^{a-e}	36.33^{a-e}	453.00^{a-e}
Sp	128^{abc}	24.00^{a-c}	104.00^{a-c}	1470^{a-c}	39.33^{a-c}	487.33^{a-c}
So+Sp	129^{abc}	24.33^{a-c}	105.00^{a-c}	1484^{a-c}	39.67^{a-c}	492.00^{a-c}
3.5 (g L^{-1})						
So	130.3^{ab}	24.67^{ab}	106.00^{ab}	1500^{ab}	40.00^{ab}	497.33^{ab}
Sp	128^{a-c}	24.00^{a-c}	104.00^{a-c}	1470^{a-c}	39.33^{a-c}	487.33^{a-c}
So+Sp	142^{a}	26.67^{a}	115.00^{a}	1550^{a}	41.33^{a}	514.00^{a}
Tartaric acid						
2.5 (g L^{-1})						
So	104.3^{e-h}	19.67^{e-g}	85.00^{e-g}	1200^{e-h}	32.00^{e-h}	398.00^{e-h}
Sp	100^{f-i}	18.67^{f-h}	81.00^{f-i}	1148^{f-j}	30.67^{f-i}	381.00^{f-j}
So+Sp	108.3^{d-h}	20.33^{e-g}	88.00^{d-g}	1247^{d-h}	33.33^{d-h}	413.33^{d-h}
3.0 (g L^{-1})						
So	113^{e-i}	21.33^{c-f}	92.00^{c-f}	1300^{e-i}	34.67^{e-i}	431.00^{e-i}
Sp	99^{g-i}	18.67^{f-h}	80.00^{f-i}	1140^{g-j}	30.33^{g-i}	378.00^{g-j}
So+Sp	124.6^{b-d}	23.67^{a-d}	101.00^{b-d}	1434^{a-d}	38.33^{a-d}	475.67^{a-d}
3.5 (g L^{-1})						
So	130.3^{ab}	24.67^{ab}	106.00^{ab}	1500^{ab}	40.00^{ab}	497.33^{ab}
Sp	108.6^{d-h}	20.33^{e-g}	88.00^{d-g}	1249^{d-h}	33.33^{d-h}	414.00^{d-h}
So+Sp	128.6^{a-c}	24.33^{a-c}	104.00^{a-c}	1480^{a-c}	39.33^{a-c}	491.00^{a-c}
Citric acid						
2.0 (g L^{-1})						
So	96^{h-j}	18.00^{g-i}	78.00^{g-j}	1104^{h-k}	29.33^{h-j}	366.00^{h-k}
Sp	93.33^{h-j}	17.67^{g-i}	76.00^{g-j}	1075^{h-k}	28.67^{h-j}	356.33^{h-k}
So+Sp	108.6^{d-h}	20.33^{e-g}	88.00^{d-g}	1249^{d-h}	33.33^{d-h}	414.00^{d-h}
2.5 (g L^{-1})						
So	104.3^{e-h}	19.67^{e-g}	85.00^{e-g}	1200^{e-h}	32.00^{e-h}	398.00^{e-h}
Sp	104^{e-h}	19.67^{e-g}	84.00^{e-h}	1194^{e-i}	32.00^{e-h}	396.00^{e-i}
So+Sp	110^{d-h}	20.67^{d-g}	89.00^{d-g}	1264^{d-h}	33.67^{d-h}	419.00^{d-h}
3.0 (g L^{-1})						
So	113^{e-i}	21.33^{c-f}	92.00^{c-f}	1300^{e-i}	34.67^{e-i}	431.00^{e-i}
Sp	105^{e-h}	19.67^{e-g}	85.00^{e-g}	1209^{e-h}	32.33^{e-h}	401.00^{e-h}
So+Sp	114.6^{b-g}	21.67^{b-f}	93.00^{b-f}	1318^{b-g}	35.00^{b-g}	437.00^{b-g}
Salicylic acid						
0.5 (g L^{-1})						
So	83.33^{i-m}	15.67^{h-l}	68.00^{i-l}	958^{j-n}	25.67^{i-m}	318.00^{j-n}
Sp	69.66^{l-n}	13.00^{k-n}	56.00^{l-n}	800^{m-o}	21.33^{l-o}	265.00^{m-o}
So+Sp	95.66^{h-j}	18.00^{g-i}	78.00^{g-j}	1100^{h-k}	29.33^{h-j}	365.00^{h-k}
1 (g L^{-1})						
So	63.66^{n}	11.67^{n}	51.67^{n}	730^{o}	19.33^{o}	242.33^{o}
Sp	74^{k-n}	14.00^{j-n}	60.00^{k-n}	850^{l-o}	22.67^{k-o}	282.00^{l-o}
So+Sp	87^{i-k}	16.33^{h-j}	70.67^{h-k}	1000^{i-l}	26.67^{i-k}	331.67^{i-l}
1.5 (g L^{-1})						
So	83.33^{i-m}	15.67^{h-l}	68.00^{i-l}	960^{j-n}	25.67^{i-m}	318.00^{j-n}
Sp	75^{k-n}	14.33^{j-n}	61.00^{k-n}	864^{l-o}	23.00^{k-o}	286.33^{l-o}
So+Sp	87^{i-k}	16.33^{h-j}	70.67^{h-k}	1000^{i-l}	26.67^{i-k}	331.67^{i-l}
Check						
So	65.33^{n}	12.33^{mn}	53.00^{mn}	750^{o}	20.00^{no}	249.00^{o}
Sp	67^{mn}	12.67^{l-n}	54.00^{mn}	771no	20.67^{m-o}	256.00^{no}
So+Sp	84.66^{i-l}	16.00^{h-k}	69.00^{i-l}	972^{j-m}	26.00^{i-l}	322.00^{j-m}

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

treatments were carried out in form of seed soaking followed by 3 times of spraying started on 30 days old plants with 15 days intervals.

It was found that GAWDA® formulation at the concentration (3.5 g L^{-1}) significantly increased the content of chlorophyll a in the leaves of 30, 45, 60 and 75 days old plants

Table 7: Effect of antioxidants along with the methods of application on yield components of potato plants grown under the natural conditions

Treatment	Weight of tuber/plant	Weight of tuber fed
Antioxidants		
GAWDA®	897.04[a]	28767[a]
Tartaric	834.11[b]	25414[b]
Citric	778.11[c]	25003[c]
Salicylic	589.19[d]	24946[d]
Check	535.26[e]	18398[e]
Concentrations		
1	690.71[c]	22995[c]
2	723.93[b]	25039[b]
3	765.58[a]	25482[a]
Methods		
So	715.89[b]	24086[b]
Sp	688.73[c]	21456[c]
So+SP	775.6[a]	27974[a]

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

to record 1.298, 1.579, 1.723 and 1.447 mg g^{-1} fresh weight, respectively. Tartaric acid at the same concentration came after to record 1.253, 1.524, 1.663 and 1.397 mg g^{-1} fresh weight, respectively while Salicylic acid at 1.5 g L^{-1} was the least effective treatment on chlorophyll a content in the plant leaves to record 1.166, 1.418, 1.548 and 1.3 mg g^{-1} fresh weight, respectively while the check recorded 0.952, 1.158, 1.263 and 1.061 mg g^{-1} fresh weight, respectively.

The application of soaking+spraying significantly increased chlorophyll a content in leaves of plant grown under the possible natural infection of *F. oxysporum, F. solani* and *R. solani* in the field plots after 30, 45, 60 and 75 days to record 1.216, 1.480, 1.614 and 1.356 mg g^{-1} fresh weight, respectively.

GAWDA® formulation at concentration of 3.5 g L^{-1} and in form of soaking+spraying significantly increased chlorophyll a content in the infected leaves after 30, 45, 60 and 75 days to record 1.543, 1.878, 2.049 and 1.721 mg g^{-1} fresh weight, respectively. Tartaric acid at the same concentration in form of soaking+spraying came after to record 1.5, 1.826, 1.992 and 1.674 mg g^{-1} fresh weight, respectively compared to the check plants which recorded 0.973, 1.184, 1.292 and 1.085 mg g^{-1} fresh weight, respectively.

Effect of the selected antioxidants on chlorophyll b content of potato plants grown under the natural conditions: Data presented in Table 11 and 12 illustrate the effect of the selected chemicals on chlorophyll b content in potato plants. The treatment was carried out in form of seed soaking, spraying on 30 days old plants and soaking followed by 3 interval times of spraying on the plant leaves at 30, 45, 60 and 75 days and found that GAWDA® formulation at the

Table 8: Interaction between antioxidants effect and methods of application on yield components of potato plants grown under the natural conditions

Treatments	Weight of tuber/plant	Weight of tuber fed
GAWDA®		
2.5 (g L^{-1})		
So	834.00[e-i]	16443[j-m]
Sp	706.00[h-k]	15475[l-p]
So+Sp	860.00[b-f]	16909[e-g]
3.0 (g L^{-1})		
So	877.00[a-e]	18299[c-e]
Sp	943.33[a-c]	17434[f-h]
So+Sp	952.00[a-c]	19943[b]
3.5 (g L^{-1})		
So	962.67[ab]	18532[bc]
Sp	943.33[a-c]	18267[f-h]
So+Sp	995.00[a]	20758[a]
Tartaric acid		
2.5 (g L^{-1})		
So	770.00[e-h]	13292[f-i]
Sp	737.00[f-j]	12509[k-o]
So+Sp	800.00[d-h]	13670[f-h]
3.0 (g L^{-1})		
So	834.00[e-i]	14793[f-i]
Sp	731.67[g-j]	14094[j-n]
So+Sp	920.00[a-d]	16122[e-g]
3.5 (g L^{-1})		
So	962.67[ab]	14981[e-h]
Sp	801.67[d-h]	14767[i-l]
So+Sp	950.00[a-c]	16781[p-r]
Citric acid		
2.0 (g L^{-1})		
So	708.33[h-k]	13765[j-n]
Sp	690.00[h-k]	12955[o-s]
So+Sp	801.67[d-h]	14156[e-h]
2.5 (g L^{-1})		
So	770.00[e-h]	15320[h-j]
Sp	766.00[e-i]	14595[k-n]
So+Sp	811.00[d-h]	16695[p-r]
3.0 (g L^{-1})		
So	834.00[e-i]	15514[f-i]
Sp	776.00[e-h]	15292[f-i]
So+Sp	846.00[b-g]	17378[b-d]
Salicylic acid		
0.5 (g L^{-1})		
So	615.00[j-n]	14710[e-g]
Sp	513.33[m-o]	13844i-k
So+Sp	706.00[h-k]	15127[e-g]
1 (g L^{-1})		
So	468.67[o]	16371[g-i]
Sp	545.33[l-o]	15597[k-o]
So+Sp	642.00[i-l]	17842[b]
1.5 (g L^{-1})		
So	616.00[j-n]	16580[m-r]
Sp	554.33[l-o]	16343[s]
So+Sp	642.00[i-l]	18571[c-e]
Check		
So	481.00[O]	15492[q-s]
Sp	495.00[No]	14913[j-m]
So+Sp	624.00[j-m]	15607[rs]

*Means followed by small and capital letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Table 9: Effect of antioxidants along with the methods of application on chlorophyll a contents of potato plants under the natural conditions

Treatments	Chlorophyll a contents mg g^{-1} fresh weight			
	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
Antioxidants				
GAWDA®	1.298[a]	1.579[a]	1.723[a]	1.447[a]
Tartaric	1.253[b]	1.524[b]	1.663[b]	1.397[b]
Citric	1.213[c]	1.476[c]	1.611[c]	1.353[c]
Salicylic	1.166[d]	1.418[d]	1.548[d]	1.300[d]
Check	0.952[e]	1.158[e]	1.263[e]	1.061[e]
Concentrations				
1	1.042[c]	1.268[c]	1.383[c]	1.162[c]
2	1.170[b]	1.424[b]	1.553[b]	1.305[b]
3	1.317[a]	1.602[a]	1.748[a]	1.468[a]
Methods				
So	1.182[b]	1.438[b]	1.569[b]	1.318[b]
Sp	1.1304[c]	1.376[c]	1.501[c]	1.261[c]
So+SP	1.216[a]	1.480[a]	1.614[a]	1.356[a]

Means followed by small and capital letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

concentration (3.5 g L^{-1}) significantly increased the content of chlorophyll b in the leaves of 30, 45, 60 and 75 days old plants to record 0.655, 0.797, 0.870 and 0.731 mg g^{-1} fresh weight, respectively, Tartaric acid at the same concentration came after to record 0.763, 0.770, 0.840 and 0.706 mg g^{-1} fresh weight, respectively while salicylic acid at 1.5 g L^{-1} was the least effective treatment on chlorophyll b content in plant leaves to record 0.589, 0.716, 0.782 and 0.657 mg g^{-1} fresh weight, respectively compared to the check, which recorded 0.481, 0.585, 0.638 and 0.536 mg g^{-1} fresh weight, respectively.

Application of soaking+spraying significantly increased chlorophyll b content in leaves of plants grown under the possible natural infection of *F. oxysporum, F. solani* and *R. solani* after 30, 45, 60 and 75 days to record 0.614, 0.747, 0.815 and 0.685 mg g^{-1} fresh weight, respectively.

GAWDA® formulation at a concentration of 3.5 g L^{-1} and in form of soaking+spraying significantly increased chlorophyll b content in the infected leaves of 30, 45, 60 and 75 days old plants to record 0.779, 0.948, 1.034 and 0.869 mg g^{-1} fresh weight, respectively. Tartaric acid at concentration 3 g L^{-1} in form of soaking+spraying came after to record 0.758, 0.922, 1.006 and 0.845 mg g^{-1} fresh weight, respectively compared to the check plants which recorded 0.491, 0.598, 0.652 and 0.548 mg g^{-1} fresh weight, respectively.

Effect of the selected antioxidants on carotenoids content in potato plants grown under the possible natural infection of the tested fungi: Data presented in Table 13 and 14 illustrate the effect of the chosen antioxidants on carotenoids content of potato plants. The treatment was carried out in form of seed soaking, spraying on 30 days old plants with 3 interval times of spraying the plant leaves and presented GAWDA® formulation at a concentration of (3.5 g L^{-1}) as a top green chemical for increasing the content of carotenoids in leaves of 30, 45, 60 and 75 days old plants to record 0.165, 0.201, 0.220 and 0.185 mg g^{-1} fresh weight, respectively, Tartaric acid at the same concentration came after to record 0.159, 0.193, 0.211 and 0.177 mg g^{-1} fresh weight, respectively while Salicylic acid at 1.5 g L^{-1} was the least effective treatment on total phenols content in plant leaves to record 0.142, 0.173, 0.189 and 0.158 mg g^{-1} fresh weight, respectively when compared to the check, which recorded 0.104, 0.126, 0.138 and 0.116 mg g^{-1} fresh weight, respectively.

In respect to the application of soaking+spraying, significant increases in carotenoids content in leaves of plants grown under the possible natural infection of *(F. oxysporum, F. solani* and *R. solani*) were shown on 30, 45, 60 and 75 days old plants to record 0.150, 0.183, 0.200 and 0.168 mg g^{-1} fresh weight, respectively.

GAWDA® formulation at a concentration 3.5 g L^{-1} and in form of soaking+spraying significantly increased carotenoids content in leaves of 30, 45, 60 and 75 days old plants to record 0.207, 0.252, 0.275 and 0.231 mg g^{-1} fresh weight, respectively. Tartaric acid at the same concentration and in form of soaking+spraying came after to record 0.198, 0.241, 0.263 and 0.221 mg g^{-1} fresh weight, respectively compared to the check plants which recorded 0.112, 0.136, 0.149 and 0.125 mg g^{-1} fresh weight, respectively.

Influence of the chosen antioxidants and their combinations on the total phenols content in potato plants grown under the possible natural infection of the focused fungi: Data presented in Table 15 and 16 illustrate the role of

Table 10: Alliance between antioxidants and methods of application to ramp up the chlorophyll a contents in potato plants under the natural conditions

Treatments	Chlorophyll a contents mg g^{-1} fresh weight			
	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
GAWDA®				
2.5 (g L^{-1})				
So	1.128^{l-n}	1.373^{l-n}	1.498^{l-n}	1.258^{l-n}
Sp	1.082^{n-p}	1.316^{n-p}	1.436^{n-p}	1.206^{n-p}
So+Sp	1.182^{j-m}	1.439^{j-m}	1.570^{j-m}	1.319^{j-m}
3.0 (g L^{-1})				
So	1.287^{f-i}	1.566^{f-i}	1.709^{f-i}	1.436^{f-i}
Sp	1.244^{h-j}	1.514^{h-j}	1.652^{h-j}	1.388^{h-j}
So+Sp	1.322^{e-h}	1.609^{e-h}	1.755^{e-h}	1.475^{e-h}
3.5 (g L^{-1})				
So	1.469^{ab}	1.788^{ab}	1.951^{ab}	1.639^{ab}
Sp	1.422^{b-d}	1.730^{b-d}	1.887^{b-d}	1.585^{b-d}
So+Sp	1.543^{a}	1.878^{a}	2.049^{a}	1.721^{a}
Tartaric acid				
2.5 (g L^{-1})				
So	1.082^{n-p}	1.316^{n-p}	1.436^{n-p}	1.206^{n-p}
Sp	1.023^{p-r}	1.245^{p-r}	1.359^{p-r}	1.142^{p-r}
So+Sp	1.128^{l-n}	1.373^{l-n}	1.498^{l-n}	1.258^{l-n}
3.0 (g L^{-1})				
So	1.241^{h-j}	1.510^{h-j}	1.647^{h-j}	1.384^{h-j}
Sp	1.198^{j-l}	1.458^{j-l}	1.590^{j-l}	1.336^{j-l}
So+Sp	1.299^{e-i}	1.580^{e-i}	1.724^{e-i}	1.449^{e-i}
3.5 (g L^{-1})				
So	1.423^{b-d}	1.731^{b-d}	1.889^{b-d}	1.587^{b-d}
Sp	1.380^{c-e}	1.679^{c-e}	1.832^{c-e}	1.539^{c-e}
So+Sp	1.500^{ab}	1.826^{ab}	1.992^{ab}	1.674^{ab}
Citric acid				
2.0 (g L^{-1})				
So	1.180^{j-m}	1.435^{j-m}	1.566^{j-m}	1.316^{j-m}
Sp	0.989^{q-s}	1.203^{q-s}	1.312^{q-s}	1.103^{q-s}
So+Sp	1.031^{o-q}	1.255^{o-q}	1.369^{o-q}	1.150^{o-q}
2.5 (g L^{-1})				
So	1.198^{j-l}	1.458^{j-l}	1.590^{j-l}	1.336^{j-l}
Sp	1.113^{m-o}	1.354^{m-o}	1.477^{m-o}	1.241^{m-o}
So+Sp	1.252^{g-j}	1.524^{g-j}	1.662^{g-j}	1.397^{g-j}
3.0 (g L^{-1})				
So	1.369^{c-f}	1.665^{c-f}	1.817^{c-e}	1.526^{c-f}
Sp	1.349^{p-r}	1.642^{p-r}	1.791^{p-r}	1.505^{p-r}
So+Sp	1.438^{bc}	1.750^{bc}	1.910^{bc}	1.604^{bc}
Salicylic acid				
0.5 (g L^{-1})				
So	0.992^{q-s}	1.208^{q-s}	1.318^{q-s}	1.107^{q-s}
Sp	0.942^{rs}	1.146^{rs}	1.251^{rs}	1.051^{rs}
So+Sp	1.027^{pq}	1.250^{pq}	1.364^{pq}	1.146^{pq}
1 (g L^{-1})				
So	1.155^{k-n}	1.406^{k-n}	1.534^{k-n}	1.289^{k-n}
Sp	1.144^{k-n}	1.392^{k-n}	1.518^{k-n}	1.276^{k-n}
So+Sp	1.217^{i-k}	1.481^{i-k}	1.616^{i-k}	1.358^{i-k}
1.5 (g L^{-1})				
So	1.334^{e-g}	1.623^{e-g}	1.771^{e-g}	1.488^{e-g}
Sp	1.299^{e-i}	1.580^{e-i}	1.724^{e-i}	1.449^{e-i}
So+Sp	1.380^{c-e}	1.679^{c-e}	1.832^{c-e}	1.539^{c-e}
Check				
So	0.958^{q-s}	1.165^{q-s}	1.271^{q-s}	1.068^{q-s}
Sp	0.911^{s}	1.109^{s}	1.210^{s}	1.016^{s}
So+Sp	0.973^{q-s}	1.184^{q-s}	1.292^{q-s}	1.085^{q-s}

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Table 11: Influence of antioxidants along with methods of application on chlorophyll b contents of potato plants grown under the natural conditions

	Chlorophyll b contents mg g^{-1} fresh weight			
Treatments	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
Antioxidants				
GAWDA®	0.655^{a}	0.797^{a}	0.870^{a}	0.731^{a}
Tartaric	0.632^{b}	0.770^{b}	0.840^{b}	0.706^{b}
Citric	0.613^{c}	0.746^{c}	0.813^{c}	0.683^{c}
Salicylic	0.589^{d}	0.716^{d}	0.782^{d}	0.657^{d}
Check	0.481^{e}	0.585^{e}	0.638^{e}	0.536^{e}
Concentrations				
1	0.526^{c}	0.640^{c}	0.698^{c}	0.587^{c}
2	0.591^{b}	0.719^{b}	0.784^{b}	0.659^{b}
3	0.526^{a}	0.809^{a}	0.882^{a}	0.742^{a}
Methods				
So	0.597^{b}	0.726^{b}	0.792^{b}	0.666^{b}
Sp	0.571^{c}	0.695^{c}	0.758^{c}	0.637^{c}
So+SP	0.614^{a}	0.747^{a}	0.815^{a}	0.685^{a}

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Table 12: Alliance of chosen antioxidants and methods of application on chlorophyll b contents of potato plants grown under the natural conditions

	Chlorophyll b contents mg g^{-1} fresh weight			
Treatments	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
GAWDA®				
2.5 g L^{-1}				
So	0.570^{l-n}	0.693^{l-n}	0.756^{l-n}	0.635^{i-o}
Sp	0.546^{n-p}	0.665^{n-p}	0.725^{n-p}	0.609^{k-q}
So+Sp	0.597^{j-m}	0.727^{j-m}	0.793^{j-m}	0.666^{g-l}
3.0 g L^{-1}				
So	0.650^{f-i}	0.791^{f-i}	0.863^{f-i}	0.725^{d-i}
Sp	0.628^{h-j}	0.765^{h-j}	0.834^{h-j}	0.701^{e-k}
So+Sp	0.668^{e-h}	0.812^{e-h}	0.886^{e-h}	0.745^{c-g}
3.5 g L^{-1}				
So	0.742^{ab}	0.903^{ab}	0.985^{ab}	0.828^{a-c}
Sp	0.718^{b-d}	0.873^{b-d}	0.953^{b-d}	0.800^{a-d}
So+Sp	0.779^{a}	0.948^{a}	1.034^{a}	0.869^{a}
Tartaric acid				
2.5 g L^{-1}				
So	0.546^{n-p}	0.665^{n-p}	0.725^{n-p}	0.609^{k-q}
Sp	0.517^{p-r}	0.629^{p-r}	0.686^{p-r}	0.576^{l-r}
So+Sp	0.570^{l-n}	0.693^{l-n}	0.756^{l-n}	0.635^{i-o}
3.0 g L^{-1}				
So	0.626^{h-j}	0.762^{h-j}	0.832^{h-j}	0.699^{e-k}
Sp	0.605^{j-l}	0.736^{j-l}	0.803^{j-l}	0.675^{f-k}
So+Sp	0.656^{e-i}	0.798^{e-i}	0.871^{e-i}	0.732^{d-h}
3.5 g L^{-1}				
So	0.718^{b-d}	0.874^{b-d}	0.954^{b-d}	0.802^{a-d}
Sp	0.697^{c-e}	0.848^{c-e}	0.925^{c-e}	0.777^{a-e}
So+Sp	0.758^{ab}	0.922^{ab}	1.006^{ab}	0.845^{ab}
Citric acid				
2.0 g L^{-1}				
So	0.596^{j-m}	0.725^{j-m}	0.791^{j-m}	0.665^{g-l}
Sp	0.499^{q-s}	0.607^{q-s}	0.663^{q-s}	0.557^{n-r}
So+Sp	0.521^{o-q}	0.634^{o-q}	0.691^{o-q}	0.581^{l-r}
2.5 g L^{-1}				
So	0.605^{j-l}	0.736^{j-l}	0.803^{j-l}	0.675^{f-k}
Sp	0.562^{m-o}	0.684^{m-o}	0.746^{m-o}	0.627^{j-p}
So+Sp	0.632^{g-j}	0.769^{g-j}	0.840^{g-j}	0.705^{e-j}
3.0 g L^{-1}				
So	0.691^{c-f}	0.841^{c-f}	0.917^{c-f}	0.771^{b-e}
Sp	0.681^{d-f}	0.829^{d-f}	0.904^{d-f}	0.760^{b-f}
So+Sp	0.726^{bc}	0.884^{bc}	0.964^{bc}	0.810^{a-d}

Table 12: Continue

Treatments	Chlorophyll b contents mg g^{-1} fresh weight			
	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
Salicylic acid				
0.5 g L^{-1}				
So	0.501^{q-s}	0.610^{q-s}	0.665^{q-s}	0.559^{m-r}
Sp	0.476^{rs}	0.579^{rs}	0.632^{rs}	0.531^{qr}
So+Sp	0.519^{pq}	0.631^{pq}	0.689^{pq}	0.579^{l-r}
1 g L^{-1}				
So	0.583^{k-n}	0.710^{k-n}	0.775^{k-n}	0.651^{h-m}
Sp	0.578^{k-n}	0.703^{k-n}	0.767^{k-n}	0.644^{h-n}
So+Sp	0.615^{i-k}	0.748^{i-k}	0.816^{i-k}	0.686^{e-k}
1.5 g L^{-1}				
So	0.673^{e-g}	0.819^{e-g}	0.894^{e-g}	0.751^{c-g}
Sp	0.656^{e-i}	0.798^{e-i}	0.871^{e-i}	0.732^{d-h}
So+Sp	0.697^{c-e}	0.848^{c-e}	0.925^{c-e}	0.777^{a-e}
Check				
So	0.484^{q-s}	0.588^{q-s}	0.642^{q-s}	0.539^{p-r}
Sp	0.460^{s}	0.560^{s}	0.611^{s}	0.513^{r}
So+Sp	0.491^{q-s}	0.598^{q-s}	0.652^{q-s}	0.548^{o-r}

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Table 13: Influence of antioxidants along with the methods of application on carotenoid contents of potato plants under the natural conditions

Treatment	Carotenoid contents mg g^{-1} fresh weight			
	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
Antioxidants				
GAWDA®	0.165^{a}	0.201^{a}	0.220^{a}	0.185^{a}
Tartaric	0.159^{b}	0.193^{b}	0.211^{b}	0.177^{b}
Citric	0.151^{c}	0.183^{c}	0.200^{c}	0.168^{c}
Salicylic	0.142^{d}	0.173^{d}	0.189^{d}	0.158^{d}
Check	0.104^{e}	0.126^{e}	0.138^{e}	0.116^{e}
Concentrations				
1	0.118^{c}	0.144^{c}	0.157^{c}	0.132^{c}
2	0.143^{b}	0.174^{b}	0.190^{b}	0.159^{b}
3	0.172^{a}	0.209^{a}	0.228^{a}	0.192^{a}
Methods				
So	0.143^{b}	0.174^{b}	0.190^{b}	0.160^{B}
Sp	0.139^{c}	0.169^{c}	0.184^{c}	0.155^{C}
So+SP	0.150^{a}	0.183^{a}	0.200^{a}	0.168^{a}

Means followed by small and capital letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

the selected antioxidants on the total phenols content of potato plants. The treatment was carried out in form of seed soaking, spraying started on 30 days old plants followed by three interval times of spraying on plant leaves.

It was found that GAWDA® formulation at a concentration of 3.5 g L^{-1} significantly increased the content of total phenols in the leaves of 30, 45, 60 and 75 days old plants to record 72.1, 89.59, 100.97 and 107.59 mg catechol/100 g fresh weight, respectively, Tartaric acid at the same concentration came after to record 71.18, 87.26, 98.37 and 105.46 mg catechol/100 g fresh weight respectively while salicylic acid at 1.5 g L^{-1} was the least effective treatment on total phenols content in plant leaves to record 67.97, 81.36, 92.79 and 100.21 mg catechol/100 g fresh weight, respectively when compared to the check, which recorded 57.73, 67.10, 77.57 and 86.70 mg catechol/100 g fresh weight, respectively.

In the meanwhile, application of soaking+spraying significantly increased total phenols content in leaves of potato plants of 30, 45, 60 and 75 days old to record 76.47, 91.61, 104.59 and 87.46 mg catechol/100 g fresh weight, respectively in compare with other methods.

GAWDA® formulation at the same concentrations in form of soaking+spraying show a significant increase in the total phenols content in the infected leaves of 30, 45, 60 and 75 days old plants to record 91.3, 109.6, 123.3 and 132.07 mg catechol/100 g fresh weight, respectively. Tartaric acid at the same concentration in form of soaking+spraying came after to record 89.7, 107.9, 121.8 and 130.5 mg catechol/100 g fresh

Table 14: Influence of antioxidants and methods of application on carotenoid contents of potato plants grown under the natural conditions

Treatments	Carotenoid contents mg g^{-1} fresh weight			
	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
GAWDA®				
2.5 g L^{-1}				
So	0.130^{n-p}	0.158^{n-p}	0.173^{n-p}	0.145^{n-p}
Sp	0.137^{mn}	0.166^{mn}	0.181^{mn}	0.152^{mn}
So+Sp	0.140^{l-n}	0.170^{l-n}	0.186^{l-n}	0.156^{l-n}
3.0 g L^{-1}				
So	0.166^{g-i}	0.202^{g-i}	0.220^{g-i}	0.185^{g-i}
Sp	0.145^{k-m}	0.176^{k-m}	0.192^{k-m}	0.161^{k-m}
So+Sp	0.172^{f-h}	0.209^{f-h}	0.228^{f-h}	0.192^{f-h}
3.5 g L^{-1}				
So	0.198^{ab}	0.241^{ab}	0.263^{ab}	0.221^{ab}
Sp	0.195^{a-c}	0.237^{a-c}	0.259^{a-c}	0.218^{a-c}
So+Sp	0.207^{a}	0.252^{a}	0.275^{a}	0.231^{a}
Tartaric acid				
2.5 g L^{-1}				
So	0.123^{o-q}	0.150^{o-q}	0.163^{o-q}	0.137^{o-q}
Sp	0.119^{p-r}	0.145^{p-r}	0.158^{p-r}	0.133^{p-r}
So+Sp	0.131^{n-p}	0.159^{n-p}	0.174^{n-p}	0.146^{n-p}
3.0 g L^{-1}				
So	0.160^{h-j}	0.195^{h-j}	0.212^{h-j}	0.178^{h-j}
Sp	0.156^{i-k}	0.190^{i-k}	0.207^{i-k}	0.174^{i-k}
So+Sp	0.163^{g-j}	0.198^{g-j}	0.216^{g-j}	0.182^{g-j}
3.5 g L^{-1}				
So	0.191^{b-d}	0.232^{b-d}	0.254^{b-d}	0.213^{b-d}
Sp	0.187^{b-e}	0.228^{b-e}	0.248^{b-e}	0.209^{b-e}
So+Sp	0.198^{ab}	0.241^{ab}	0.263^{ab}	0.221^{ab}
Citric acid				
2.0 g L^{-1}				
So	0.111^{q-s}	0.135^{q-s}	0.147^{q-s}	0.124^{q-s}
Sp	0.113^{q-s}	0.138^{q-s}	0.150^{q-s}	0.126^{q-s}
So+Sp	0.123^{o-q}	0.150^{o-q}	0.163^{o-q}	0.137^{o-q}
2.5 g L^{-1}				
So	0.151^{j-l}	0.184^{j-l}	0.200^{j-l}	0.168^{j-l}
Sp	0.144^{k-m}	0.175^{k-m}	0.191^{k-m}	0.161^{k-m}
So+Sp	0.155^{i-k}	0.189^{i-k}	0.206^{i-k}	0.173^{i-k}
3.0 g L^{-1}				
So	0.187^{b-e}	0.228^{b-e}	0.248^{b-e}	0.209^{b-e}
Sp	0.183^{c-f}	0.223^{c-f}	0.243^{c-f}	0.204^{c-f}
So+Sp	0.188^{b-d}	0.229^{b-d}	0.250^{b-d}	0.210^{b-d}
Salicylic acid				
0.5 g L^{-1}				
So	0.109^{r-t}	0.133^{rst}	0.145^{r-t}	0.122^{r-t}
Sp	0.104st	0.127st	0.138st	0.116st
So+Sp	0.117^{qr}	0.142^{qr}	0.155^{qr}	0.131^{qr}
1 g L^{-1}				
So	0.139^{l-n}	0.169^{l-n}	0.185^{l-n}	0.155^{l-n}
Sp	0.135^{m-o}	0.164^{m-o}	0.179^{m-o}	0.151^{m-o}
So+Sp	0.146^{k-m}	0.178^{k-m}	0.194^{k-m}	0.163^{k-m}
1.5 g L^{-1}				
So	0.175^{e-g}	0.213^{e-g}	0.232^{e-g}	0.195^{e-g}
Sp	0.173^{fg}	0.211^{fg}	0.230^{fg}	0.193^{fg}
So+Sp	0.180^{d-f}	0.219^{d-f}	0.239^{d-f}	0.201^{d-f}
Check				
So	0.103st	0.125st	0.137st	0.115st
Sp	0.097^{t}	0.118^{t}	0.129^{t}	0.108^{t}
So+Sp	0.112^{q-s}	0.136^{q-s}	0.149^{q-s}	0.125^{q-s}

Means followed by different letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Table 15: Effect of antioxidants along with methods of application on total phenol contents of potato plants grown under natural conditions

	Total phenol contents mg/100 g fresh weight			
Treatments	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
Antioxidants				
GAWDA®	72.10[a]	89.59[a]	100.97[a]	107.59[a]
Tartaric	71.18[b]	87.26[b]	98.37[b]	105.46[b]
Citric	70.26[c]	84.34[c]	95.79[c]	102.59[c]
Salicylic	67.97[d]	81.36[d]	92.79[d]	100.21[d]
Check	57.73[e]	67.10[e]	77.57[e]	86.70[e]
Concentrations				
1	61.81[c]	73.04[c]	83.72[c]	91.83[c]
2	68.36[b]	82.57[b]	93.37[b]	101.01[b]
3	73.37[a]	90.173[a]	102.20[a]	108.68[a]
Methods				
So	69.69[b]	73.41[c]	81.23[c]	115.30[c]
Sp	57.38[c]	80.77[b]	93.46[b]	98.76[b]
So+SP	76.47[a]	91.61[a]	104.59[a]	87.46[a]

*Means followed by small and capital letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Table 16: Interaction between the tested antioxidants along with the methods of application on total phenol contents of potato plants grown under natural condition

	Total phenol contents mg/100 g fresh weight			
Treatments	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
GAWDA®				
2.5 g L^{-1}				
So	64.8[z]	71.9[e]	76.8[c]	83.5[G]
Sp	55.7[l]	76.8[z]	90.4[t]	95.2[x]
So+Sp	71.5[p]	87.9[n]	101.4[m]	111.3[k]
3.0 g L^{-1}				
So	72.7[o]	80.8[t]	88.9[u]	93.7[z]
Sp	62.9[b]	88.9[m]	102.3[l]	106.2[n]
So+Sp	80.3[h]	101.3[e]	114.8[e]	125.2[e]
3.5 g L^{-1}				
So	82.9[f]	89.3[l]	98.7[o]	103.7[q]
Sp	68.4[u]	99.8[f]	112.1[f]	117.4[h]
So+Sp	91.3[a]	109.6[a]	123.3[a]	132.07[a]
Tartaric acid				
2.5 g L^{-1}				
So	67.2[v]	68.8[G]	75[d]	81.9[H]
Sp	58.1[H]	75.9[a]	87.1[v]	94.2[y]
So+Sp	73.8[n]	84.1[r]	98.9[o]	107.9[m]
3.0 g L^{-1}				
So	75.3[m]	79.6[v]	85.6[w]	91.5[A]
Sp	64.2[a]	85.7[p]	99.3[n]	104.3[p]
So+Sp	82.7[g]	98.6[g]	110.5[g]	122.4[f]
3.5 g L^{-1}				
So	85.4[d]	87.5[o]	96.9[p]	101.3[s]
Sp	42.6[M]	97.2[h]	110.2[g]	115.1[j]
So+Sp	89.7[b]	107.9[b]	121.8[b]	130.5[b]
Citric acid				
2.0 g L^{-1}				
So	62.3[c]	65.4[l]	74.1[e]	80.1[l]
Sp	53.4[J]	73.1[d]	83.7[x]	89.8[B]
So+Sp	69.2[s]	80.3[u]	94.5[r]	105.7[o]
2.5 g L^{-1}				
So	70.2[r]	77.2[y]	82.4[y]	89.4[C]
Sp	61.1[d]	81.3[s]	96.6[p]	101.4[s]
So+Sp	77.9[j]	97.2[h]	108.7[h]	119.1[g]
3.0 g L^{-1}				
So	79.8[i]	84.5[q]	95.2[q]	98.2[v]
Sp	71.3[q]	93.4[j]	107.5[j]	109.7[l]
So+Sp	87.1[c]	106.7[c]	119.4[c]	129.9[c]

Table 16: Continue

Treatments	Total phenol contents mg/100 g fresh weight			
	30 days from sowing	45 days from sowing	60 days from sowing	75 days from sowing
Salicylic acid				
0.5 g L^{-1}				
So	60.9^{E}	62.7^{J}	69.7^{F}	77.9^{J}
Sp	50.2^{K}	69.8^{F}	80.9^{z}	87.1^{E}
So+Sp	66.9^{w}	77.6^{x}	90.6^{t}	102.8^{r}
1 g L^{-1}				
So	68.7^{t}	74.5^{c}	79.3^{a}	87.8^{D}
Sp	59.8^{F}	78.4^{w}	94.2^{r}	98.5^{u}
So+Sp	76.4^{l}	93.8^{i}	105.2^{j}	115.5^{i}
1.5 g L^{-1}				
So	77.6^{k}	81.3^{s}	92.5^{s}	96.4^{w}
Sp	66.3^{x}	90.6^{k}	104.8^{k}	107.8^{m}
So+Sp	84.9^{e}	103.5^{d}	117.9^{d}	128.1^{d}
Check				
So	59.2^{G}	59.2^{K}	67.8^{G}	75.5^{K}
Sp	48.9^{L}	66.9^{H}	77.6^{b}	84.9^{F}
So+Sp	65.1^{y}	75.2^{b}	87.3^{v}	99.7^{t}

Means followed by small and capital letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Table 17: Effect of antioxidants along with methods of application on total sugar, starch, potassium (K) and carotene contents in the fresh tubers

Treatment	Fresh tubers			
	Total sugar	Starch	Potassium (K)	Carotene
Antioxidants				
GAWDA®	1.92^{e}	11.14^{a}	3.35^{a}	1.65^{a}
Tartaric	2.10^{d}	11.11^{b}	3.23^{b}	1.59^{b}
Citric	2.24^{c}	10.98^{c}	3.13^{c}	1.51^{c}
Salicylic	2.37^{b}	10.40^{d}	3.01^{d}	1.42^{d}
Check	3.01^{a}	10.16^{e}	2.45^{e}	1.04^{e}
Concentrations				
1	2.79^{a}	10.63^{c}	2.69^{c}	1.18^{C}
2	2.35^{b}	10.69^{b}	3.02^{b}	1.43^{b}
3	1.85^{c}	10.95^{a}	3.40^{a}	1.72^{a}
Methods				
So	2.32^{b}	10.72^{b}	3.05^{b}	1.43^{b}
Sp	2.49^{a}	10.69^{c}	2.92^{c}	1.39^{C}
So+SP	2.18^{c}	10.86^{a}	3.14^{a}	1.50^{a}

*Means followed by small and capital letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

weight, respectively compared to the check plants which recorded 65.1, 75.2, 87.3 and 99.7 mg catechol/100 g fresh weight, respectively.

Effect of the selected antioxidants on total sugar content in potato tubers grown under the possible natural infection of the tested fungi: Data presented in Table 17 and 18 illustrate the possible role of the selected antioxidants on the total content of sugar in potato tubers. The treatment was carried out in form of seed soaking, spraying started on 30 days old plants and soaking followed by three interval times of spraying plant leaves on 30, 45, 60 and 75 days old plants.

It was found that GAWDA® formulation at a concentration of 3.5 g L^{-1} significantly decreased the content of total sugar in the fresh tubers by 1.92%, tartaric acid at the same concentration came after to record 2.10% while, salicylic acid at 1.5 g L^{-1} was the least effective treatment on the total sugar content in the tubers to record 2.37%, while the check to recorded 3.01%.

The application of soaking+spraying significantly decreased total sugar content in fresh tubers to record 2.18%.

GAWDA® formulation at the concentration of 3.5 g L^{-1} and in form of soaking+spraying significantly decreased the total sugar content in tubers to record 1.22% followed by tartaric acid at the same concentration in form of soaking+spraying to record 1.35% while the check recorded 2.85%.

Effect of the selected antioxidants on the starch content in potato tubers grown under the possible natural infection of the tested fungi: Data presented in Table 17 and 18 illustrate the effect of the selected antioxidants on the starch content in potato tubers. The treatment was carried out in form of seed soaking, spraying leaves of 30 days old plants and soaking followed by 3 interval times of spraying each antioxidant or formulated antioxidants on 30, 45, 60 and 75 aged old plants.

GAWDA® formulation at a concentration of 3.5 g L^{-1}, significantly increased the content of starch in fresh tubers to record 11.14%, tartaric acid at the same concentrations came after to record 11.11% while salicylic acid at 1.5 g L^{-1} was the least effective treatment on the starch content to record 10.40%, while the check recorded 10.16% increases.

Table 18: Interaction between antioxidants and methods of application on total sugar, starch, potassium (K) and carotene contents of potato fresh tubers

	Fresh tubers			
Treatments	Total sugar	Starch	Potassium (K)	Carotene
GAWDA®				
2.5 g L^{-1}				
So	2.52^{n}	10.67^{k-s}	2.91^{l-n}	1.3^{n-p}
Sp	2.69^{j}	10.45^{n-s}	2.79^{n-p}	1.37^{mn}
So+Sp	2.39^{q}	11.15^{f-m}	3.05^{j-m}	1.4^{l-n}
3.0 g L^{-1}				
So	1.93^{z}	10.23^{q-s}	3.32^{f-i}	1.66^{g-i}
Sp	1.96^{x}	10.91^{g-p}	3.21^{h-j}	1.45^{k-m}
So+Sp	1.78^{b}	11.64^{b-f}	3.41^{e-h}	1.72^{f-h}
3.5 g L^{-1}				
So	1.38^{J}	11.65^{b-f}	3.79^{ab}	1.98^{ab}
Sp	1.44^{I}	11.25^{d-k}	3.67^{b-d}	1.95^{a-c}
So+Sp	1.22^{L}	12.27^{a}	3.98^{a}	2.07^{a}
Tartaric acid				
2.5 g L^{-1}				
So	2.66^{k}	10.54^{m-s}	2.79^{n-p}	1.23^{o-q}
Sp	2.81^{g}	10.31^{p-s}	2.64^{p-r}	1.19^{p-r}
So+Sp	2.50^{o}	11.02^{g-o}	2.91^{l-n}	1.31^{n-p}
3.0 g L^{-1}				
So	2.17^{v}	10.98^{g-o}	3.20^{h-j}	1.6^{h-j}
Sp	2.32^{s}	10.84^{j-q}	3.09^{j-l}	1.56^{i-k}
So+Sp	1.94^{y}	11.47^{c-h}	3.35^{e-i}	1.63^{g-j}
3.5 g L^{-1}				
So	1.52^{G}	11.52^{b-g}	3.67^{b-d}	1.91^{b-d}
Sp	1.63^{F}	11.19^{e-l}	3.56^{c-e}	1.87^{b-e}
So+Sp	1.35^{K}	12.13^{ab}	3.87^{ab}	1.98^{ab}
Citric acid				
2.0 g L^{-1}				
So	2.78^{i}	10.42^{o-s}	3.04^{j-m}	1.11^{q-s}
Sp	3.02^{c}	10.18^{rs}	2.55^{q-s}	1.13^{q-s}
So+Sp	2.63^{l}	10.89^{h-p}	2.66^{o-q}	1.23^{o-q}
2.5 g L^{-1}				
So	2.25^{u}	10.83^{i-q}	3.09^{j-l}	1.51^{j-l}
Sp	2.48^{p}	10.73^{k-r}	2.87^{m-o}	1.44^{k-m}
So+Sp	2.10^{w}	11.35^{c-j}	3.23^{g-j}	1.55^{i-k}
3.0 g L^{-1}				
So	1.65^{E}	11.38^{c-i}	3.53^{c-f}	1.87^{b-e}
Sp	1.77^{c}	11.12^{f-m}	3.48^{d-f}	1.83^{c-f}
So+Sp	1.49^{H}	11.92^{a-c}	3.71^{bc}	1.88^{b-d}
Salicylic acid				
0.5 g L^{-1}				
So	2.91^{e}	10.31^{p-s}	2.56^{q-s}	1.09^{r-t}
Sp	3.13^{b}	10.07^{s}	2.43^{rs}	1.04st
So+Sp	2.79^{h}	10.83^{i-q}	2.65^{pq}	1.17^{qr}
1 g L^{-1}				
So	2.38^{r}	10.31^{p-s}	2.98^{k-n}	1.39^{l-n}
Sp	2.56^{m}	10.07^{s}	2.95^{k-n}	1.35^{m-o}
So+Sp	2.27^{t}	10.83^{i-q}	3.14^{i-k}	1.46^{k-m}
1.5 g L^{-1}				
So	1.71^{D}	10.31^{p-s}	3.44^{e-g}	1.75^{e-g}
Sp	1.91^{a}	10.07^{s}	3.35^{e-i}	1.73^{fg}
So+Sp	1.65^{E}	10.83^{i-q}	3.56^{c-e}	1.8^{d-f}
Check				
So	2.98^{d}	11.77^{a-e}	2.47^{q-s}	1.03st
Sp	3.20^{a}	11.52^{b-g}	2.35^{s}	0.97^{t}
So+Sp	2.85^{f}	1.39^{T}	2.51^{q-s}	1.12^{q-s}

Means followed by small and capital letter (s) in the column are significantly different according to Duncan's multiple range test at p = 0.05, So: Soaking, Sp: Spraying

Application of soaking+spraying showed less starch content in fresh tubers to record 10.86%.

GAWDA® formulation at a concentration of 3.5 g L^{-1} and in form of soaking+spraying significantly increased starch content in tubers to record 12.27% followed by tartaric acid at the same concentration to record 12.13% compared to the check plants which recorded 1.39%.

Effect of the tested antioxidants on potassium (K) fresh content of potato tubers grown under the possible natural infection of the fungus: Data presented in Table 17 and 18 illustrate the effect of the selected antioxidants on potassium content of potato tubers. The treatment was carried out in form of seed soaking, spraying on 30 days old plants and soaking followed by three interval times of spraying the plant leaves as shown in materials and methods.

It was found that GAWDA® formulation at a concentration of 3.5 g L^{-1} significantly increased the content of potassium in the fresh tubers to record 3.35%. Tartaric acid at the same concentration came after to record 3.23% while salicylic acid at 1.5 g L^{-1} was the least effective treatment on potassium content in plant leaves and recorded 3.01% increase, while the check recorded only 2.45% increase.

On the other hand, the application of soaking+spraying reflects the increases in the fresh tubers by 3.14% only.

GAWDA® formulation at the same concentration in form of soaking+spraying significantly increased potassium content in tubers to record 3.98% increase followed by tartaric acid of the same concentration in form of soaking+spraying to record 3.87% while the increase in check was 2.51%.

Effect of the tested antioxidants on carotene content in potato tubers harvested from plants grown under the possible natural infection of the fungi: Data presented in Table 17 and 18 illustrate the effect of the selected antioxidants on the carotene content in potato tubers. The treatment was carried out in form of seed soaking, spraying on 30 days old plants and soaking followed by 3 interval times of spraying the plant leaves.

GAWDA® formulation at the concentration of 3.5 g L^{-1}, significantly increased the content of carotene in fresh tubers to record 1.65 mg/100 g, tartaric acid at the same concentration came after to record 1.59 mg/100 g while salicylic acid at 1.5 g L^{-1} was the least effective treatment to record 1.42 mg/100 g, while the check recorded 1.04 mg/100 g fresh weight. On the other hand, the application of soaking+spraying did not show a significant increases in carotene content in fresh tubers as it recorded 1.5 mg/100 g only.

GAWDA® formulation at 3.5 g L^{-1} and in form of soaking+spraying significantly increased carotene content in the fresh tubers to record 2.07 mg/100 g Followed by tartaric acid at the same concentration in form of soaking+spraying to record 1.98 mg/100 g compared to the tubers of the check plants which recorded 1.12 mg/100 g.

DISCUSSION

Induced resistance is a promising modern approach in the control of plant diseases. It could be induced on plants via elicitors[55], which enhance the defense mechanism in plants against a number of diseases or produce new compounds to ramp up the infection.

The research chart was planned to use GAWDA® formulation, tartaric acid, citric acid and salicylic acid as green chemicals to be applied *in vitro* and *in vivo*.

It was found that these antioxidants accelerate the resistance of potato plants against the biotic stress caused by *F. oxysporum*, *F. solani*, *R. solani*.

In this respect, GAWDA® formulation at 3.5 g L^{-1}, tartaric acid at 3.5 g L^{-1}, citric acid at 3 g L^{-1} and salicylic acid at 1.5 g L^{-1} when used for soaking potato tubers before sowing or soaking tubers plus 3 times of spraying the plants with the same concentrations significantly improved potato yield and increased the tuber quantity.

This trend in controlling plant diseases with antioxidant of potential to affect the growth of several fungi were applied on other crops including wheat, peanut, sunflower and cucumber and showed their positive effect as presented in this research ElwakilandEl-Metwally[56], Elwakil[25], Farouk *et al*.[57] and Abd El-Hai *et al*.[58].

A verified evidence of these results were shown by a number of investigators, who had worked on a number different pathogens[59-61].

To support these results, Abd El-Hai *et al*.[58] found that salicylic acid at 10 mM singly or in combination with citric acid completely inhibited the linear growth of *Rhizoctonia solani* the causal agents of damping-off as well as other microorganisms including *F. oxysporum*[60].

All tested antioxidants increased photosynthetic pigments and in turn increases carbohydrate content in plant tissues[62], while, salicylic acid (SA), tartaric acid, citric acid and GAWDA® formulation showed their significant inhibitory effect against the mycelial growth of the above pathogens. The results are in agreement with the finding of Ismail[63], who found that tartaric acid at 10 mM reduced the linear growth of the pathogenic fungi caused damping-off, root rot, wilt in sesame (*Sesamum indicum*. L). Elwakil and El-Metwally[56], who found a reduction in the linear growth of *Cephalosporium* sp., *Fusarium moniliforme*, *F. oxysporum*, *F. solani*, *Rhizoctonia solani*, *Sclerotium bataticola* and *Verticillium* sp. in the presence of hydroquinone at 20 mM.

CONCLUSION

Results presented in this research address a strong correlation between the systemic acquired resistances of potato enhanced plants by green chemicals (antioxidants) and the reduction in the colonized soil-borne fungi attacking potato plants resulting in production of higher yield, quality tubers.

SIGNIFICANCE OF STATEMENTS

This study showed the role of green chemicals in controlling soil-borne fungi attacking potato plants and subsequently produced quality tubers. Also, direct the attention to replace the pesticides used for controlling the potato diseases with the green chemicals mentioned here to produce healthy food and protect the environment from the contamination with toxic chemicals.

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