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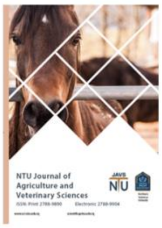

Effect of Calcium Chloride, Magnesium Sulfate, and Maleic Acid Spraying on Growth and Yield of Two Potato Varieties (*Solanum tuberosum* L.)

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A B S T R A C T

Two different potato varieties, Riviera and Argana, were used in this study to evaluate their performance under the influence of foliar fertilization (calcium and magnesium) at four concentrations (0%, 0.5%, and 1% calcium chloride, and 0.4% magnesium sulfate) and foliar spraying with malic acid at three concentrations (0, 250, and 500 mg L^{-1}) in the vegetable field of the Department of Horticulture and Landscape Design at the College of Agriculture and Forestry during the spring growing season of 2023. The study was conducted using a complete randomized block design with three replicates. Argana variety showed significant superiority over Riviera in traits such as plant height, leaf area, average tuber weight, and yield per plant, while Riviera variety outperformed Argana significantly in the number of aerial stems. The best yield per plant for Argana variety was obtained with 0.4% magnesium sulfate and 250 mg L^{-1} malic acid treatment, while the best plant height was achieved in the same variety with 0.4% magnesium sulfate and 500 mg L^{-1} malic acid treatment. The highest number of stems was observed in Riviera variety with 0% calcium chloride and 500 mg L^{-1} malic acid treatment, while the lowest was in Argana variety with 0.5% calcium chloride and 250 mg L^{-1} malic acid treatment. The highest leaf area was found in Riviera variety treated with 0.5% calcium chloride and 0 mg L^{-1} malic acid, while the lowest was in the control treatment of the same variety. The highest average tuber weight was recorded in Argana variety with 0.5% calcium chloride and 250 mg L^{-1} malic acid treatment, while the lowest was in Riviera variety with 0% calcium chloride and 250 mg L^{-1} malic acid treatment.

Introduction

Potato (***Solanum tuberosum*** L.) is considered one of the most important vegetables in the Solanaceae family, which comprises more than 2000 species and 90 genera, all falling under the genus Solanum. Potatoes rank fourth globally among food crops after maize, wheat, and rice, or first if cereal crops are excluded. Typically, the part consumed is the underground tuberous stems, commonly starch-filled tubers. Potatoes are recognized as nutrient-rich and easily digestible vegetables. The dry matter content in tubers ranges from 15 to 29%, with starch content varying between 10 and 24%. They have a low protein content ranging from 1 to 2% and approximately 17.5% carbohydrates. Potatoes also contain mineral salts, constituting around 1%, primarily composed of potassium, phosphorus, magnesium, calcium, sodium, and iron, in addition to vitamins A, B, and C [1, 2]. According to the Central Statistical Organization data, the cultivated area in Iraq for the year 2021 was 76,673 Dunums, with a production rate of 466,127 tons per cultivated area. The productivity per dunum was 6,079.4 kg /Dunum. When comparing cultivated areas and production quantity globally, there is a noticeable decrease in local production, necessitating a study of the reasons and an attempt to increase productivity through various methods and technologies. One of these methods is the introduction of new varieties and fertilization with calcium and magnesium.

The variability in growth and productivity among potato varieties primarily depends on the physiological processes controlled by the interaction between genetic and environmental variations. This diversity can be attributed to the adaptability of genes and their morphological characteristics, as well as physiological factors throughout the crop's growth period [3]. Different potato varieties exhibit distinct characteristics based on their genetic composition [4].

Calcium plays a fundamental role in growth as both cell division and elongation processes require the presence of this element. It is considered one of the major essential nutrients for the growth of all green plants, playing a significant role in many biological processes within the plant [5]. Several studies highlight the importance of calcium in the growth and development of plants, as it is a major essential nutrient involved in the formation of the middle lamella of the primary cell wall due to the formation of calcium pectate. This, in turn, contributes to strengthening the cell wall [6].

Magnesium plays a crucial role in carbohydrate metabolism, protein synthesis, and enhances plant resistance to stress. It is a central unit in the chlorophyll molecule and activates metabolic activities in plants. The growth rate of crops is influenced by the use of nitrogen, and its utilization is dependent, to a large extent, on the availability of magnesium and sulfur in plants. Magnesium is considered an essential element that aids in the absorption of nitrogen and also controls various processes, including photosynthesis and metabolism. Due to the physiological effectiveness of magnesium, a deficiency in magnesium may likely reduce the efficiency of photosynthesis in leaves, affecting dry matter production and the movement of nitrogen from green plant parts. This, in turn, can impact the development of plant parts consumed. Therefore, due to the significant impact of magnesium on photosynthesis, metabolism, and translocation, it is assumed to have an effect on the quality of potatoes, especially when used in the food industry (content of starch and sugar). In a previous field experiment using magnesium fertilization at rates of 0-100 kg per hectare as magnesium sulfate, it was found to increase dry matter and starch concentration [7]. Several research studies have explored the impact of Malic Hydrazide (MH) on inhibiting potato sprouting. However, these studies also mentioned that MH may have toxic effects and could leave residues in the tubers. The mechanism of MH action as a sprout inhibitor involves the release of malic acid after oxidation. This gives the impression that malic acid and similar acids may play a role in preventing the sprouting of potato tubers. It has been found that both malic acid and tartaric acid are effective as sprout inhibitors. Each of them can delay sprouting for 6 and 4 weeks after treatment, respectively, at room temperature in the dark. Importantly, they do not negatively impact qualitative traits, and the tubers retain their moisture and appearance throughout the storage period. Therefore, malic acid and tartaric acid are considered effective and cost-effective alternatives for sprout inhibition in stored potatoes [8].

The current study aims to...

A study to evaluate two imported potato varieties aims to determine which one is superior in terms of both quantitative and qualitative production.

The study also seeks to enhance vegetative growth characteristics and both quantitative and qualitative yields through foliar spraying with calcium, magnesium, and malic acid.

Materials and Methods

A study was conducted in the vegetable field affiliated with the Department of Horticulture and, Landscape Design College of Agriculture and Forestry, Mosul University, during the spring growing season of 2023. The first factor involved two imported potato varieties "Riviera" and "Argana" classified as Elite. Meanwhile, the second factor included foliar spraying with calcium at concentrations of 0%, 0.5%, and 1%, and magnesium at 0.4%. As for the third factor, foliar spraying on the vegetative mass was done with malic acid at concentrations of 0, 250, and 500 mg liter^{-1}. The potato tubers of the Elite-class varieties, "Riviera" and "Argana", were planted on 1/2/2023 in furrows with a length of 2 meters and a width of 75 cm, spaced 25 cm apart. Four furrows were allocated for each treatment. The plants were sprayed with magnesium sulfate in three stages: the first after 15 days from sprouting, the second after 15 days from the first spray, and the third after 15 days from the second spray. Calcium chloride was applied in two stages: the first after 50 days from planting and the second after 20 days from the first application. As for malic acid spraying, it was done in three stages: the first after 40 days from planting, the second after 15 days from the first spray, and the third after 15 days from the second spray.

The experiment was conducted in the field using the Split-Plot design within the framework of the Randomized Complete Block Design (RCBD) [9]. The varieties were placed in the main plots, and the interaction between foliar fertilization treatments with calcium, magnesium, and malic acid was applied to the subplots. Each treatment was replicated three times. The Duncan multiple range test was utilized to test the means at a significance level of 0.05 using the SAS software (2017).

Harvesting was carried out on 28/5/2023, 117 days after planting, for the Riviera variety. As for the Argana variety, it was harvested on 7/6/2023, 127 days after planting. The tubers were manually excavated.

Some characteristics have been studied…..

Plant height (cm/plant): It was measured using a tape measure from the soil surface to the top of the plant.

Number of aerial stems stem plant^{-1}: The count of stems for the five plants was determined, and then the average was calculated.

Leaf area (cm²/plant): It was measured using the replication method.

Average total tuber weight (g/tuber): It was calculated as follows:

Average total tuber weight=Experimental unit tub er count/Experimental unit tuber yield

Individual plant yield (g/plant): It was calculated from the total yield of the experimental unit using the following equation:

Individual plant yield=Experimental unit plant co unt/Experimental unit yield

RESULTS AND DISCUSSION

There is a significant superiority of the Argana variety over the "Riviera" variety, as well as the superiority of all fertilizer spray treatments and malic acid over the control treatment (Table 1). The best results for interaction treatments were observed in the "Argana" variety, across all its treatments except for the control treatment. The least favorable results were observed in the control treatment for the "Riviera" variety.

The statistical analysis (Table 2) reveals a significant superiority of the "Riviera" variety in the trait of the number of aerial stems compared to the "Argana" variety. However, no significant effect was observed for the fertilizer and malic acid spray treatments. Minimal significant differences were found among the treatments, and the highest value was recorded for the "Riviera" variety at 0% fertilization and 500 mg L^{-1} of malic acid, while the lowest was observed significantly in the "Argana" variety at 0.5% calcium chloride and 250 mg L^{-1} of malic acid (Table 2).

The results from Table (3) reveal the significant superiority of the "Argana" variety in leaf area over the "Riviera" variety. Additionally, all foliar fertilizer treatments outperformed the control treatment, with the foliar spray treatment of 500 mg L^{-1} malic acid showing the highest and statistically significant leaf area. There were significant differences between treatments, where the highest leaf area was observed for the "Riviera" variety at 0.5% calcium chloride and 0 mg L^{-1} malic acid, while the lowest was in the control treatment for the same variety.

The "Argana" variety exhibited a statistically significant superiority over the "Riviera" variety, and the calcium foliar spraying treatments outperformed other treatments. Additionally, the treatment with 250 mg/L malic acid showed a significant improvement. Significant differences were observed among the treatments, with the highest yield per plant for the "Argana" variety treated with 0.4% magnesium sulfate and 250 mg/L malic acid. In contrast, the "Riviera" variety had the lowest yield per plant in the control treatment.

It is evident that the "Argana" variety excels in tuber weight compared to the "Riviera" variety. Additionally, all foliar fertilizer treatments, along with malic acid, outperformed the control treatment. There were significant differences among the interaction treatments. Specifically, the "Argana" variety, when treated with 0.5% calcium chloride and 250 mg L^{-1} malic acid, exhibited the highest tuber weight, while the "Riviera" variety showed the lowest tuber weight in the treatment with 0% foliar fertilization and 250 mg L^{-1} malic acid (Table 5).

The significant differences observed between the two studied varieties in the evaluated traits may be attributed to variations in their genetic structures. The interaction between different genes and the environment contributes to the variations observed between these studied varieties. this is consistent with the findings of [10, 11, 12] who reported significant differences in several growth and yield traits among the varieties used in their studies.

The significant effects observed in several growth and yield traits when spraying with calcium and magnesium may be attributed to the crucial role of calcium in plant growth. Both cell division and elongation processes require the presence of calcium, making it a major essential nutrient for the growth of all green plants. Calcium plays a significant role in various physiological processes in plants [5]. Additionally, it contributes to the growth and development of plants by being a major nutrient involved in the composition of the middle lamella of the primary cell wall. This is due to the formation of calcium pectates, strengthening the cell wall [6]. the previously mentioned findings align with the results reported by [13, 14,15,16, 17].

Magnesium plays a crucial role in the metabolism of carbohydrates and protein synthesis, enhancing the plant's resistance to stress. It is a key component in the chlorophyll molecule and activates metabolic processes in plants. Additionally, magnesium is an essential element that aids in nitrogen absorption. It controls various processes, including photosynthesis and metabolism. Based on the physiological effectiveness of magnesium, a deficiency may likely reduce the efficiency of photosynthesis in leaves, potentially resulting in decreased quantitative and qualitative yield [18]. Fertilizing with magnesium has been shown to increase quantitative yield and improve quality in potato plants due to its impact on chlorophyll levels in plants. This, in turn, positively affects the photosynthetic process, leading to an increase in yield. These findings align with previous studies by [15, 19, 20].

The impact of Malic hydrazide (MH) on inhibiting potato sprouting has been the subject of numerous studies. However, these studies have also indicated that MH may have toxic effects, and it could leave residues in the tubers. The mechanism of MH as a sprouting inhibitor involves the release of malic acid after oxidation. This suggests that malic acid and similar acids may play a role in preventing potato tuber sprouting.

The effect of malic acid varied depending on the potato variety used in the study. In some varieties, it increased plant yield, while in others, it had no significant effect. Additionally, it influenced some desirable chemical properties of certain potato varieties. These findings align with the results of [21, 22] who reported similar variability in the impact of malic acid on different potato varieties.

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Table 1. Effect of Variety, Calcium, Magnesium Foliar Spray, Malic Acid, and their Interaction on the Plant Height (cm) of Potato Plants.

varieties	Spray treatment	Malic acid (mg $Leter^{-1}$)			Average of varieties
		0	250	500	
Riviera	0	33.667 c	44.267 b	41.600 b c	43.842 b
	calcium chloride %0.5	42.833 b c	47.867 b	46.567 b	
	calcium chloride %1	44.167 b	46.400 b	46.600 b	
	magnesium sulfate %0.4	42.667 b c	43.833 b	45.633 b	
Argana	0	44.000 b	67.000 a	71.633 a	64.364 a
	calcium chloride %0.5	63.767 a	67.267 a	67.700 a	
	calcium chloride %1	62.933 a	65.667 a	65.533 a	
	magnesium sulfate %0.4	63.033 a	62.000 a	71.833 a	
Average of malic acid		49.633 b	55.538 a	57.138 a	
Average of spray treatment	0	50.361 b			
	calcium chloride %0.5	56.000 a			
	calcium chloride %1	55.217 a			
	magnesium sulfate %0.4	54.833 a			

The means that share the same alphabetical letter for each factor and interaction do not differ significantly according to the Duncan's multiple range test at a significance level of 0.05 ($P \leq 0.05$).

Table 2. Effect of variety, calcium, magnesium foliar spray, malic acid, and their interaction on the number of aerial stems (stem $plant^{-1}$) for potato plants.

varieties	Spray treatment	Malic acid (mg $Leter^{-1}$)			Average of varieties
		0	250	500	
Riviera	0	3.466 a – e	4.166 a - d	4.333 a - c	3.900 a
	calcium chloride %0.5	3.900 a –e	4.866 a	3.200 a – e	
	calcium chloride %1	3.466 a – e	3.233 a – e	4.166 a – d	
	magnesium sulfate %0.4	4.533 a b	3.500 a – e	3.966 a – e	
Argana	0	3.033 b – e	3.166 a – e	2.566 de	3.105 b
	calcium chloride %0.5	3.166 a – e	2.400 e	2.833 b –e	
	calcium chloride %1	3.200 a – e	3.933 a – e	3.500 a – e	
	magnesium sulfate %0.4	2.833 b – e	4.000 a – e	2.633 c –e	
Average of malic acid		3.450 a	3.658 a	3.400 a	
Average of spray treatment	0	3.455 a			
	calcium chloride %0.5	3.394 a			
	calcium chloride %1	3.583 a			
	magnesium sulfate %0.4	3.577 a			

The means that share the same alphabetical letter for each factor and interaction do not differ significantly according to the Duncan's multiple range test at a significance level of 0.05 ($P \leq 0.05$

Tabel 3. Effect of the variety and foliar spray with calcium, magnesium, malic acid, and their interaction on the leaf area (cm^2) of potato plants.

Varieties	Spray treatment	Malic acid (mg $Leter^{-1}$)			Average of varieties
		0	250	500	
Riviera	0	7616.0 i	12252.0 f – h	13807.0 e - h	14041.9 b
	calcium chloride %0.5	20069.0 a	13565.0 e – h	15000.0 d - g	
	calcium chloride %1	16339.0 a - f	14360.0 e – h	14189.0 e - h	
	magnesium sulfate %0.4	14480.0 h - e	11805.0 g h	15021.0 g -d	
Argana	0	10468.0 hi	15584.0 b – g	19667.0 a b	16413.7 a
	calcium chloride %0.5	16603.0 a – e	11602.0 g h	16876.0 a – e	
	calcium chloride %1	15382.0 d - g	19679.0 a b	19268.0 a – c	
	magnesium sulfate %0.4	15782.0 b - g	18725.0 a – d	17329.0 a – e	
Average of malic acid		14592.2 b	14696.5 b	16394.6 a	
Average of spray treatment	0	13232.3 b			
	calcium chloride %0.5	15.619.0 a			
	calcium chloride %1	16536.0 a			
	magnesium sulfate %0.4	15523.9 a			

The means that share the same alphabetical letter for each factor and interaction do not differ significantly according to the Duncan's multiple range test at a significance level of 0.05 (P≤0.05

Table 4. the effect of the variety and foliar spray with calcium, magnesium, malic acid, and their interaction on the average of tuber weight (g $tuber^{-1}$) of potato plants.

Varieties	Spray treatment	Malic acid (mg $Leter^{-1}$)			Average of varieties
		0	250	500	
Riviera	0	114.010 f	111.330 f	114.190 f	120.239 b
	calcium chloride %0.5	105.820 f	132.800 e f	124.110 ef	
	calcium chloride %1	122.220 e f	135.670 c - f	118.660 f	
	magnesium sulfate %0.4	109.960 f	132.470 d - f	121.620 e f	
Argana	0	110.000 f	133.670 d-f	178.050 a b	159.566 a
	calcium chloride %0.5	153.330 b – e	187.330 a	174.570 b - f	
	calcium chloride %1	137.140 c - f	167.560 a – c	186.020 a b	
	magnesium sulfate %0.4	154.840 a – e	167.590 a -c	164.69 a – d	
Average of malic acid		125.916 b	146.054 a	147.738 a	
Average of spray treatment	0	126.874 b			
	calcium chloride %0.5	146.328 a			
	calcium chloride %1	144.546 a			
	magnesium sulfate %0.4	141.863 a			

The means that share the same alphabetical letter for each factor and interaction do not differ significantly according to the Duncan's multiple range test at a significance level of 0.05 (P≤0.05).

Tabel 5. the effect of the variety and foliar spray with calcium, magnesium, malic acid, and their interaction the yield per plant (kg $plant^{-1}$).

Varieties	Spray treatment	Malic acid (mg $Leter^{-1}$)			Average of varieties
		0	250	500	
Riviera	0	0.938 d	1.027 b - d	1.004 cd	1.095 b
	calcium chloride %0.5	1.003 cd	1.289 a – c	1.147 a - c	
	calcium chloride %1	1.099 b - d	1.385 a b	1.097 b - d	
	magnesium sulfate %0.4	1.013 cd	1.117 d - b	1.024 cd	
Argana	0	1.162 a – d	1.202 a -d	1.079 b - d	1.226 a
	calcium chloride %0.5	1.170 a– d	1.310 a - c	1.174 b - d	
	calcium chloride %1	1.164 a - d	1.391 a b	1.273 a - c	
	magnesium sulfate %0.4	1.094 b - d	1.449 a	1.265 a – c	
Average of malic acid		1.078 b	1.271 a	1.133 b	
Average of spray treatment	0	1.068 b			
	calcium chloride %0.5	1.182 a			
	calcium chloride %1	1.232 a			
	magnesium sulfate %0.4	1.160 a b			

The means that share the same alphabetical letter for each factor and interaction do not differ significantly according to the Duncan's multiple range test at a significance level of 0.05 (P≤0.05).