Molecular Detection of PVY^{C} Strain of Potato Virus Y (PVY) in Three Potato Cultivars and Their Responses to Pesticides and Growth Regulator GA3 for Protective and Curative Control of Infection

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Abstract:

This study was conducted at the Al-Dour Agricultural Research Station of the General Authority for Agricultural Research, Ministry of Agriculture, Salahaddin Governorate, Iraq, during the 2024–2025 growing season. This study aimed to evaluate the effectiveness of several chemical treatments in reducing infection of Potato virus Y (PVY) strian and improving physiological and yield traits in three potato cultivars (Harry, Elmondo, and Sifra). PVY infection was first diagnosed based on characteristic disease symptoms and then confirmed molecularly using polymerase chain reaction (PCR). A 353 bp amplicon was detected in infected samples using a strain-specific primer, representing the first report of the PVY^{C} strain in this region. Pre-plant treatment with the pesticide VITAJAT combined with foliar application of SIVANTO$_{Prime}$ was the most effective regime, resulting in the greatest reduction in infection incidence and severity. This treatment also produced the highest leaf area (32.66 cm²), catalase activity (568.4 U g^{-1} FW), and chlorophyll content (SPAD 51.16), and consequently the highest marketable yield (52.07 t ha^{-1}), compared with the infected untreated control, which produced only 24.35 t ha^{-1}. No significant differences were observed among the cultivars for most measured traits, indicating that the chemical treatments had a greater impact on PVY resistance than cultivar genetic differences. Overall, the results highlight the importance of integrating pre-plant pesticide treatments with products such as Bevantoprim and Movento to limit PVY spread, enhance plant resistance and physiological performance, and increase marketable yield.

Keywords: Potato Virus Y (PVY), *Myzus persicae*, *Solanum tuberosum* L., SVANTO Prime , GA3 , Induced Plant Resistance.

1. Introduction

Potato (*Solanum tuberosum* L.) is one of the world's most important food crops, serving as a major source of carbohydrates and energy and ranking fourth globally in production and consumption after wheat, rice, and maize [1]. However, this vital crop faces numerous biotic and abiotic constraints that adversely affect its productivity and quality. Among the many diseases affecting potato, viral pathogens are the most widespread, causing severe reductions in seed and tuber yield, with an estimated 40–50 viruses capable of infecting potato worldwide[2].

Potato virus Y (PVY) is considered one of the most damaging viruses of potato and is primarily transmitted by sap-sucking insects, especially the green peach aphid, *Myzus persicae*, which acts as the main vector of the virus; therefore, vector control is a critical component of PVY management [3].Classification of PVY has undergone substantial refinement, with the PVY^{C} strain recognized as one of the most important

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non-recombinant strains [4].[5,6] confirmed that PVY^C possesses a distinct molecular profile, forming a well-defined subgroup within the PVY complex, yet this strain has not previously been identified in the present study region.

The spread of these viruses is associated with environmental fluctuations and the density of vector insects, in addition to the use of infected seed tubers, which contributes to the persistence and dissemination of infection across growing seasons[7]. Recent studies have highlighted the importance of biostimulants in virus control and plant resistance induction, such as algae, amino acids, and certain biocontrol fungi, alongside the application of biofertilizers to enhance plant health[8,9]. In this study, the focus was on a preventive system for virus resistance through enhancing plant resistance, using virus-free seed tubers, controlling vector insects, and applying appropriate agronomic treatments that reduce infection opportunities and disease spread.

2. Materials and Methods

2.1. Experimental Site

The field experiment was conducted at Al-Dour Agricultural Research Station (General Authority for Agricultural Research, Iraqi Ministry of Agriculture) during the spring season of 2024–2025 in Al-Dour District, Salah al-Din Governorate (34°27′ N, 43°46′ E). Planting was carried out in medium-textured gypsiferous soil with moderate drainage following standard agronomic practices for potato cultivation.

2.2. Field Survey and Diagnosis of PVY^C Strain

Plant samples were collected from potato fields at several locations in Salah al-Din Governorate and visually examined to identify characteristic symptoms of Potato virus Y (PVY) infection, Leaf yellowing, edge curling, stunting, and mottling were key visual indicators used for virus detection. [10]. Then, the PVY^C strain was genetically confirmed using specific primers for PVY^C.

The strain was then confirmed using a primer specific for the C strain. Total RNA was extracted from various plant samples (such as leaves, stems, buds, flowers, fruits, and seeds) using the Quick-RNA™ Plant Miniprep kit. The extraction was carried out according to the manufacturer's instructions.

To confirm infection, molecular diagnosis was performed using reverse transcription polymerase chain reaction (RT-PCR) after extracting total RNA from infected plant samples. Specific primers targeting the PVY-C strain were used: forward (5′-CAGCCATCTGAAAGTAGTGC-3′) and reverse (5′-TTGAAAACCGTCTTAGTTAGTT-3′). The RT-PCR reaction was carried out using Maxime RT-PCR PreMix kit (i-Taq) (Intron Biotechnology, Korea) according to the manufacturer's instructions. The reaction mixture (20 µL) consisted of 10 µL of PreMix, 1 µL of each primer (10 pmol), 2 µL of cDNA template, and 6 µL of nuclease-free water. Thermal cycling conditions included reverse transcription at 50°C for 30 min, initial denaturation at 95°C for 5 min, followed by 35 cycles of denaturation at 95°C for 30 sec, annealing at 55°C for 30 sec, and extension at 72°C for 1 min, with a final extension at 72°C for 7 min. PCR products were analyzed by electrophoresis on 1.5% agarose gel stained with ethidium bromide and visualized under UV light.

2.2.1. Virus Diagnosis

Visual diagnosis at the study site showed typical PVY symptoms, including leaf yellowing and mottling, leaf margin

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curling, stunted growth, and weakened vegetative development. These symptoms are recognized as clear diagnostic indicators of PVY infection, as reported by[11,12].

2.3. Potato Varieties in the Experiment

Three potato cultivars were used in this study, as detailed in Table (1):

No.	Cultivar	Origin Company	Country of Origin
1	Sifra	HZPC	Holland
2	Elmondo	HZPC	Holland
3	Harry	Cullen Allen	Ireland

2.4. Treatments Used in the Study

The experiment included an integrated virus and vector management program with both pre- and post-planting treatments. Pre-planting treatments were gibberellin (Gibberellic acid, 4% active ingredient) at 1 mg/L and VITAJAT WP (active ingredients …). Post-planting treatments included SIVANTO Prime (Flupyradifurone, 50–60 mL/100 L), MOVENTO SC (Spirotetramat, 60–75 mL/100 L), a positive control (infected plants without treatment), and a negative control (healthy plants free from PVY-C). The design also allowed evaluation of interactions between pre- and post-planting treatments.

2.5. Studied Traits

2.5.1. Viral Infection Percentage (%):

The infection percentage for each treatment was calculated based on the number of infected plants relative to the total number of plants after full field growth and clear symptom expression, using the formula:

Infection% = Number of infected plants ÷ Total number of plants per treatment * 100

2.5.2. Infection Severity (%)

Disease severity was estimated based on a disease rating scale designed in this study by Prof. Dr. Maadh A. Al-Fahad-Tikrit University/College of Agriculture/Virus Research Laboratory, consisting of five grades as shown in Figure(1), according to the equation[13]:

Severity of infection = [(No. of plants grade 0×0) + … + (grade 5×5)] ÷ (Total examined plants × 5).

Disease Grade Appearance Description Symptoms of infection

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0	Healthy plant	
1	Mild to moderate mosaic	
2	Severe mosaic with onset of curling	
3	Leaf yellowing and curling	
4	Severe yellowing and leaf edge scorching with onset of tissue necrosis	
5	Tissue necrosis and leaf curling with previous symptoms	

Figure (1). Guide to Stages of PVY Infection Severity

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2.5.3. Measurement of Catalase Activity

Catalase enzyme activity was determined according to the method of[14] using a reaction mixture (3 ml total volume) consisting of 2 ml of acetate buffer solution (pH 5.6), 0.3 ml of hydrogen peroxide solution (3%), and 0.2 ml of crude enzyme extract (leaves). The mixture was incubated for 4 minutes at room temperature. The enzymatic reaction was then stopped by adding 1ml of ammonium molybdate (32.4 mM). Absorbance readings were recorded at 405 nm using a spectrophotometer to determine the enzyme activity. Enzyme activity was then calculated as units/g fresh plant tissue weight as follows:

Enzyme activity (U/g fresh weight) = Enzyme unit \ (Sample weight ÷ Extraction volume) *Volume of reaction mixture taken for reading

2.5.4. Chlorophyll Content Estimation (%)

Chlorophyll content was measured using a Chlorophyll Meter of SPAD type, Indian-made, according to[15]. This was done by taking three leaves per plant from the top, middle, and bottom positions, selected randomly, per treatment. Subsequently, the average of three readings per leaf was taken at the flowering stage.

2.5.5. Leaf Area Calculation (cm²)

Leaf area was measured after the plants reached full vegetative growth and disease symptoms became visible, using the leaf-disc method based on fresh weight. Five leaves were taken from each plant for five plants, and discs were cut using a metal circular cutter with an area of 0.75 cm². The area of each leaf was calculated and averaged, then multiplied by the total number of leaves to obtain the leaf area per plant, according to the method of [16].

Leaf area per plant (cm^2 $plant^{-1}$) = (Leaf disc area × Average leaf fresh weight × Number of leaves per plant) ÷ Average disc weight

2.5.6. Total Yield Calculation

Total yield was calculated according to[17] using the following equation:

Total yield (t ha^{-1}) = (Yield per experimental unit (kg) ÷ Experimental unit area (m^2)) × 10,000

2.6. Experimental Design and Statistical Analysis

The experiment was conducted using a Randomized Complete Block Design (RCBD) with three replications. Data for each studied trait were collected, and statistical analysis was performed using SAS software (Version 9.1). Means were compared using the Least Significant Difference (LSD) test at a probability level of 0.05 to determine significant differences among treatments.

3. Results and Discussion

3.1. Molecular diagnosis of Potato Virus Y (PVY)

After electrophoresis on a 1.5% agarose gel, the PCR results (Figure 2) clearly showed a distinct band at the expected size of 353 base pairs (bp) in samples (1, 2, 5, and 6). This confirms the presence of Potato Virus Y (PVY) in these samples and indicates successful amplification of the targeted viral genomic region. The band was clearly visible when compared with the molecular weight marker (100 bp DNA ladder), which was used to estimate the size of the amplified fragments.

These findings indicate that samples 1 and 2 were positive for PVY^C strain,

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confirming infection and demonstrating the efficiency of the reaction and the accuracy of the primers used to amplify the virus-specific gene. In contrast, the absence of a band in the remaining samples suggests either the lack of infection with the virus or insufficient quality and/or concentration of the extracted nucleic acid. These results are in agreement with those reported by[18], and[19], who confirmed that PCR is one of the most sensitive and specific techniques for the detection of potato viruses such as Potato virus Y (PVY), and that it can detect the virus even at early stages before the appearance of field symptoms [20].

It was observed that the molecular results matched the field symptoms indicated by those molecular studies and the symptoms that appeared on infected plants, such as stunting, leaf yellowing, crinkling, and general growth weakness, which are characteristic signs of potato virus infection. This confirms the agreement between visual and laboratory examinations, highlighting the importance of relying on molecular diagnosis as a precise tool for confirming infection and reliably identifying the responsible virus. Molecular detection using PCR technology is thus crucial for definitively identifying the virus and its prevalent strains, enabling subsequent understanding and management of the virus lifecycle and transmission methods, which aligns with findings from several studies[21,22].

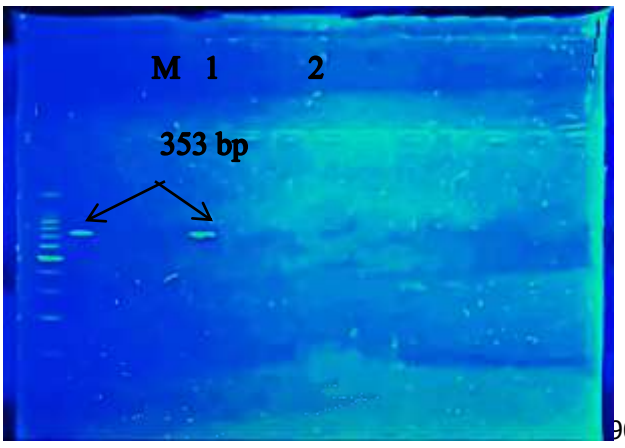

Figure (2) PCR product for the detection of potato virus at 353 base pairs.

3.2. Effect of Treatments on PVY^{C} Strain Infection Rate in Potato Yield

The statistical analysis results in Table (2) showed the superiority of the VITAJAT treatment combined with the insecticides SIVANTO$_{Prime}$ and Movento (foliar spraying), as it exhibited zero infection rate (0.00%) across all three studied potato cultivars. This likely indicates the high efficiency of this treatment in reducing viral infection. The reduction may be attributed to the dual effect of imidacloprid and thiamethoxam in controlling the aphid vector (the primary transmitter of PVY virus) by decreasing their population and inhibiting their mobility on treated plants, as well as their role in activating systemic induced resistance within plant tissues.

In contrast, the highest infection rates were recorded in the positive control treatment, ranging from 70.00% to 80.00%. This reflects the severity of infection in untreated plants. The results of the present study are consistent with those reported by [23], who evaluated the efficacy of colored traps and certain insecticides against the green peach aphid (Myzus persicae) on tomato plants. The study demonstrated that systemic insecticides such as imidacloprid, acetamiprid, and thiamethoxam significantly reduced aphid populations. Since M. persicae is one of the most important vectors of plant viruses, reducing its population density indirectly limits the spread of viral diseases and improves plant health.

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The potato cultivars showed no significant effect on values of this trait, recording 26.17%, 26.30%, and 25.79% for Elmondo, Sefra, and Harry, respectively. Cultivar tolerance does not serve as a primary factor in reducing infection, aligning with[24], who stated that varietal differences alone are insufficient for PVY control. Effective management primarily depends on the type of treatment applied to handle potato virus Y (PVY), as confirmed by[25].

Meanwhile, treatment with gibberellin (GA_3) showed relatively high infection rates (56.66%–73.33%), indicating that stimulating vegetative growth was not sufficient to reduce viral transmission. It may have even increased susceptibility due to larger leaf area and a more favorable environment for aphids. This explanation agrees with the observations by[26].

Table (2): Effect of Chemical Treatments, GA_3 Growth Regulator, and Their Interaction on the Infection Rate of the PVY^C Strain in Potato Cultivar

Treatments		Cultivars%			Interaction
		Elmondo	Sefra	Harry	
GA_3		66.67	56.66	73.33	65.56
GA_3	SIVANTO $_{Prime}$ drip irrigation	30	26.67	33.33	30.00
	SIVANTO $_{Prime}$ foliar spray	30	23.33	33.33	28.89
	MOVENTO drip irrigation	23.33	20	26.67	23.33
	MOVENTO foliar spray	20	13.33	13.33	15.56
VITAJAT		0.00	0.00	6.67	2.22
VITAJAT	SIVANTO$_{Prime}$ drip irrigation	0.00	0.00	3.33	1.11
	SIVANTO $_{Prime}$ foliar spray	0.00	0.00	0.00	0.00
	MOVENTO drip irrigation	0.00	0.00	3.33	1.11
	MOVENTO foliar spray	0.00	0.00	0.00	0.00
Actara		63.33	53.33	66.67	61.11
Actara	SIVANTO$_{Prime}$ drip irrigation	26.67	20.00	30.00	25.56
	SIVANTO $_{Prime}$ foliar spray	23.33	13.33	26.67	21.11
	MOVENTO drip irrigation	13.33	6.67	16.67	12.22

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MOVENTO foliar spray	16.67	10	16.67	14.44
SIVANTO$_{Prime}$ drip irrigation	43.33	40	50	44.44
SIVANTO $_{Prime}$ foliar spray	40	33.33	40	37.78
MOVENTO drip irrigation	36.67	33.33	36.67	35.56
MOVENTO foliar spray	43.33	33.33	36.67	37.78
Positive control	73.33	70	80	74.44
Negative Control	0	0	0	0.00
L.S.D 0.05	10.215			5.8978
Cultivars interaction	26.17	26.30	25.79	
L.S.D 0.05	2.2292			

3.3. Effect of Treatments on PVY^{C} Strain Infection Severity in Potato Yield

Statistical analysis results presented in Table (3) showed significant differences in infection severity. The treatment combining VITAJAT with the insecticide SIVANTO $_{Prime}$ (foliar spray) recorded the lowest infection severity (0.00%) across all cultivars. This reduction is likely due to the ability of the two active ingredients (imidacloprid and thiamethoxam) to suppress infection development inside the plant after initial inoculation through their protective effect and induction of resistance. This finding aligns with [27], who reported that imidacloprid application impedes virus movement within plant tissues by inhibiting aphid feeding. Similarly, [28] reported that the insecticide imidacloprid reduces the spread of Potato Virus Y (PVY) by significantly lowering populations of aphid vectors, which in turn decreases the severity of viral infection. In contrast, the positive control treatment showed the highest infection severity, with a disease index value of 0.65 on a scale ranging from 0 to 5.

As for the varieties, the severity of infection ranged between (0.25–0.30) with no clear significant differences, indicating similarity in the response of the three varieties to viral infection. However, the Sefra variety showed a slight decrease in infection severity compared to the other varieties, which may be attributed to its partial ability to tolerate the infection. This explanation is consistent with the findings of [29] and helps clarify the behavior of the virus at the sites of infection. It also corresponds with the observations of [30], who reported that the virus can localize within different parts of the cell, including the cytoplasm, nucleus, and chloroplasts.

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Table (3) : Effect of chemical treatments, GA_3 growth regulator, and their interaction on PVY^C infection severity in potato cultivars.

Treatments		Cultivars			interactions
		Elmondo	Sefra	Harry	
GA_3		0.52	0.49	0.53	0.51
GA_3	SIVANTO$_{Prime}$ drip irrigation	0.4	0.4	0.42	0.41
	SIVANTO $_{Prime}$ foliar spray	0.38	0.34	0.4	0.37
	MOVENTO drip irrigation	0.4	0.38	0.4	0.39
	MOVENTO foliar spray	0.35	0.23	0.27	0.29
VITAJAT		0	0	0.033	0.011
VITAJAT	SIVANTO$_{Prime}$ drip irrigation	0	0	0.013	0.004
	SIVANTO $_{Prime}$ foliar spray	0	0	0	0.00
	MOVENTO drip irrigation	0	0	0.02	0.006
	MOVENTO foliar spray	0	0	0	0.00
Actara		0.51	0.49	0.54	0.51
Actara	SIVANTO$_{Prime}$ drip irrigation	0.4	0.35	0.4	0.38
	SIVANTO $_{Prime}$ foliar spray	0.36	0.23	0.38	0.32
	MOVENTO drip irrigation	0.26	0.13	0.26	0.21
	MOVENTO foliar spray	0.24	0.1	0.17	0.17
SIVANTO$_{Prime}$ drip irrigation		0.49	0.44	0.49	0.47
SIVANTO $_{Prime}$ foliar spray		0.45	0.37	0.45	0.42
MOVENTO drip irrigation		0.52	0.44	0.52	0.49
MOVENTO foliar spray		0.37	0.34	0.4	0.37
Positive control		0.62	0.6	0.73	0.65
Negative Control		0	0	0	0.00

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L.S.D 0.05	0.1281			0.074
Cultivars interaction	0.299	0.255	0.306	
L.S.D 0.05	0.028			

The results indicate a strong positive correlation between the infection rate and its severity; as the percentage of virus-infected plants increases, the degree of development and severity of visible symptoms also increases. The pre-planting treatment with VITAJAT combined with the insecticides SIVANTO $_{Prime}$ and Movento (foliar spraying) excelled by showing no viral infection, and no clear viral disease severity was recorded. This agreement between the infection rate and severity might be due to controlling the virus-transmitting insects, which reduced the primary infection rate, resulting in delayed virus accumulation within plant tissues, hence reducing symptom severity such as mottling, stunting, and leaf yellowing[31]. Furthermore, the activation of the oxidative defense system in treated plants contributed to suppressing the development of secondary infection and mitigating its damage[32]. This was directly reflected in the reduction of both infection rate and viral severity.[33] showed that the decreased viral infection rate in pepper plants infected with PepGMV virus was associated with a 42% reduction in leaf symptom severity, attributing this to increased activities of defensive enzymes and the induction of systemic acquired resistance (SAR), which slows viral spread within tissues.

3.4. Effect of treatments on leaf area of plants infected with PVY^C strain

The results presented in Table (4) revealed clear variation in leaf area among the different growth treatments across the potato cultivars. The overall mean leaf area values were 25.79, 26.30, and 26.17 cm² for Elmondo, Sefra, and Harry, respectively, indicating no significant differences among the three cultivars for this trait.

Regarding the two-way interaction, the treatment of VITAJAT combined with foliar application of $SIVANTO_{Prime}$ outperformed most other treatments, recording the highest leaf area of 32.66 cm², while the positive control treatment exhibited the lowest mean value of 19.87 cm². This superiority may be attributed to VITAJAT

role in reducing insect infestation, which alleviated biotic stress and allowed the plant to allocate more physiological resources toward growth, including enhanced cell division and vegetative development, resulting in expanded leaf area. Additionally, foliar application of $SIVANTO_{Prime}$ improved micronutrient availability and increased chlorophyll content within the leaves, thereby enhancing photosynthetic efficiency. This approach aligns with Integrated Pest Management (IPM) strategies, which integrate chemical control measures to improve plant health and physiological performance [34].

The interaction between treatments and cultivars showed significant variation. The VITAJAT + SIVANTO Prime treatment in the Sefra cultivar produced the highest leaf area (32.75 cm²), while the positive control in the Harry cultivar recorded the lowest value (19.54 cm²). This outcome can be explained

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by the amplified response of cultivars with high genetic potential for vegetative growth. The cultivar Sefra exhibited greater responsiveness to growth-promoting factors, likely due to its higher efficiency in micronutrient uptake. These findings are supported by [35], who highlighted the superiority of certain treatment–cultivar interactions in improving productivity and emphasized the role of genetic composition in determining plant response and agronomic performance.

Table (4): Effect of chemical treatments and GA_3 growth regulator, and their interaction, on the leaf area of potato cultivars infected with PVY^C strain.

Treatments		Cultivars			Interactions
		Elmondo	Sefra	Harry	
GA_3		20.13	21.80	19.54	20.49
GA_3	SIVANTO$_{Prime}$ drip irrigation	22.67	22.65	21.70	22.34
	SIVANTO $_{Prime}$ foliar spray	22.95	23.75	22.71	23.14
	MOVENTO drip irrigation	22.41	22.19	22.09	22.23
	MOVENTO foliar spray	23.71	23.91	22.97	23.53
VITAJAT		30.92	30.11	29.45	30.16
VITAJAT	SIVANTO$_{Prime}$ drip irrigation	31.41	30.99	30.58	30.99
	SIVANTO $_{Prime}$ foliar spray	33.71	32.75	31.53	32.66
	MOVENTO drip irrigation	30.61	30.88	30.87	30.79
	MOVENTO foliar spray	31.65	31.63	31.25	31.51
Actara		24.11	25.20	24.49	24.60
Actara	SIVANTO$_{Prime}$ drip irrigation	24.95	25.31	26.78	25.68
	SIVANTO $_{Prime}$ foliar spray	26.68	27.07	26.36	26.70
	MOVENTO drip irrigation	25.63	25.33	25.29	25.42
	MOVENTO foliar spray	25.95	26.97	26.03	26.32
SIVANTO$_{Prime}$ drip irrigation		27.07	27.00	26.14	26.74
SIVANTO $_{Prime}$ foliar spray		27.90	27.80	27.29	27.66

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MOVENTO drip irrigation	26.02	26.78	26.37	26.39
MOVENTO foliar spray	27.68	27.88	27.42	27.66
Positive control	20.32	19.05	20.25	19.87
Negative Control	23.12	23.30	22.41	22.94
L.S.D 0.05	2.7589			1.5928
Cultivars interaction	26.17	26.30	25.79	
L.S.D 0.05	0.602			

3.5. Effect of treatments on catalase enzyme activity in plants infected with PVY^C strain

Results in Table (5) showed that foliar spraying with $SIVANTO_{Prime}$ combined with gibberellin(GA_3) treatments recorded the highest enzyme activity rate of 568.4 U/g FW, outperforming other treatments. In contrast, the positive control treatment showed the lowest activity with 267.9 U/g FW. This decrease may be attributed to enzyme activity inhibition caused by the high viral replication within cells, which leads to suppression of certain antioxidant enzymes and increased oxidative stress[36].

The results indicate that the elevated catalase activity in gibberellin(GA_3) +$SIVANTO_{Prime}$ treatments reflects an effective physiological defense response of the plant against viral infection, as this enzyme helps protect plant cells from excessive oxidation induced by the virus. This aligns with observations by[37]. Similarly,[38] reported increased catalase enzyme activity in maize cultivar ZmCATs upon infection with Sugarcane mosaic virus (SCMV), which suggests enzymatic response to oxidative stress caused by the virus. Thus, the current results can be interpreted as the chemical treatments and growth regulator stimulating the plant's defensive enzymatic activity, contributing to reduced viral infection severity and improved physiological stability of the leaves.

The binary interaction between treatments and cultivars revealed that the Harry cultivar recorded the highest average enzyme activity at 422.28 U/g FW. This likely indicates its high efficiency in activating oxidative defense systems compared to other cultivars. This is consistent with[39], who showed that the variation in catalase activity among potato cultivars is related to differential gene expression of catalase isoenzymes. Some isoenzymes, such as CAT2, increase enzymatic activity levels in response to oxidative stress, whereas others remain stable. The increased total catalase activity in potato leaves primarily reflects upregulation of specific gene isoforms, explaining the observed cultivar differences in defense capacity against oxidative pathogenic factors , This aligns with the findings of[40], who demonstrated the impact of various types of enzymes on general cell growth, in addition to the pathological

effects of some of them.

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Table (5) Effect of chemical treatments and GA_3 growth regulator, and their interaction on catalase enzyme activity (U/g FW) in potato cultivars infected with PVY^C strain.

Treatments		Cultivars			interactions
		Elmondo	Sefra	Harry	
GA_3		526.04	509.25	550.61	528.6
GA_3	$SIVANTO_{Prime}$ drip irrigation	553.62	536.83	578.19	556.2
	$SIVANTO_{Prime}$ foliar spray	566.44	548.65	590.01	568.4
	MOVENTO drip irrigation	533.92	517.14	558.49	536.5
	MOVENTO foliar spray	545.74	528.95	570.33	548.3
VITAJAT		423.65	404.81	448.17	425.5
VITAJAT	$SIVANTO_{Prime}$ drip irrigation	445.27	429.48	469.84	448.2
	$SIVANTO_{Prime}$ foliar spray	455.12	438.33	479.69	457.7
	MOVENTO drip irrigation	447.24	430.45	471.81	449.8
	MOVENTO foliar spray	464.97	448.18	489.54	467.6
Actara		327.08	311.28	352.64	330.3
Actara	$SIVANTO_{Prime}$ drip irrigation	360.56	343.77	385.13	363.2
	$SIVANTO_{Prime}$ foliar spray	382.21	366.43	407.83	385.5
	MOVENTO drip irrigation	334.95	318.16	359.52	337.5
	MOVENTO foliar spray	362.53	344.75	387.14	364.8
$SIVANTO_{Prime}$ drip irrigation		356.62	339.83	381.19	359.2
$SIVANTO_{Prime}$ foliar spray		368.44	351.65	393.04	371.0
MOVENTO drip irrigation		299.49	282.72	324.06	302.1
MOVENTO foliar spray		312.31	294.52	336.88	314.6
Positive control		265.03	247.21	291.57	267.9
Negative Control		202.96	186.17	227.53	205.6

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L.S.D 0.05	111.29			64.252
Cultivars interaction	406.4	368.52	422.28	
L.S.D 0.05	24.285			

3.6. Effect of treatments on chlorophyll content in plants infected with PVY^C strain

Statistical analysis results presented in Table (6) show that the foliar spraying treatment with $SIVANTO_{Prime}$ combined with VITAJAT insecticide significantly outperformed other treatments, achieving the highest chlorophyll content with a SPAD value of 51.16. This was followed by the gibberellin(GA_3) treatment combined with foliar spraying of $SIVANTO_{Prime}$, which recorded 49.59 SPAD. In contrast, the positive control treatment had the lowest value of 38.68 SPAD. These results indicate that the foliar spray with $SIVANTO_{Prime}$ contributed to increasing leaf chlorophyll content, likely due to enhanced nutrient uptake and activation of enzymes responsible for synthesizing green pigments in the leaves. This result is consistent with what was reported by[41] in a study on some potato cultivars, where they observed variation in vegetative growth traits.

The results also show that reducing insect and virus infection was positively reflected in decreasing the pathological damage caused by the virus, particularly with respect to chlorophyll content, and consequently improving growth parameters. This is close to what was reported by[42] in their study on this interrelated effect on growth improvement, as these results agreed with the periodic field observations for monitoring viral symptoms and the low infection severity in the treatment combining Phytagat and the insecticide Sefantopyram compared with the control treatment. In addition,[43] demonstrated that soaking treatment with gibberellic acid at a concentration of 100 mg/L led to a significant increase in most vegetative growth traits and chlorophyll content. As for the effect of the other factor, it was not of a significant impact compared with the effect of the treatments.

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Table (6) Effect of chemical treatments and GA_3 growth regulator, and their interaction on chlorophyll content (SPAD) of potato cultivars infected with PVY^C strain.

Treatments		Cultivars			interactions
		Elmondo	Sefra	Harry	
GA_3		42.32	42.56	42.73	42.54
GA_3	$SIVANTO_{Prime}$ drip irrigation	47.74	47.75	47.83	47.75
	$SIVANTO_{Prime}$ foliar spray	49.79	49.6	49.39	49.59
	MOVENTO drip irrigation	46.39	46.55	46.49	46.51
	MOVENTO foliar spray	49.64	49.61	49.22	49.49
VITAJAT		44.05	44.77	44.34	44.39
VITAJAT	$SIVANTO_{Prime}$ drip irrigation	49.82	49.96	49.84	49.86
	$SIVANTO_{Prime}$ foliar spray	50.89	51.69	50.89	51.16
	MOVENTO drip irrigation	47.6	47.47	47.67	47.58
	MOVENTO foliar spray	49.39	49.69	49.54	49.54
Actara		37.33	36.97	36.35	36.89
Actara	$SIVANTO_{Prime}$ drip irrigation	39.36	40.3	39.71	39.79
	$SIVANTO_{Prime}$ foliar spray	41.86	42.08	41.93	41.95
	MOVENTO drip irrigation	39.14	39.53	39.98	39.55
	MOVENTO foliar spray	40.49	40.76	40.58	40.61
$SIVANTO_{Prime}$ drip irrigation		43.65	43.2	43.465	43.45
$SIVANTO_{Prime}$ foliar spray		47.47	47.37	47.49	47.44
MOVENTO drip irrigation		42.30	42.54	42.61	42.49
MOVENTO foliar spray		45.85	45.47	45.5	45.61
Positive control		38.38	38.84	38.84	38.68

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Negative Control	39.69	39.85	39.39	39.64
L.S.D 0.05	0.879			0.5075
Cultivars interaction	44.44	44.59	44.47	
L.S.D 0.05	0.1918			

3.7. Effect of treatments on total yield (ton/ha)

The treatments shown in Table (7), which included the combination of VITAJAT with SIVANTO$_{Prime}$ and Movento (foliar spraying), achieved the highest yield across all studied cultivars. The highest average marketable yield reached 51.16 ton/ha in the treatment combining VITAJAT with foliar spraying of SIVANTO $_{Prime}$, compared to the positive control treatment (infected untreated plants) that gave the lowest yield with an average of 24.35 ton/ha. This clearly demonstrates the positive impact of preventive and curative treatments in enhancing marketing efficiency and reducing losses caused by viral infection.

Interaction analysis between treatments and cultivars showed that the combined VITAJAT with SIVANTO$_{Prime}$ and Movento foliar spraying treatments significantly outperformed all other treatments, achieving yield increases ranging from 40% to 85% compared to the positive control. This substantial productivity improvement may be attributed to the reduced viral infection rates under these treatments, which allowed healthy vegetative growth and sustained high photosynthetic efficiency. Additionally, the effectiveness of SIVANTO$_{Prime}$ and Movento insecticides in reducing populations of virus-vector aphids, especially the green peach aphid (Myzus persicae), curtailed reinfection and viral spread in the field. These findings are consistent with[44].

Among cultivars, Elmondo surpassed Sefra and Harry in average total yield (39.06 ton/ha vs. 37.25 and 38.18 ton/ha, respectively), indicating its superior genetic capacity to benefit from biological and chemical treatments. This agrees with[45], who reported that phenotypic variation among potato cultivars due to genetic differences impacts important traits such as number of sprouts, emergence time, and tuber size, leading to clear differences in yield under similar environmental conditions.

The increase in marketable yield in effective treatments can be directly explained by improved physiological traits in treated plants, as evidenced by

the significant increase in chlorophyll content (51.16 SPAD) and catalase enzyme activity (568.4 U/g FW). These enhancements contributed to higher photosynthetic efficiency and carbohydrate transport to tubers, limiting PVY^{C} strain pathogenicity and restricting its spread in plants. This is supported by studies showing that total yield is significantly correlated with leaf chlorophyll content[46].

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Table (7) Effect of chemical treatments and GA_3 growth regulator, and their interaction on total yield (ton/ha) of potato cultivars infected with PVY^C strain.

Treatments		Cultivars			interactions
		Elmondo	Sefra	Harry	
GA_3		33.02	32.24	32.82	32.69
GA_3	SIVANTO$_{Prime}$ drip irrigation	40.34	40.46	41.32	40.71
	SIVANTO $_{Prime}$ foliar spray	42.65	44.55	42.81	43.33
	MOVENTO drip irrigation	41.50	41.91	42.57	41.99
	MOVENTO foliar spray	42.94	41.42	41.19	41.85
VITAJAT		35.44	36.91	34.84	35.73
VITAJAT	SIVANTO$_{Prime}$ drip irrigation	50.29	47.02	46.55	47.95
	SIVANTO $_{Prime}$ foliar spray	52.85	54.04	49.31	52.07
	MOVENTO drip irrigation	46.87	46.91	48.67	47.48
	MOVENTO foliar spray	51.03	52.11	50.37	51.17
Actara		35.91	37.11	35.57	36.19
Actara	SIVANTO$_{Prime}$ drip irrigation	39.43	39.21	39.03	39.22
	SIVANTO $_{Prime}$ foliar spray	41.79	41.30	39.29	40.79
	MOVENTO drip irrigation	40.02	41.89	42.66	41.53
	MOVENTO foliar spray	40.04	39.97	40.75	40.25
SIVANTO$_{Prime}$ drip irrigation		33.02	32.95	32.72	32.89
SIVANTO $_{Prime}$ foliar spray		34.88	33.68	34.00	34.19
MOVENTO drip irrigation		31.57	32.61	33.51	32.56
MOVENTO foliar spray		34.19	35.17	33.89	34.42
Positive control		23.85	24.68	24.53	24.35
Negative Control		28.71	28.73	28.44	28.63

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L.S.D 0.05	4.057			2.3423
Cultivars interaction	39.06	39.28	39.06	39.28
L.S.D 0.05	0.8866			

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