Contreras-Liza and Vargas-Luna
CABI Agriculture and Bioscience (2022) 3:19
https://doi.org/10.1186/s43170-022-00088-5

CABI Agriculture and Bioscience

RESEARCH

Open Access

Use of acetylsalicylic acid and agronomic performance of potatoes in Lima region

Sergio Contreras-Liza[1*] and Luis Vargas-Luna[2]

Abstract

Background: Salicylic acid participates in the regulation of the plant's response to a series of environmental stresses such as extreme temperatures, salinity, and oxidative condition of potato growth, so it is necessary to determine a safe application dosage for potato in field conditions.

Methods: The purpose of the research was to evaluate the effect of increasing doses of acetylsalicylic acid on the agronomic traits of two potato cultivars in Lima, Peru. In a field experiment, an RCBD with 3 replications was used under a split-plot arrangement in which five doses (0.0, 0.2, 0.4, 0.6, and 0.8 mM) of acetylsalicylic acid plus control with Biol (biostimulant) were assigned to plots, and two potato cultivars ('Perricholi' and 'Unica') were assigned to subplots. The average temperatures were between 15 and 21º C, the air relative humidity was between 61 and 73% and the soil was loam textural class, free of salts.

Results: No statistical differences were found for the number and weight of tubers and biomass due to the effect of the application of the treatments. The effects of doses of acetylsalicylic acid showed statistical differences for sprouting, vegetative vigor, and percentage of flowering; likewise, significant interactions ($p < 0.05$) were shown between potato cultivars and dose of acetylsalicylic acid for the number of stems per plant and percentage of flowering, which indicated a specific effect for the dose of acetylsalicylic acid in each potato cultivar. Statistical differences ($p < 0.05$) were found between the two potato cultivars for most of the characters studied.

Conclusion: No dose of the product significantly affected the potato yield in two potato cultivars however, the effect of the dosage of acetylsalicylic acid improved the performance of the crop in terms of sprouting in the field, vegetative vigor, a greater number of stems per plant as well as stimulation of flowering, with respect to control.

Keywords: Potato, Agronomic performance, Acetylsalicylic acid, Field experiment, Safe dose

Background

The potato (*Solanum tuberosum*) is the main food of the Andean people (BID 2020; FAO 2020). This region is the center of origin of the potato and its wild relatives (de Haan and Rodríguez 2016), so it is convenient to develop new agronomic management technologies with less impact on the ecosystem (Quiroz et al. 2018) since the use of chemical pesticides in the potato is increasing in developing countries as farmers intensify production (FAO 2008a). Most farm households in the Peruvian Andes hold diversified, low-input cropping systems (Ponce 2020) but other countries in South America have increased their use due to a shift from small-scale peasant farming to more intensive farming systems (Bakker 2021).

Likewise, the virtues of the potato, in particular its great nutritional value and its ability to increase farmers' income, have not received the attention they deserve from governments, therefore it is necessary to invest in new technologies with the potential to reduce crop risks (FAO 2008b), as climate change has a significant effect on

*Correspondence: scontreras@unjfsc.edu.pe
[1] Department of Agronomy, Universidad Nacional Jose Faustino Sanchez Carrion, Av. Mercedes Indacochea 609, Huacho, Peru
Full list of author information is available at the end of the article

the magnitude and frequency of the incidence of pests and diseases in potato (Quiroz et al. 2018). Adaptation to climate changes raises concern about current adaptation responses that may hamper the agricultural system's sustainability in the face of climate change (Ponce 2020).

Some signals from low molecular weight compounds, including jasmonic acid, ethylene, and salicylic acid, regulate the expression of defense-related genes (Delaney et al. 1994). With the use of these regulators, the plant refines its expression of defense genes against aggressors that, in some cases, may be able to alter or expand defense signal pathways (Reymond and Farmer 1998). Salicylic acid (SA) is a molecule related to the stress response in plants (Hayat and Ahmad 2007) and is therefore considered a candidate for exogenous applications as an activator of induced systemic resistance. In particular, acetylsalicylic acid (the active ingredient in aspirin) is a phenolic compound analogous to SA, which has been identified as a low-cost, non-phytotoxic product (Raskin 1992). Typically caused by local infection, plants respond with a cascade of salicylic acid-dependent signaling that leads to systemic expression of broad-spectrum resistance and long-lasting resistance that is effective against fungi, bacteria, and viral infections; salicylic acid acts as a potent plant growth regulator that can effectively modulate various plant growth responses (Hayat et al. 2010).

In the words of Walters et al. (2013), induced resistance has the potential to revolutionize disease control in crops, but it remains an unconventional type of crop protection. The results of numerous investigations conducted over the last two decades have shown that SA plays an important role in various aspects of defense responses after a pathogen attack (Vlot et al. 2009). These include, among others, the activation of cell death, the expression of pathogen resistance proteins, as well as the induction of local and systemic resistance to diseases (Hayat and Ahmad 2007).

SA stimulates resistance to viral replication, intercellular spread, and systemic movement in plants (Murphy et al. 2020). The efficiency in obtaining potato seedlings without virus infection by thermotherapy increased from 30.6 to 72.2% in seedlings treated with salicylic acid (Gonzalez and Huarte 2011). The importance of SA in the viral multiplication of PVY and in symptoms was confirmed by Baebler et al. (2011) with the development of pronounced symptoms in a NahG-Desiree transgenic potato variety devoid of salicylic acid and the reversal of the effect after spraying with 2,6-dichloro isonicotinic acid, a compound analogous to salicylic acid. Halim et al. (2007) determined in transgenic NahG potato plants, incapable of accumulating salicylic acid, a drastic increase in the growth of pathogens and increased susceptibility of the transformed plants. These same plants previously treated with the salicylic acid analogue 2,6 dichloro-isonicotinic acid allowed the growth of pathogens to a level similar to that of non-transgenic plants, indicating that salicylic acid is an important compound that is required for basal defense of the potato against late blight. *Bacillus subtilis*, individually and in composition with SA, increased ascorbic acid content and decreased pathogen-induced proline accumulation and lipid peroxidation, for postharvest diseases (*Phytophthora infestans* and *Fusarium oxysporum*) development in stored potato tubers (Lastochkina et al. 2020).

Salicylic acid treatments significantly stimulated ethylene production in potato slices during 24 h of aging. With 90 uM of salicylic acid, the stimulation was positively correlated with the applied concentrations (Liang et al. 1997). Salicylic acid showed a maximum stimulating effect on ethylene production at pH 6.4; this effect of salicylic acid is different from the general view that salicylic acid ultimately inhibits ethylene biosynthesis in plants. Zhang et al. (2013) consider that the enzyme salicylic acid 3-hydroxylase regulates the longevity of the leaf in Arabidopsis through the catabolism of salicylic acid.

According to González-Gallegos et al. (2015), the production of salicylic acid in potato plants was manifested by inoculation with *Bacillus* spp. and *Pseudomonas fluorescens*, which led to increased resistance to plant diseases. The numbers and size of lesions per plant were reduced by the application of SA against *Phytophthora infestans* in potatoes and plants treated with SA had higher peroxidase and polyphenol oxidase activity (Ghazanfar et al. 2020). Zhou et al. (2018) demonstrated that the gene *StbZIP61* functions in concert with *StNPR3L* to regulate the temporal activation of SA biosynthesis, which contributes to SA-mediated immunity against *P. infestans* infection in potatoes.

Makarova et al. (2018) suggested that responses to heat stress and PVY infection in potatoes have some common underlying mechanisms, which may be integrated into a specific consolidated network that controls plant sensitivity to multiple stresses in a cultivar-specific manner, and that the SA pretreatment subverted the sensitive combined (heat and PVY) stress phenotype in potatoes implicating SA as a key component of such a regulatory network. Li et al. (2019) indicated that exogenous SA can play a positive regulatory role in alleviating Cd toxicity in potato plants.

Despite the high basal levels of salicylic acid that potatoes naturally have, this crop can respond to exogenous application of salicylic acid at a low concentration when sprayed on plants. However, plants grown in field conditions seem less sensitive at certain times (Navarre and Mayo 2004). It is necessary to continue exploring the signaling pathways of this molecule in the context of resistance to diseases in crops (Delaney et al. 1994) and to evaluate the dose–effect of salicylic acid since, like any phytohormone, it requires a specificity for its action in the induction of defenses in plants (Van Loon 2007). The weakness of salicylic acid is that its life inside the plant is very short, being immobilized in the cell walls, which is why a routine application is necessary throughout the life of the crop in order to maintain high levels of resistance (USAID 2006). The role of SA in potato and its involvement in SAR signaling has been an ongoing debate because, unlike tobacco and Arabidopsis, potato is considered to display high levels of endogenous SA (Alexandersson et al. 2016). The objective of the present research was to determine response to exogenous application of acetylsalicylic acid—a pharmacological compound derived from salicylic acid- on the agronomic performance of two commercial potato cultivars under field conditions in Lima, Peru.

Material and methods

Description of the experimental site

The experiment was carried out under field conditions during the winter season in the district of Imperial, province of Cañete (Peru). The average temperature was in the range between 15 and 21 ºC, the relative humidity between 61 and 73%, with an average of 2 h of sunshine per day and 3 mm of evaporation per day. The soil was of a loamy textural class, pH 7.5, low content of organic matter, high content of phosphorus, and medium in potassium (Additional file 1: Table S1). A fertilization formula of 100–80–120 and the equivalent of one ton of dry manure per hectare was applied, according to the soil analysis carried out.

Materials

Two potato cultivars, "Unica" (CIP 392,797.22) and "Perricholi" (CIP 374,080.5) provided by the International Potato Center (Lima), which are commercial varieties for direct consumption in Peru, were used as plant material. The seed tubers were disinfected with Benlate (Benomyl) and when they were properly sprouted, they were applied with the selected treatments and sown. On the other hand, the doses of acetylsalicylic acid (ASA) were formulated using the commercial pharmacological product aspirin® (diluted previously in ethanol 90º) at concentrations of 0.2, 0.4, 0.6, and 0.8 mmol L^{-1} in filtered water (Additional file 1: Table S2). An organic treatment with Biol (liquid commercial product) at a concentration of 1% was included, in addition to the absolute control without acetylsalicylic acid. Agricultural pesticides (cyromazine 75 WP) were also used to control the leaf miner fly (*Liriomyz*a *huidobrensis*), for hyaline mite (*Polyphagotarsonemus latus*) abamectin 0.15 EC, and for *Alternaria* sp., propineb 70% WP, as part of the control of pests and diseases in the field.

Form of application of the treatments

Five applications were made during the vegetative period of the crop (105 days). The first application was in seed tuber immersion; the following applications of the treatments were sprayed on the foliage at the doses considered in Additional file 1: Table S2, with a fortnightly frequency from the sprouting in the field. The volume of water applied was dependent on the size of the foliage of the plants, maintaining the concentration of the treatments. The plots with the control treatment were applied with running water.

Characteristics evaluated

The following agronomic characteristics were evaluated: plant density per experimental unit 30 days after sowing, number of stems per plant at 45 days, vegetative vigor (a phenotypic scale for the vigor rating: very weak, weak, medium, vigorous, very vigorous was converted to a numerical scale (1, 3, 5, 7, 9), plant height, percentage of flowering plants, percentage of plants with virus symptoms (the incidence data of plants with virus symptoms were transformed to square root), percentage of plant survival to harvest, the weight of foliage per plant, number of tubers per plant, the weight of tubers per plant and the total weight of biomass (kg ha^{-1}).

Experimental design and statistical analysis

A Random Complete Blocks Design with three replications was used, under an arrangement of split plots, in which the acetylsalicylic acid treatments and the control were assigned to complete plots (six) and the cultivars (two) to subplots. The size of the basic experimental unit (subplot) was 60 plants per treatment (18.5 m^2) and the total experimental area was 640 m^2. The data were statistically analyzed to determine the significance of the main effects and interactions at a 95% confidence level, using analysis of variance. Principal Component Analysis (PCA) for the responses of the potato varieties to different treatments was performed. The means of the treatments were compared using the Tukey test and the data were processed with the Infostat program, version 2019.

Results

In Table 1, it can be shown that the treatments applied with acetylsalicylic acid and Biol affected the variability of agronomic characters such as plant density per experimental unit, vegetative vigor, and the percentage of flowering, and there were some significant interactions between the potato cultivars and the treatments

Table 1 ANOVA for plant parameters in 2 potato cultivars under the effect of acetylsalicylic acid

Sources	dF	Mean Squares				
		PD	NSP	VV	PH	PV
Blocks	2	ns	ns	*	ns	ns
Cultivars	1	*	*	ns	*	*
Treatments	5	*	ns	*	ns	ns
Error a	10					
Cultivar/Treatment	5	*	*	ns	ns	ns
Error b	12					
Total	35					
Means		87.90	2.63	7.06	47.42	2.24
R^2		0.87	0.83	0.86	0.93	0.88
CV, %		17.13	13.05	4.02	9.65	29.7
Units		n	n	Scale 1–9	cm	.$\sqrt{(\% + 1)}$

ns = non significant mean squares, * = significant mean squares ($P < 0.05$). PD = density of plants per experimental unit at 15 days, NS = number of stems/plant at 30 days, VV = vegetative vigor (phenotypic scale 1–9), PH = plant height at 60 days (cm.), PV = percentage of plants with virus symptoms (square root transformed data). R^2 = coefficient of determination, CV, % = coefficient of variation

applied with acetylsalicylic acid, in plant density, number of stems per plant, and flowering.

There were statistical differences for the potato genotypes in the characters studied, such as sprouting, number of stems per plant, plant height, percentage of flowering, the incidence of viruses, weight of foliage, weight of tubers, number of tubers, and plant survival to harvest (Tables 1 and 2).

There were no significant differences for the acetylsalicylic acid and Biol treatments in terms of biomass yield per hectare, nor their components of number and weight of tubers per plant; there were also no statistical differences in the fresh weight of the foliage as a result of the inducing treatments (Table 2).

For plant density per experimental unit, it is noted in Table 3 that Biol and acetylsalicylic acid treatments at a dose of 0.4 mmol significantly increased sprouting in both cultivars compared to the control. In the case of the number of stems per plant at 30 days, significant differences were observed between doses and in the interaction of doses and cultivars.

Likewise, for the number of stems per plant, the treatments with Biol or with the dosage of acetylsalicylic acid between 0.2 and 0.4 mmol had a significant effect in the Perricholi variety for this character in relation to the control without application, not so in the cv. Unica where no significant differences were evidenced to stimulate sprouting per plant (Table 3); these results

Table 2 ANOVA for productive traits in 2 potato cultivars under the effect of acetylsalicylic acid

Sources	dF	Mean Squares					
		PF	WFP	NTP	WTP	PS	BIO
Blocks	2	ns	*	*	ns	ns	*
Cultivars	1	*	*	*	*	*	*
Treatments	5	*	ns	ns	ns	ns	ns
Error a	10						
Cultivar/Treatment	5	*	ns	ns	ns	ns	ns
Error b	12						
Total	35						
Means		19.04	0.31	5.40	0.48	93.17	29 601
R^2		0.99	0.78	0.71	0.77	0.87	0.77
CV, %		16.48	20.74	23.91	19.97	3.92	17.68
Units		%	kg	n	kg	%	kg

ns, non-significant mean squares, *, significant mean squares ($P < 0.05$). *PF* percentage of flowering, *PS* percentage of plants surviving to harvest, *WFP* fresh weight of foliage per plant, *NTP* number of tubers per plant, *WTP* weight of tubers/plant, *BIO* total weight of biomass (kg ha^{-1})

Table 3 Effect of acetylsalicylic acid doses on the plant parameters of two potato cultivars

Cultivar	Dose	PD	NSP	VV	PH	PV
Perricholi	0.0	56.0^{b}	1.75^{b}	7.67^{a}	53.23^{ab}	2.90^{abc}
	0.2	105.3^{ab}	3.09^{a}	7.27^{ab}	59.27^{a}	3.87^{a}
	0.4	109.3^{a}	2.97^{a}	7.20^{ab}	59.61^{a}	2.97^{abc}
	0.6	71.0^{ab}	2.14^{ab}	7.07^{ab}	63.53^{a}	2.93^{ab}
	0.8	88.3^{ab}	2.69^{ab}	6.90^{ab}	60.37^{a}	3.67^{abc}
	Biol	84.3^{ab}	2.51^{ab}	6.87^{ab}	60.16^{a}	2.83^{abc}
Unica	0.0	103.3^{ab}	2.93^{a}	7.23^{ab}	39.31^{bc}	1.30^{c}
	0.2	98.7^{ab}	2.85^{ab}	7.23^{ab}	34.55^{c}	1.00^{c}
	0.4	107.7^{a}	2.82^{ab}	7.20^{ab}	41.06^{bc}	1.00^{c}
	0.6	106.7^{ab}	2.95^{a}	7.17^{ab}	43.58^{bc}	1.60^{bc}
	0.8	67.3^{ab}	2.67^{ab}	7.07^{ab}	42.20^{bc}	1.00^{c}
	Biol	112.0^{a}	2.99^{a}	6.57^{b}	40.27^{bc}	1.60^{bc}
SE		9.15	0.2	0.17	2.77	0.38

Means with the same letter in columns are not significant ($P < 0.05$). PD = density of plants per experimental unit at 15 days, NSP = number of stems/plant at 30 days, VV = vegetative vigor (phenotypic scale 1–9), PH = plant height at 60 days (cm.), PV = percentage of plants with virus symptoms (square root transformed data), *SE* standard error. Additional details are listed in Table S1

can be attributed to the different emergence speeds and dormancy periods between both varieties.

The vegetative vigor showed an interaction effect between potato cultivars and ASA dosage as observed in Table 3; 0.4 mmol dose of acetylsalicylic acid had a better effect on vigor for the Perricholi cultivar than in the control treatment for cv. Unica.

Flowering was stimulated by the effect of the application of acetylsalicylic acid in cv. Perricholi at a dose of 0.4 mM, as can be seen in Table 4 where this treatment statistically surpassed the control and the application of Biol; cv. Unica did not show flowering.

It can be seen in Table 4, that the acetylsalicylic acid and Biol treatments did not significantly affect the biomass per hectare (fresh weight of tubers and foliage), number and weight of tubers per plant in both cultivars under field conditions.

Principal component analysis (PCA)

The PCA of the responses of the potato varieties to different treatments is shown in Fig. 1. Both the PCs explained

Table 4 Effect of acetylsalicylic acid dose on production-related parameters of two potato cultivars

Cultivar	Dose	PF	WFP	NTP	WTP	PS	BIO
Perricholi	0.0	38.07^{b}	0.25^{a}	3.72^{a}	0.35^{a}	91.2^{abc}	21 666.7^{a}
	0.2	40.65^{ab}	0.39^{a}	5.73^{a}	0.52^{a}	86.8^{c}	31 508.8^{a}
	0.4	50.97^{a}	0.39^{a}	5.43^{a}	0.48^{a}	88.6^{abc}	30 877.2^{a}
	0.6	41.06^{ab}	0.40^{a}	5.01^{a}	0.43^{a}	91.2^{abc}	30 140.4^{a}
	0.8	48.64^{ab}	0.29^{a}	4.69^{a}	0.35^{a}	87.7^{bc}	22 438.6^{a}
	Biol	38.99^{b}	0.43^{a}	5.92^{a}	0.49^{a}	89.5^{abc}	32 701.8^{a}
Unica	0.0	nd	0.29^{a}	6.46^{a}	0.56^{a}	99.1^{abc}	33 964.9^{a}
	0.2	nd	0.30^{a}	5.13^{a}	0.58^{a}	100.0^{a}	35 263.1^{a}
	0.4	nd	0.29^{a}	6.19^{a}	0.54^{a}	99.1^{ab}	32 754.4^{a}
	0.6	nd	0.31^{a}	6.64^{a}	0.61^{a}	97.4^{abc}	35 754.4^{a}
	0.8	nd	0.26^{a}	6.52^{a}	0.53^{a}	100.0^{a}	31 543.9^{a}
	Biol	nd	0.28^{a}	6.37^{a}	0.55^{a}	100.0^{a}	33 228.1^{a}
SE		2.05	0.04	0.86	0.06	2.13	3 163.32

Means with the same letter in columns are not significant ($P < 0.05$). nd = cv. Unica did not show flowering. PF = percentage of flowering, WFP = fresh weight of foliage per plant, NTP = number of tubers per plant, WTP = weight of tubers/plant, PS = percentage of plants surviving to harvest, BIO = total weight of biomass (kg ha^{-1}), *SE* standard error

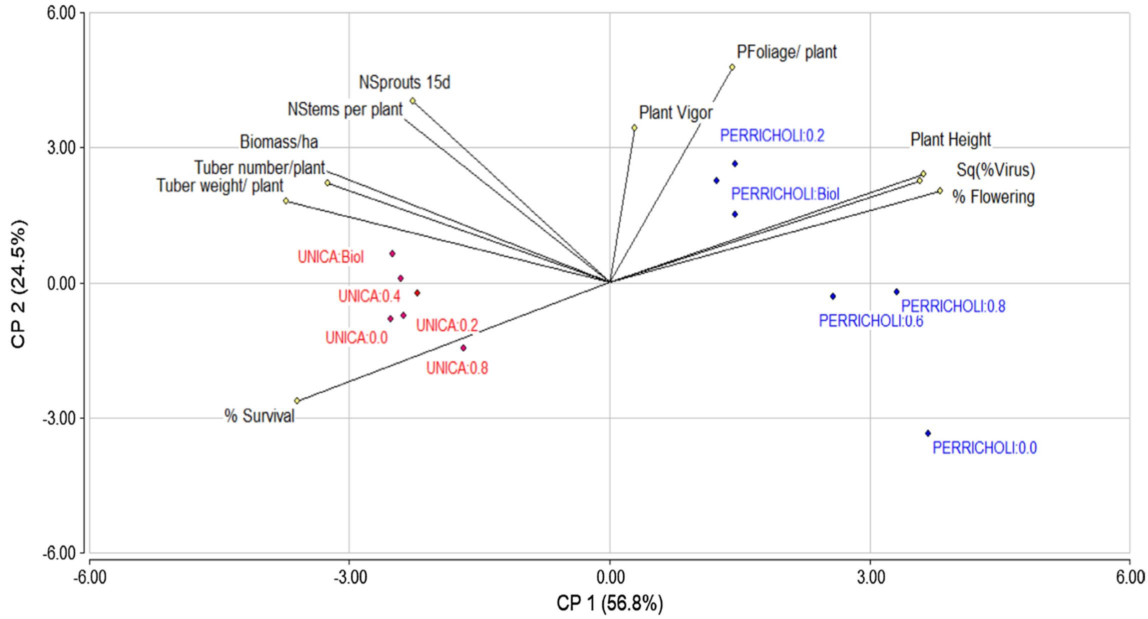

Fig. 1 PCA biplot showing the relationship between ASA doses and observed parameters. Variables are distributed in different ordinates depending on the divergence among them. In this biplot, the length in different ordinates are depending on the divergence; the length of a vector indicates the contribution of the traits to the principal components (CP)

81,3% of the total variability. The PCA biplot showed that PC1 exhibited 56,8% of the variability and contributed positively via some traits, i.e. plant vigor, foliage weight, plant height, virus incidence and flowering. The second PC accounted for approximately 24.5% of the total variability and contributed mainly to plant density, biomass, number and weight of tubers; it contributed negatively via plant survival to harvest.

Discussion

Applied salicylic acid improves photosynthesis, growth, and various other physiological and biochemical characteristics in stressed plants (Wani et al. 2017) but the effective concentrations of SA for potatoes need to be determined, as a high dose of SA not only induces enhanced disease resistance (Hayat et al. 2010) but also has adverse effects on plant growth and productivity, which is caused by undesirable balancing between cost and benefit of limited energy that plant can use (Koo et al. 2020). Therefore the hypothesis of this work was that there is an optimal dose for the exogenous application of acetylsalicylic acid in potato field conditions, that is, a concentration in which the plant maintains its development due to the required balance between resistance to biotic or abiotic factors and the expected productivity.

Our results show that the effects of the exogenous application of acetylsalicylic acid in both potato cultivars were mainly on parameters related to the physiology of the plant such as tuber sprouting, plant density, vigor, and plant flowering. This may be related to the fact that the potato responds to the exogenous application of salicylic acid at a relatively low concentration (Navarre & Mayo 2004). The doses used in the established application frequencies did not significantly affect the weights of tubers, foliage, and total biomass, so they can be considered safe for field application. It is considered that the plant uses part of the energy in the systemic resistance and could have production loss problems due to overdosing; likewise, an overdose of salicylic acid can stress the plant, causing a reduction in yield, as also considered by USAID (2006) and Koo et al. (2020).

Regarding the aspects related to the production of tubers and potato biomass per hectare, no differences were found for the dosage used of acetylsalicylic acid in the present investigation, although some authors affirm that salicylic acid can improve the production of photosynthates in potatoes under conditions of temperature stress and protect potato plants from damage caused by phytoplasmas (López-Delgado et al. 2013), thus improving the photosynthetic assimilation of the tuber (Sánchez-Rojo et al. 2011), thermo-tolerance in vitro (López Delgado et al. 2007), tolerance to heat and PVX (López Delgado et al. 2004), induced resistance to *P. infestans* (Ghazanfar et al. 2020), preventing post-harvest diseases development in stored potato tubers (Lastochkina et al. 2020), to enhance plant survival and eliminate PVS from potato plants (Ruiz-Sáenz et al. 2019) or tuber rot caused by *Erwinia* sp. (Lopez-López et al. 1995).

According to various authors (Hayat and Ahmad, 2007; Hayat et al 2010), SA may be related to tolerance to osmotic stress; the role of phytohormones like abscisic acid, jasmonic acid, and salicylic acid in the regulation of metabolic network under osmotic stress conditions has emerged through crosstalk between chemical signaling pathways (Singh and Gautam 2013). In this research, the results obtained can be interpreted differently for environmental conditions such as drought, in which osmotic stress causes considerable effects on potato production as potato plant is highly prone to high temperature, drought, and soil salinity (Dahal et al. 2019), unlike the irrigation conditions in which the work was carried out.

Fakhimi et al. (2020) showed that exogenous application of salicylic acid increased the expression level of genes and lead to enhancement of plant tolerance to salinity stress; the efficacy of salt tolerance of salicylic acid was proven to improve potato yield under salt stress, according to Faried et al. (2017), recommending using a dose of salicylic acid at 0.5 mM L^{-1} in potato under saline soil, a similar concentration of salicylic acid as we found in the present research to improve agronomic characters.

On the other hand, unlike what was found by Gonzáles and Huarte (2011) and Murphy et al. (2020), no significant differences were shown in terms of the incidence of viruses in potato cultivars due to the effect of acetylsalicylic acid, but this could be due to various factors, among which we can highlight the potato genotypes used that could have differences in terms of the degree of susceptibility to viruses, as well as the incidence of the virus under field conditions.

Conclusions

The dose of 0.4 mmol (72 mg L^{-1}) was the most appropriate to apply acetylsalicylic acid during potato cultivation to improve sprouting under field conditions, plant density per unit area, vegetative vigor, and flowering, although it is necessary to test these doses in other environmental conditions since plants grown in field conditions seem to be less sensitive to exogenous applications of salicylic acid or its derivatives at certain times. At the mentioned dose, both the yield and the biomass produced by the crop were not significantly affected. This knowledge could be instrumental in evaluating the response of potato crops to environmental stresses.

Abbreviations

CIP: International Potato Center; CV: Coefficient of Variation;; dF: Degrees of freedom; mM: Mmol; BID: International Development Bank; RCBD: Randomized Complete Block Design; PVY: Potato virus Y.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43170-022-00088-5.

Additional file 1: Table S1. Soil Analysis in the experimental area. **Table S2.** Application treatments with acetylsalicylic acid.

Acknowledgements

The authors acknowledge support provided by Vicerrectorado de Investigacion, Universidad Nacional Jose Faustino Sanchez Carrion, Huacho, Perú.

Authors' contributions

SC carried out the fieldwork, performed the statistical analysis, and drafted the manuscript. LV coordinated the study in the field in the Andean region and contributed to corrections of the manuscript. Both authors read and approved the final manuscript.

Funding

The authors received no specific funding for this work.

Availability of data and materials

Supporting data will be made available in a publicly accessible data repository.

Declarations

Ethics approval and consent to participate

There were no humans or animals in this research and informed consent is not applicable.

Consent for publication

The authors give consent for the publication of the research in the Journal CABI Agriculture and Biosciences.

Competing interests

The authors declare that have no competing interests.

Author details

[1]Department of Agronomy, Universidad Nacional Jose Faustino Sanchez Carrion, Av. Mercedes Indacochea 609, Huacho, Peru. [2]Facultad de Ingeniería, Universidad Nacional de Barranca, Av. Toribio de Luzuriaga 376, Barranca, Peru.

Received: 30 March 2021 Accepted: 22 March 2022
Published online: 01 April 2022

References

Alexandersson E, Mulugeta T, Lankinen Å, Liljeroth E, Andreasson E. Plant resistance inducers against pathogens in solanaceae species—from molecular mechanisms to field application. Int J Mol Sci. 2016;17:1673. https://doi.org/10.3390/ijms17101673.

Baebler Š, Stare K, Kovač M, Blejec A, Prezelj N, Stare T, et al. Dynamics of responses in compatible potato - potato virus y interaction are modulated by salicylic acid. PLoS ONE. 2011;6(12): e29009. https://doi.org/10.1371/journal.pone.0029009.

Bakker L. Insects and insecticides in agricultural landscapes: socio-ecological challenges and patterns. Wageningen University. 2021; https://doi.org/10.18174/538522

BID (Banco Interamericano para el Desarrollo). Retornos económicos de la contribución de FONTAGRO a la innovación agropecuaria en América Latina y el Caribe. Informe final Estudio de beneficios económicos de resultados de proyectos cofinanciados por FONTAGRO. 2020; p. 46. http://repositorio.iica.int/handle/11324/9755

Dahal K, Li XQ, Tai H, Creelman A, Bizimungu B. Improving potato stress tolerance and tuber yield under a climate change scenario–a current overview. Front Plant Sci. 2019;10:563. https://doi.org/10.3389/fpls.2019.00563.

Delaney S, Uknes S, Vernooij B, Friedrich L, Weymann K, Negrotto D, et al. A central role of salicylic acid in plant disease resistance. Science. 1994;266:1247–50. https://doi.org/10.1126/science.266.5188.1247.
Fakhimi F, Motallebi A, Zaree F, Sokhandan N, Gohari G. Effect of salicylic acid on betaine aldehyde dehydrogenase gene expression in potato (*Solanum tuberosum* L., cv. Agria) under salinity stress. Environ Stress Crop Sci. 2020;13(1):1–8. https://doi.org/10.22077/escs.2019.1847.1436.
FAO. (Food and Agriculture Organization). Production of disease-free seed tubers. International Year of the Potato Secretariat Food and Agriculture Organization of the United Nations. Rome: FAO; 2008a. http://www.fao.org/potato-2008a/pdf/IYP-9en.pdf
FAO (Food and Agriculture Organization). Potato pest and disease management. International Year of the Potato Secretariat Food and Agriculture Organization of the United Nations. Rome: FAO. 2008b. http://www.fao.org/potato-2008b/en/potato/pests.html
FAO (Food and Agriculture Organization). World Food and Agriculture - Statistical Pocketbook 2020. 2020; Rome. https://doi.org/10.4060/cb1521en
Faried HN, Ayyub CM, Amjad M, Ahmed R, Wattoo FM, Butt M, et al. Salicylic acid confers salt tolerance in potato plants by improving water relations, gaseous exchange, antioxidant activities and osmoregulation. J Sci Food Agric. 2017;97(6):1868–75. https://doi.org/10.1002/jsfa.7989.
Ghazanfar MU, Raza W, Wakil W, Hussain I, Qamar MI. Management of late blight and sucking insect pests of potato with application of salicylic acid and β-aminobutyric acid under greenhouse conditions. Sarhad J Agric. 2020;36(2):646–54. https://doi.org/10.17582/journal.sja/2020/36.2.646.654.
González-Gallegos E, Laredo-Alcalá E, Ascacio-Valdés J, de Rodríguez D, Hernández-Castillo FD. Changes in the production of salicylic and jasmonic acid in potato plants (*Solanum tuberosum*) as response to foliar application of biotic and abiotic inductors. Am J Plant Sci. 2015;6:1785–91.
de Haan S, Rodriguez, F. Potato origin, and production. In: Advances in potato chemistry and technology. Academic Press; 2016. p. 1–32. https://doi.org/10.1016/B978-0-12-800002-1.00001-7
Halim VA, Eschen-Lippold L, Altmann S, Birschwilks M, Scheel D, Rosahl S. Salicylic acid is important for basal defense of *Solanum tuberosum* against *Phytophthora infestans*. MPMI. 2007;20(11):1346–52. https://doi.org/10.1094/MPMI-20-11-1346.
Hayat Q, Hayat S, Irfan M, Ahmad A. Effect of exogenous salicylic acid under changing environment: A review. Environ Exp Bot. 2010;68(1):14–25. https://doi.org/10.1016/J.ENVEXPBOT.2009.08.005.
Hayat S, Ahmad A. Salicylic Acid: A Plant Hormone. Springer: The Netherlands; 2007. https://doi.org/10.1007/1-4020-5184-0
Koo YM, Heo AY, Choi HW. Salicylic acid as a safe plant protector and growth regulator. Plant Pathol J. 2020;36(1):1–10. https://doi.org/10.5423/PPJ.RW.12.2019.0295.
Lastochkina O, Baymiev A, Shayahmetova A, Garshina D, Koryakov I, Shpirnaya I, et al. Effects of endophytic *Bacillus subtilis* and salicylic acid on postharvest diseases (*Phytophthora infestans, Fusarium oxysporum*) development in stored potato tubers. Plants. 2020;9(1):76. https://doi.org/10.3390/plants9010076.
Li Q, Wang G, Wang Y, Yang D, Guan C, Ji J. Foliar application of salicylic acid alleviate the cadmium toxicity by modulation the reactive oxygen species in potato. Ecotoxicol Environ Saf. 2019;172:317–25. https://doi.org/10.1016/j.ecoenv.2019.01.078.
Liang WS, Wen JQ, Liang HG. Growth and metabolism stimulation of ethylene production in aged potato tuber slices by salicylic acid. Phytochemistry. 1997;44(2):221–3. https://doi.org/10.1016/S0031-9422(96)00468-2.
López-Delgado H, Mora-Herrera ME, Zavaleta-Mancera HA, Cadena-Hinojosa M, Scott IM. Salicylic acid enhances heat tolerance and potato virus X (PVX) elimination during thermotherapy of potato microplants. Am J Potato Res. 2004;81(3):171–6. https://doi.org/10.1007/BF02871746.
Lopez-Delgado HA, Scott I M, Mora-Herrera M E. Stress and Antistress Effects of Salicylic Acid and Acetyl Salicylic Acid on Potato Culture Technology. In: Hayat S, Ahmad A. (eds) Salicylic Acid: A Plant Hormone. Springer: Dordrecht, 2007. https://doi.org/10.1007/1-4020-5184-0_7
López-Delgado H A, Mora-Herrera M E, Martínez-Gutiérrez R, Sánchez-Rojo S. Short and Long Term Effects of Salicylic Acid on Protection to Phytoplasma Associated Stress in Potato Plants. In: Hayat S., Ahmad A., Alyemeni M. (eds) Salicylic Acid. Springer: Dordrecht, 2013. https://doi.org/10.1007/978-94-007-6428-6_14
López-López MJ, Liebana E, Marcilla P, Beltra R. Resistance induced in potato tubers by treatment with acetylsalicylic acid to soft rot produced by *Erwinia carotovora* subsp. carotovora. J Phytopathol. 1995;143(11):719–24. https://doi.org/10.1111/j.1439-0434.1995.tb00229.x.
Makarova S, Makhotenko A, Spechenkova N, Love AJ, Kalinina NO, Taliansky M. Interactive responses of potato (*Solanum tuberosum* L.) plants to heat stress and infection with Potato virus Y. Frontiers in microbiology. 2018;9:2582. https://doi.org/10.3389/fmicb.2018.02582.
Murphy AM, Zhou T, Carr JP. An update on salicylic acid biosynthesis, its induction and potential exploitation by plant viruses. Curr Opin Virol. 2020;42:8–17. https://doi.org/10.1016/j.coviro.2020.02.008.
Navarre DA, Mayo D. Differential characteristics of salicylic acid-mediated signaling in potato. Physiol Mol Plant Pathol. 2004;64(4):179–88. https://doi.org/10.1016/j.pmpp.2004.09.001.
Ponce C. Intra-seasonal climate variability and crop diversification strategies in the Peruvian Andes: a word of caution on the sustainability of adaptation to climate change. World Dev. 2020;127: 104740. https://doi.org/10.1016/j.worlddev.2019.104740.
Quiroz R, Ramírez DA, Kroschel J, Andrade-Piedra J, Barreda C, Condori B, et al. Impact of climate change on the potato crop and biodiversity in its center of origin. Open Agric. 2018;3(1):273–83. https://doi.org/10.1515/opag-2018-0029.
Raskin I. Role of salicylic acid in plants. Ann Rev Plant Physiol Plant Mol Biol. 1992;43:439–63. https://doi.org/10.1146/annurev.pp.43.060192.002255.
Reymond P, Farmer E. Jasmonate and salicylate as global signals for defense gene expression. Curr Opin Plant Biol. 1998;1:404–11. https://doi.org/10.1016/S1369-5266(98)80264-1.
Ruiz-Sáenz DR, Ayala-Hernández DD, Niino T, Cruz-Gutiérrez EJ, Aquino-Martínez JG, López-Delgado HA. Salicylic acid-cryotherapy treatment for elimination of potato virus S from *Solanum tuberosum*. Am J Potato Res. 2019;96(3):225–34. https://doi.org/10.1007/s12230-018-09694-4.
Sánchez-Rojo S, López-Delgado HA, Mora-Herrera ME, Almeyda-León HI, Zavaleta-Mancera HA, Espinosa-Victoria D. Salicylic acid protects potato plants from phytoplasma-associated stress and improves tuber photosynthate assimilation. Am J Potato Res. 2011;88(2):175–83. https://doi.org/10.1007/s12230-010-9175-y.
Singh PK, Gautam S. Role of salicylic acid on physiological and biochemical mechanism of salinity stress tolerance in plants. Acta Physiol Plant. 2013;35:2345–53. https://doi.org/10.1007/s11738-013-1279-9.
USAID (United States Agency for International Development). El Uso del Ácido Salicílico y Fosfonatos (Fosfitos) para Activar el Sistema de Resistencia de la Planta (SAR). Boletín técnico de producción, USAID-RED, Oficina FHIA, La Lima, Cortes, Honduras; 2006. http://marcelozingarielllo.com/afital/salicilico.pdf
Van Loon LC. Plant responses to plant growth-promoting rhizobacteria. Eur J Plant Pathol. 2007;119:243–54. https://doi.org/10.1007/978-1-4020-6776-1_2.
Vlot AC, Dempsey DA, Klessig DF. Salicylic Acid, a multifaceted hormone to combat disease. Annu Rev Phytopathol. 2009;47:177–206. https://doi.org/10.1146/annurev.phyto.050908.135202.
Walters D, Ratsep J, Havis N. Controlling crop diseases using induced resistance: challenges for the future. J Exp Bot. 2013;64(5):1263–80. https://doi.org/10.1093/jxb/ert026.
Wani AB, Chadar H, Wani AH, Singh S, Upadhyay N. Salicylic acid to decrease plant stress. Environ Chem Lett. 2017;15(1):101–23. https://doi.org/10.1007/s10311-016-0584-0.
Zhang K, Halitschkec R, Yina C, Liub C, Gana S. Salicylic acid 3-hydroxylase regulates Arabidopsis leaf longevity by mediating salicylic acid catabolism. PNAS. 2013;113(36):14807–12. https://doi.org/10.1073/pnas.1302702110.
Zhou XT, Jia LJ, Wang HY, Zhao P, Wang WY, Liu N, et al. The potato transcription factor Stb ZIP 61 regulates dynamic biosynthesis of salicylic acid in defense against *Phytophthora infestans* infection. Plant J. 2018;95(6):1055–68. https://doi.org/10.1111/tpj.14010.

Publisher's Note