Journal of Plant Growth Regulation (2024) 43:2165–2178
https://doi.org/10.1007/s00344-024-11252-8

Species-Dependent Impacts on the Nutritional Profile of Tomato (*Solanum lycopersicum* L.) and Rocket (*Eruca sativa* L.) Plants Following to Foliar Application of Yeast Suspensions

Andrea Tóbiás[1] · Márta Ladányi[2] · Dániel Koren[3] · László Csambalik[4]

Received: 12 June 2023 / Accepted: 21 January 2024 / Published online: 12 March 2024
© The Author(s) 2024

Abstract

The foliar application of yeast (*Saccharomyces cerevisiae*) suspensions is a widely used small-scale horticultural practice against stress impacts and to boost vegetative and nutritional characteristics. In this study, the impact of two strains of *S. cerevisiae* was investigated on tomato (*Solanum lycopersicum* L.) and rocket (*Eruca sativa* L.) plants in terms of vegetative growth and nutritional content, focusing on antioxidant properties (FRAP, DPPH, TPC, lycopene) and chlorophyll content. The treatments were applied in two dilutions (0.1 and 1% v/v) and two frequencies (once and three times). When the type strain solutions were applied, DPPH values of both tomato and rocket samples were elevated up to 7.18 and 17.98 *i%*, respectively, compared to control values of 6.26 and 14.11 *i%*, respectively. While the other investigated antioxidant traits (FRAP, TPC, lycopene) were identical or slightly lower, than the control values, total chlorophyll content was significantly increased for tomato, up to 61.18 g/100 g, from the control value of 53.46 g/100 g, and for rocket, reaching 43.14 g/100 g, from the control value of 39.13 g/100 g, after using instant yeast solutions. Among the combinations, the double-sprayed 1% suspension and the single-sprayed 0.1% suspension had the most favorable impact on the investigated nutritional traits. Species-level application technology details are still open for refinements.

Keywords Antioxidants · Chlorophyll · Foliar spraying technology · Biostimulants · Yeast

Introduction

The vegetative development and yield of cultivated plants can be enhanced by the application of biostimulators (Hammad 2008; Parađiković et al. 2011). Yeast (*S. cerevisiae*) strains can be used as natural biostimulants, containing

Handling Editor: Jose M. Miguel.

✉ László Csambalik
csambalik.laszlo.orban@uni-mate.hu

Andrea Tóbiás
tobias.andrea@uni-mate.hu

Márta Ladányi
ladanyi.marta@uni-mate.hu

Dániel Koren
danikoren3@gmail.com

[1] National Collection of Agricultural and Industrial Microorganisms, Institute of Food Science and Technology, Hungarian University of Agriculture and Life Sciences, Somlói út 14-16, Budapest 1118, Hungary

[2] Department of Applied Statistics, Institute of Mathematics and Basic Science, Hungarian University of Agriculture and Life Sciences, Villányi út 29-43., Budapest 1118, Hungary

[3] Department of Bioengineering and Alcoholic Drink Technology, Institute of Food Science and Technology, Hungarian University of Agriculture and Life Sciences, Ménesi út 45, Budapest 1118, Hungary

[4] Department of Agroecology and Organic Farming, Institute of Rural Development and Sustainable Production, Hungarian University of Agricultural and Life Sciences, Villányi út 29-43., Budapest 1118, Hungary

different phytohormones (thiamine, riboflavin, piridoxin, niacin, vitamin B, cytokinins), along with proteins, carbohydrates, nucleic acids, lipids, and various nutrients (Kowalska et al. 2022). Until now, over 23 genera of yeasts were identified as supportive for plant development, referred to as plant growth-promoting yeasts (PGPY) (Nimsi et al. 2023). The most common application of *S. cerevisiae* suspensions, especially in open field experiments, is foliar spraying. The positive impact of yeast on vegetative growth is confirmed in the case of several crops, such as *Solanaceae* species: potato, pepper, and tomato (Alali et al. 2017; El-Desouky et al. 2011; Mohamed et al. 2021; Sarhan and Abdullah 2010) and leafy vegetables, such as spinach (Al-Mharib et al. 2022) or head lettuce (Abd El Galil et al. 2021). By inducing vegetative development, the assimilating surface of plants is increased, which, in turn, can have a positive impact on the synthesis of assimilates. Yeast suspensions with a natural origin fit well into the production systems of certified organic farming and environmental-friendly approaches (Zlotek and Swieca 2016).

Tomato (*Solanum lycopersicum* L.) is among the world's most important vegetables, with a yearly production of almost 190 million tons on 5.1 million hectares (FAOSTAT 2021). Although tomatoes do not contain high amounts of vitamins, minerals, and antioxidants, their frequent all-year consumption makes them an essential source of these compounds (Ali et al. 2021). Tomatoes are the main source of lycopene, a phytochemical with outstanding antioxidant power (Chaudhary et al. 2018; Pennathur et al. 2010). Lycopene can contribute to the reduction of certain types of cancer and cardiovascular diseases (Bianchi et al. 2023; Blekkenhorst et al. 2017; Canene-Adams et al. 2005; Giovannucci 1999; Hedayati et al. 2019; Kun et al. 2006; Mozos et al. 2018), and improves cell-to-cell communication (Ozkan et al. 2023).

Rocket (*Eruca sativa* L.) from the Brassicaceae family is primarily cultivated for its spicy, bitter taste as a leafy green. This vegetable is rich in glucosinates, sulphureous secondary plant metabolites, and flavonols, which are collectively associated with a reduced risk of certain cancer types (Royston and Tollefsbol 2015) and cardiovascular diseases (Blekkenhorst et al. 2017; Podsędek 2007).

Several studies investigated the effect of foliar-applied yeast suspensions on the nutritional content of various plant species (Csambalik and Tóbiás 2018). The high number of studies and the diverse experimental designs highlight differences in the extent of the impact among crop species (Zlotek and Swieca 2016). Therefore, at least a species-level approach is needed in this area.

Fawzy (2010) measured changes in ascorbic acid levels after yeast treatments and found a significant rise; however, Zlotek and Swieca (2016) did not observe any significant difference in the case of lettuce. A positive impact was observed on tomatoes and sweet peppers as well (Abou El-Yazied and Mady 2011; Ghoname et al. 2010).

The application of biostimulants based on plant and yeast extracts improved the heat stress tolerance of four tomato landraces grown under Mediterranean conditions (Rouphael and Colla 2020). Abiotic stresses can cause a substantial decline in fruit quality due to negative impacts on plant growth, physiology, and reproduction However, according to Francesca et al. (2020), the use of yeast extracts can ensure good crop yield and quality in tomato plants grown at elevated temperatures (up to 42 ℃). Physiological and biochemical studies on drought tolerance of wheat plants through the application of amino acids and yeast extract are also validate these findings (Hammad and Ali 2014).

Regarding phenolics, several authors detected a significant rise in red sage (Yan et al. 2006), sugar beet (Neseim et al. 2014), quinoa (Abdallah et al. 2016), broccoli (Gawlik-Dziki et al. 2013), pea (Hammad 2008), and onion (Abd-Elbaky et al. 2021). The phenolic profile of broccoli sprouts was investigated by Gawlik-Dziki et al. (2013) after yeast treatments: the amount of p-coumaric and syringic acid increased, while chlorogenic and p-hydroxybenzoic acid decreased. While no significant impact of yeast treatment effect was detected by Zlotek and Swieca (2016) and by Abdallah et al. (2016) on the flavonoid content of lettuce and quinoa, respectively, a significantly increased content of catechin, quercetin, and kaempferol in broccoli sprouts was proved by in vitro yeast treatment trials (Gawlik-Dziki et al. 2013). The same study found increased antiradical activity as well.

This is in agreement with the findings of Zlotek and Swieca (2016); they reported a significant increase of DPPH and ABTS in lettuce plants. However, no significant DPPH increase was detected in quinoa and in milk thistle plants (Abdallah et al. 2016; Saad-Allah et al. 2017).

The chlorophyll a and b contents of arable, vegetable, medicinal, and ornamental plants show a general increase after foliar yeast treatments (Abd-Elbaky et al. 2021; Csambalik and Tóbiás 2018). Contrarily, no significant differences were found by Neseim et al. (2014) and by Agamy et al. (2013) in sugar beet, and by Zlotek and Swieca (2016) on chlorophyll parameters of butter lettuce.

Although several publications investigated the effect of yeast suspensions on several traits of plant species, differences in experimental designs hinder the comparison of the results in terms of treatment details. The combined impact of spraying frequency, concentration, and material still lacks in-depth comparative experiments. Therefore, the objective of the present study is to conduct a comparative experiment on yeast foliar spraying using both leafy and fruiting vegetable species. The study involves two different concentrations and spraying frequencies. Additionally, commonly used instant yeast is compared with the type strain in terms of

investigated nutritional traits. The hypothesis of the study is that the applied foliar treatments can contribute to the elevation of antioxidant and chlorophyll properties in the examined plant varieties.

Materials and Methods

Experimental Design

Two open field experiments were conducted at the Experimental Station of the Hungarian University of Agricultural and Life Sciences in 2017, situated on the certified organic lands of Organic Farming Unit, Experimental and Educational Site of Soroksár (47°23′N 19°08′E, 115 m above sea level). The plant materials used were tomato (*Solanum lycopersicum* L.), 'Mobil' variety with an indeterminate growing type, and rocket (*Eruca sativa* L.), a national variety. The management practices adhered to organic regulation and practices.

Tomato seeds were sown into seedling trays filled with a peat, sand, and compost mixture on 22 March 2017. The seedlings were then grown in an unheated plastic tunnel and transplanted at the four true-leaf stage into the open field on 2 May 2017, with a plant and row spacing of 45 × 60 cm. Each row contained five plants, and treatments were applied in four repetitions, with each treatment represented by a total of 20 plants. The 36 plots were arranged in a randomized complete block design (RCBD). The soil was covered with wowen plastic fabric, and drip irrigation was installed underneath. The first treatment was applied three weeks after transplanting (25 May) and was repeated twice at three-week intervals (19 June, 10 July).

Rocket seeds were directly sown in the field on 4 September 2017, with a row and plant distance of 10 × 10 cm. The area was left uncovered, and no irrigation was provided. Each plot contained fifteen plants in a row. Treatments were applied in four repetitions, with each treatment represented by a total of 60 plants. The 36 plots were arranged in a randomized complete block design (RCBD). Treatments were adjusted to the lifespan of rocket: the first treatments were applied two weeks after sowing (18 September) and were repeated twice at ten-day intervals.

Treatments

Yeast suspensions were prepared following the method outlined by Gawlik-Dziki et al. (2013) at the laboratory of National Collection of Agricultural and Industrial Microorganisms, Hungarian University of Life Sciences (MATE NCAIM). Distilled water served as the control for the treatments. For the preparation of suspensions, commercially available instant yeast (IY) and *S. cerevisiae* NCAIM Y.00801 strains (NCAIM) were employed. Suspensions were prepared in two concentrations (0.1, 1% v/v). Foliar treatments were administered using handheld sprayers, with approximately 2 ml of suspensions distributed on each tomato plant. Physical separation was employed for the time of the treatment to avoid suspension drift. In the case of rocket plants, one row (15 plants) was sprayed with approximately 2 ml of suspension doses, equally distributed among individual plants. Rocket rows were physically separated during the time of treatments. Detailed parameters of the treatments are provided in Table 1.

Sample Preparation

Approximately, 1.5 kg of fully ripened tomato fruits was harvested from every plot on 18 September. The fruits were at the full biological ripened stage (S6) (USDA 1991) and showed no visible symptoms of infestation or disorder. After removing the pedicels, the fruits were washed in distilled water, and homogenization was performed using a laboratory homogenizer. The homogenates were then frozen until instrumental measurements.

For rocket plants, 10 complete specimens were collected from every plot on 8 November. Leaves were carefully detached from the stems, washed, and subsequently

Table 1 Concentration, material, and application frequency of investigated treatments on tomato and rocket plants

Treatment code	Concentration % (v/v)	Material	Number of application
C	–	Distilled water	3
0.1IY	0.1	Instant yeast	1
0.1IY3	0.1	Instant yeast	3
1IY	1	Instant yeast	1
1IY3	1	Instant yeast	3
0.1NCAIM	0.1	S. cerevisiae NCAIM Y.00801	1
0.1NCAIM3	0.1	S. cerevisiae NCAIM Y.00801	3
1NCAIM	1	S. cerevisiae NCAIM Y.00801	1
1NCAIM3	1	S. cerevisiae NCAIM Y.00801	3

homogenized using a laboratory homogenizer. The resulting samples were then frozen before instrumental measurements.

Instrumental Measurements

The instrumental measurements were conducted in triplicate by the Department of Bioengineering and Alcoholic Drink Technology, Institute of Food Science and Technology, Hungarian University of Agriculture and Life Sciences. For antioxidant analyses (FRAP, TPC, DPPH), the supernatant of homogenates was used, collected after centrifugation at 2000×*g*. The FRAP assay followed the method of Benzie and Strain (1996) was used. Samples were spectrophotometrically measured at 593 nm, and values were expressed in ascorbic acid equivalent (mg AA/l) according to (Huang et al. 2005). The DPPH-free radical method was conducted as per Molyneux (2003). A 100 µl of supernatant obtained by centrifugal separation was added to 3.9 ml of 6×10^{-5} M DPPH solution and kept in dark for 20 min; the absorbance was recorded at 517 nm. Values were expressed in inhibition % (*i*%). Total phenolic content (TPC) was measured using Folin–Ciocalteu's reagent (Singleton and Rossi 1965). Absorbance was determined spectrophotometrically at 760 nm. Results were expressed in gallic acid equivalent in kg GA/l.

Lycopene content was determined spectrophotometrically according to Fish et al. (2002), and was expressed in mg/100 g. For the preparation of chemicals, 12.5 g of Butylated hydroxytoluene (BHT) was dissolved in 250 cm^3 acetone. 250 cm^3 of EtOH and 250 cm^3 of BHT-containing acetone were measured into a 1000 cm^3 cylinder, then filled to the mark with petroleum ether (boiling range: 30–50 ℃) and mixed thoroughly. For the measurement, 0.20–0.60 g of the homogeneous samples were measured into 50 cm^3 Erlenmeyer flasks. The exact weight was documented. After that, 20 cm^3 solution was added to it with a dispenser. The flasks were immediately closed with aluminum foil to prevent evaporation, then put in a shaker, and shook for 20 min (100 rpm). After 20 min, 3 cm^3 distilled water was added then shook for further 5 min. The acetone and water separated from the petroleum ether. The samples were poured into test tubes that were covered with aluminum foil to prevent evaporation and were left to stand for 5 min until the phases separated. The upper, golden phase was sucked into a glass cuvette with a Pasteur pipette, then the absorbance was measured at $\lambda = 503$ nm against a petroleum ether blank.

Calculation was done with the following formula:

$$\text{Lycopene content (mg/100g)} = A \times 31.2/\text{measured amount in grams}/10,$$

where A indicates the absorbance value.

Chlorophyll content was determined spectrophotometrically according to the methodology of Lichtenthaler and Buschmann (2001) and expressed in mg/100 g.

Statistical Analysis

The effects of the materials [M, such as IY: instant yeast, NCAIM: NCAIM Y.00801 type strain, C: control (distilled water)], the *Saccharomyces cerevisiae* suspension concentration (SCC: 0.1; 1 v/v), and the number of application (NoA: single/triple) on antioxidant parameters (DPPH, TPC, FRAP, Lyc) of tomatoes and (DPPH, TPC, FRAP) in rocket were analyzed using 3-way MANOVA models. Similarly, the same factor effects on chlorophyll content parameters (Chlorophyll a, Chlorophyll b, and total Chlorophyll) in tomatoes and rocket were tested using again 3-way MANOVA model. To stabilize the variances and satisfy the normality assumption, the three chlorophyll parameters were transformed by taking their natural logarithm values. The normality of residuals was confirmed by the absolute values of their skewness and kurtosis that were below 1 in each case. Homogeneity of variances was tested using Levene's test ($p > 0.05$). Having significant overall MANOVA results, we performed follow-up 3-way univariate ANOVA models for all the dependent variables individually, with Bonferroni's Type I error correction to keep the familywise error rate below 0.05. The levels of factor 'materials' were pairwisely compared by Tukey's post hoc test.

The relationship between antioxidant parameters of rocket leaves (DPPH, TPC, FRAP) and their chlorophyll contents (Chlorophyll a, Chlorophyll b and total Chlorophyll) was evaluated by calculating Pearson's correlation coefficients, and their significance levels were determined using *t* tests. Similarly, the correlation of antioxidant parameters (DPPH, TPC, FRAP) for tomato fruit samples, as well as the correlation of chlorophyll traits (Chlorophyll a, Chlorophyll b and total Chlorophyll) in tomato leaves was calculated using the same method.

The statistical analysis was performed by using IBM SPSS Statistics (v.27, IBM Corp.).

Results

Antioxidant Status of Tomato Samples

The overall MANOVA result together with the follow-up univariate analysis output is given in Table 2.

For the DPPH values of tomato samples, there was no significant difference corresponding to concentration, although higher concentrations yielded higher results (Table 3). This pattern also held true for both TPC and lycopene values. Regarding lycopene content, the results of NCAIM treatment

Table 2 Results of MANOVA for dependent antioxidant variables (both tomato and rocket: DPPH, TPC, FRAP; only for tomato: Lycopene) depending on factors SC suspension concentration (SCC: 0.1; 1% v/v), material (M: IY: instant yeast, NCAIM: NCAIM Y.00801 strain, C: control (distilled water)), and the number of application (1 or 3). Wilk's lambda provides the unexplained variance rate; F values are the outcome of the follow-up univariate ANOVA with Bonferroni's correction

Factors	Tomato			Rocket	
	Wilk's lambda with degrees of freedom (df)	F(df_1[a];79)	Investigated parameter	Wilk's lambda with degrees of freedom (df)	F(df_1[a];36)
SC susp. conc (SCC)	0.32*** df = 4;76	0.07 ns	DPPH	0.09*** df = 3;34	249.29***
		3.32 ns	TPC		0.03 ns
		3.35 ns	FRAP		218.71***
		130.60***	Lycopene		NA
Material (M)	0.36*** df = 8;152	9.49***	DPPH	0.03*** df = 6;68	33.32***
		10.87***	TPC		44.35***
		4.66*	FRAP		91.84***
		35.96***	Lycopene		NA
Number of Application (NoA)	0.53*** df = 4;76	1.13 ns	DPPH	0.41*** df = 3;34	3.41 ns
		0.16 ns	TPC		45.91***
		11.36**	FRAP		0.89 ns
		34.46***	Lycopene		NA
SCC*M interaction	0.32*** df = 4;76	7.51**	DPPH	0.36*** df = 3;34	32.61***
		1.94 ns	TPC		7.06*
		35.23***	FRAP		33.87***
		7.34**	Lycopene		NA
M*NoA interaction	> 0.90 ns		DPPH	0.41*** df = 3;34	6.35*
			TPC		8.65*
			FRAP		29.82***
			Lycopene		NA
SCC*NoA interaction			DPPH	0.15*** df = 3;34	70.53***
			TPC		6.70*
			FRAP		79.16***
			Lycopene		NA
SCC*M*NoA interaction			DPPH	0.68** df = 3;34	4.06 ns
			TPC		12.39**
			FRAP		0.11 ns
			Lycopene		NA

[a]$df_1 = 1$ in cases of factors 'SCC' and 'NoA', while $df_1 = 2$ in case of factor 'material'

Significant at *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ns not significant

divide notably. Regarding FRAP results, significant differences were observed in three out of four cases. However, it is worth noting that lower concentrations of NCAIM and higher concentrations of IY were more favorable simultaneously.

For the tomato test plant, the frequency of application had no significant effect on DPPH results, although more frequent use generally resulted in slightly higher values. The same trend was observed for TPC, but noteworthy differences emerged in the 0.1% IY treatments. Regarding FRAP results, lower concentrations appeared to be more favorable, although a significant difference was found only in one treatment. A more pronounced effect was observed in the case of lycopene; the triple-use of suspensions yielded higher results compared to single-use treatments. Significant differences were found in three out of four cases for this nutritional parameter.

As for the effect of different materials on DPPH values in tomatoes, type strain-based treatments yielded higher values than IY ones. However, no significant difference was found between treatments based on DPPH results. Only two treatments could elevate DPPH values: 1% NCAIM suspensions used once and three times. Among single-use 1% suspensions, the NCAIM treatment produced significantly higher DPPH results than IY. The TPC results of yeast-sprayed samples were generally lower than of the control samples.

Table 3 Antioxidant status of tomato and rocket samples (means ± standard deviations) in the function of Saccharomyces cerevisiae suspensions' application

		DPPH			TPC			FRAP			Lycopene		
Mat.	v/v	Single appl.		Triple appl	Single appl.		Triple appl.	Single appl.		Triple appl.	Single appl.		Triple appl.
Tomato													
IY	0.1	4.14 ± 1.84	ns	5.03 ± 1.97	**28.10 ± 2.51**	ns	29.53 ± 2.30	**11.17** ± 1.06	*	**9.76** ± 1.07	**7.29** ± 1.98	ns	**7.57** ± 0.28
		ns	ns	ns	ns	ns	ns	*	ns	*	ns		ns
	1	4.85 ± 2.25	ns	5.34 ± 3.34	31.43 ± 3.23	ns	31.65 ± 3.98	14.51 ± 1.23	ns	13.47 ± 2.38	8.17 ± 3.07	*	10.48 ± 4.22
NCAIM	0.1	5.12 ± 3.19	ns	5.58 ± 3.00	31.73 ± 2.51	ns	31.30 ± 2.37	13.90 ± 0.59	ns	13.78 ± 1.32	**5,77** ± 1,91	*	**7,48** ± 0,92
		ns		ns	ns		ns	ns		*	*		*
	1	7.18 ± 1.54	ns	6.75 ± 3.14	32.30 ± 3.06	ns	32.05 ± 2.64	13.11 ± 4.17	ns	**10.28** ± 0.27	9.07 ± 1.77	*	10.67 ± 1.14
C	–		6.26 ± 2.06			34.50 ± 2.74			14.91 ± 2,93			10.94 ± 4.21	

		DPPH		TPC		FRAP	
Mat.	v/v	Single appl.	Triple appl.	Single appl.	Triple appl.	Single appl.	Triple appl.
Rocket							
IY	0.1	14.91 ± 0.60 *	**16.93** ± 0.53	209.78 ± 10.11 ns	217.18 ± 8.19	**41.97** ± 2.56 *	**52.95** ± 2.21
		ns	*	ns	ns	*	ns
	1	14.97 ± 0.51 *	13.19 ± 0.59	200.18 ± 6.35 ns	212.33 ± 7.84	54.75 ± 2.61 ns	**52.76** ± 2.33
NCAIM	0.1	**17.61** ± 0.73 ns	**17.98** ± 0.60	**166.73** ± 6.43 *	207.08 ± 7.90	**46.90** ± 1.98 ns	**49.74** ± 1.77
		*	*	*	ns	*	*
	1	14.85 ± 0.59 *	**12.88** ± 0.50	**188.63** ± 7.59 ns	197.83 ± 9.05	**67.37** ± 2.83 *	58.19 ± 1.68
C	-	14.11 ± 0.50		211.78 ± 8.39		58.51 ± 1.69	

IY instant yeast, NCAIM: NCAIM Y.00801 strain, *C* control (distilled water). Bold means significant difference from C in terms of material. Asterisks between rows indicate significant difference between samples in terms of concentration. Asterisks between columns indicate significant difference between samples in terms of spraying frequency.

This difference was significant in every concentration and material used three times, as well as in the case of single-use 0.1% IY solution. When NCAIM and IY were compared, IY yielded lower TPC results, which is significant when the 0.1% suspension was used once. The same tendency is seen in the case of FRAP results: the control treatment showed the highest values. This difference is significant in the case of both 0.1% IY, and triple-use 1% NCAIM suspensions. In lower concentrations, NCAIM yielded significantly higher FRAP values, while 1% IY seemed to be more effective in this trait than 1% NCAIM. Considering lycopene, the treatments showed lower values than the control, but this difference was insignificant in almost all cases—an exception is the single-sprayed 0.1% IY suspension. Regarding lycopene content, IY and NCAIM-treated samples do not differ significantly.

Antioxidant Status of Rocket Samples

The DPPH values of rocket were more favorably affected by lower concentrations; this effect was significant in three out of four cases. The same tendency was observed for the TPC values, except in the case of the NCAIM single-use treatments, where an opposite effect was observed; the latter was significant, in contrast to the differences in the other cases. FRAP values showed a direct positive coherence with concentrations, significant in three out of four cases.

In the case of rocket plants, DPPH values were strongly influenced by application frequency, as three out of four cases were significantly divided. However, this effect was concentration dependent. Triple application of 0.1% suspensions and single application of 1% suspensions resulted in higher values. More frequent use of suspensions seems to support the increase of TPC content in rocket samples; however, the differences were not significant, except in the case of 0.1% NCAIM treatments. IY treatments showed a higher increase than NCAIM treatments, also exceeding the control value. The effect of frequency of application on FRAP values seems to be inconsistent. Triple application of 0.1% and single-use of 1% suspensions seem to be more effective, but significant differences were found only in two cases (0.1% IY and 1% NCAIM).

In the case of rocket, the DPPH values of most combinations exceeded those of the control, except for the triple-use 1% IY and NCAIM suspensions. In this combination, NCAIM differed significantly from the control. At the same time, all treatments with 0.1% suspensions gave higher DPPH results compared to the control; this difference is significant in three out of four cases. The effect of the IY and NCAIM materials only separated when three 0.1% concentrations were used, with the highest results in the case of the NCAIM treatment. The TPC results of the treatments were under the control, except both concentrations of triple-use IY treatments; this difference is not significant. At the same time, single treatments with 0.1% and 1% NCAIM resulted in significantly lower TPC results than the control. A general decrease in FRAP results was observed when treatments were applied. In five out of eight cases, this decrease was significant. The only exception was the 1% NCAIM single-use. When comparing materials, NCAIM treatments were generally more effective in increasing FRAP values, with the difference being significant in three out of four cases.

Chlorophyll Content of Tomato Samples

The overall MANOVA result together with the follow-up univariate analysis output is given in Table 4. The highest chlorophyll a value was obtained with by the triple application of 1% NCAIM solution on tomato (Table 5). Except for the single application of 0.1% IY treatment, all cases showed higher values with the higher concentration, although the difference was significant only in the case of both NCAIM treatments. Chlorophyll b values were affected by concentration, with a significant difference found in each case. However, there were also different tendencies in the case of treatment frequency and material. The higher concentration was more favorable when IY was applied once and when NCAIM was applied three times. Complementarily, the lower concentration was better in the case of single application of NCAIM and triple application of IY. Overall, the highest chlorophyll b result was given by the triple-use 0.1% IY solution, which even significantly exceeded the control value. A similar pattern was observed for total chlorophyll. Except for the 0.1% single-use solutions, all IY exceeded the control treatment; the triple treatments differed significantly. While chlorophyll a was slightly affected by application frequency, both chlorophyll b and total chlorophyll content showed significant changes in this factor. Although triple application of suspensions had some effect on chlorophyll a values, only one out of four cases was significant (1% NCAIM). The effect of more frequent spraying was radical on chlorophyll b and total chlorophyll values, as all comparisons showed significant differences. However, this effect was not clear in every case: the triple application of 0.1% NCAIM decreased, while the triple-use of other treatments increased both chlorophyll b and total chlorophyll content in tomato plants.

There is little effect on the chlorophyll a content of tomato samples after yeast suspension applications. Single applications of 0.1% IY and 1% NCAIM gave significantly lower results, while triple applications of 1% NCAIM gave significantly higher results than the control. However, a strong influence is shown on the chlorophyll b values: all eight cases deviated significantly from the control. Triple-use IY solutions increased, while the other six treatments decreased the chlorophyll b content of the samples. The same tendency

Table 4 Results of MANOVA for dependent Chlorophyll content variables (Chl a, Chl b and total Chl) in tomato and rocket leaves depending on factors SC suspension concentration (SCC: 0.1; 1 v/v), material (M: IY: instant yeast, NCAIM: NCAIM Y.00801 strain, C: control (distilled water)) and the number of application (1 or 3). Wilk's lambda provides the unexplained variance rate; F values are the outcome of follow-up univariate ANOVA with Bonferroni's correction

Factors	Tomato			Rocket	
	Wilk's lambda with degrees of freedom	$F(df_1 = {}^a;79)$	Chlorophyll parameters	Wilk's lambda with degrees of freedom	$F(df_1 = {}^a;36)$
SC susp. conc (SCC)	0.03*** df = 3;34	16.65***	Chl a	0.09*** df = 3;34	111.66***
		< 0.01 ns	Chl b		33.47***
		15.82***	Chl sum		57.02***
Material (M)	< 0.01*** df = 6;68	1.98 ns	Chl a	0.03*** df = 3;34	78.74***
		3775.45***	Chl b		137.79***
		2002.96***	Chl sum		142.97***
Number of Application (NoA)	< 0.01*** df = 3;34	148.56***	Chl a	0.41*** df = 3;34	1101.12***
		5656.55***	Chl b		994.88***
		3557.67***	Chl sum		1241.78***
SCC*M interaction	0.01*** df = 3;34	83.63***	Chl a	0.36*** df = 3;34	74.06***
		1197.79***	Chl b		0.01 ns
		624.85***	Chl sum		9.60*
M*NoA interaction	0.01*** df = 3;34	67.89***	Chl a	0.41*** df = 3;34	79.48***
		2442.21***	Chl b		22.34***
		1121.19***	Chl sum		49.10***
SCC*NoA interaction	0.02*** df = 3;34	96.60***	Chl a	0.15*** df = 3;34	661.01***
		230.47***	Chl b		441.77***
		70.25***	Chl sum		607.91***
SCC*M*NoA interaction	< 0.01*** df = 3;34	81.53***	Chl a	0.68** df = 3;34	14.66**
		6837.99***	Chl b		5.10 ns
		3870.23***	Chl sum		7.79*

[a] $df_1 = 1$ in cases of factors 'SCC' and 'NoA', while df1 = 2 in case of factor 'material'

Significant at *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$; ns not significant

applies to the total chlorophyll content: the difference is significant in seven out of eight cases, and again the triple-use IY solutions gave higher values.

Chlorophyll Content of Rocket Samples

The chlorophyll content of rocket was significantly influenced by the concentrations applied (Table 5), and by the frequency of application, which, in this case, defines what is the better treatment for increasing chlorophyll values. Considering the chlorophyll a, b, and total chlorophyll contents, it can be seen that in the case of a single application of the solutions, the 1% concentrations gave higher values, while in the case of a triple application, the lower concentration gave higher chlorophyll values. Except for the result of chlorophyll, a of the single-use 0.1% IY, every difference for concentration was significant. Chlorophyll values of rocket were notably influenced by the number of applications; chlorophyll a, b, and total chlorophyll contents were higher when suspensions were sprayed once. The only exception was 0.1% NCAIM, where chlorophyll a was significantly higher, after three application than after one. This is the only treatment that did not show significant differences in chlorophyll b and total chlorophyll content as a function of spraying frequency, all other treatments showed significant differences between single and triple spraying.

The treatments had a negative effect on the chlorophyll a value of the rocket samples. It is clear that regardless of the material, triple-use had a negative effect, which was significantly divided in three out of four cases. However, single-use significantly increased the chlorophyll a content, except for 0.1% NCAIM. IY induced higher increases than NCAIM in this characteristic. Similarly, IY had a greater effect on the chlorophyll b content of the samples. This effect was significantly positive with a single application, whereas the materials applied three times showed similar or lower values than the control, depending on the concentration. The same pattern was observed for total chlorophyll content: IY induced higher values, but both single treatments were higher than the control.

Table 5 Chlorophyll a, Chlorophyll b, and total chlorophyll content (means ± standard deviations) of tomato leaf and rocket leaf samples in the function of Saccharomyces cerevisiae suspensions' application

		Chlorophyll a			Chlorophyll b			Total chlorophyll		
M	v/v	Single appl.		Triple appl.	Single appl.		Triple appl.	Single appl.		Triple appl.
Tomato										
IY	0.1	**26.25** ± 0.09	ns	**26.38** ± 0.16	**17.32** ± 0.19	*	**33.78** ± 0.32	**43.56** ± 0.28	*	**61.18** ± 0.47
		ns		ns	*		*	*		*
	1	26.45 ± 0.23	ns	26.76 ± 0.12	26.23 ± 0.17	*	**28.55** ± 0.22	52.68 ± 0.33	*	**55.31** ± 0.28
NCAIM	0.1	26.79 ± 0.08	ns	**26.87** ± 0.06	**23.51** ± 0.17	*	**20.63** ± 0.33	**50.30** ± 0.24	*	**47.49** ± 0.37
		*		*	*		*	*		*
	1	**25.29** ± 0.12	*	**27.14** ± 0.11	**17.07** ± 0.15	*	**22.87** ± 0.08	**42.36** ± 0.22	*	**50.01** ± 0.09
C	-	26.62 ± 0.16			26.84 ± 0.38			53.46 ± 0.53		

		Chlorophyll a			Chlorophyll b			Total chlorophyll		
M	v/v	Single appl.		Triple appl.	Single appl.		Triple appl.	Single appl.		Triple appl.
Rocket										
IY	0.1	**26.78** ± 0.10	*	26.06 ± 0.08	**15.14** ± 0.19	*	**13.75** ± 0.21	**41.92** ± 0.22	*	**39.81** ± 0.17
		ns		*	*		*	*		*
	1	**26.88** ± 0.22	*	**24.65** ± 0.10	**16.25** ± 0.38	*	**12.01** ± 0.16	**43.14** ± 0.59	*	**36.66** ± 0.24
NCAIM	0.1	**25.71** ± 0.05	*	25.89 ± 0.06	**13.65** ± 0.21	ns	13.39 ± 0.22	39.36 ± 0.20	ns	39.28 ± 0.28
		*		*	*		*	*		*
	1	**26.69** ± 0.12	*	**24.81** ± 0.09	**15.04** ± 0.35	*	**11.42** ± 0.17	**41.73** ± 0.46	*	**36.23** ± 0.21
C	–	26.08 ± 0.10			13.05 ± 0.25			39.13 ± 0.35		

IY instant yeast, NCAIM: NCAIM Y.00801 strain, *C* control (distilled water). Bold means significant difference from C in terms of material. Asterisks between rows indicate significant difference between samples in terms of concentration. Asterisks between columns indicate significant difference between samples in terms of spraying frequency

Correlation of the Investigated Nutritional Traits

The statistical analysis shows a positive correlation between the chlorophyll parameters (chlorophyll a, b, and total chlorophyll, Table 6). This correlation is stronger for rocket samples (R values ranged between 0.933 and 0.992 $p < 0.01$). In the case of tomato leaves, the highest correlation was found between chlorophyll b and total chlorophyll ($R = 0.996$, $p < 0.01$). Tomato antioxidant indicators showed positive correlation in case of DPPH and TPC assays. Lycopene also correlated with DPPH and TPC levels. In rocket, negative correlation was found for DPPH and FRAP. Positive correlation was found for DPPH and chlorophyll a ($R = 0.306$, $p = 0.041$), and total chlorophyll ($R = 0.301$, $p = 0.044$). FRAP and TPC are negatively correlated with chlorophyll values, but none is significant.

Discussion

Effect of Concentration on Tomato and Rocket Nutritional Traits

Previous research results showed a positive trend in nutritional value toward higher concentrations, while the concentration of a yeast suspension with deleterious effect on a test plant has not yet been defined. However, the effect of yeast is not always significant on the traits studied; this is often influenced by seasonal environmental parameters (El-Naggar et al. 2015; Gawlik-Dziki et al. 2013). In the present case, significance was also influenced by environmental parameters. Antioxidant properties are known to be affected by abiotic and biotic stresses, which may explain

Table 6 Correlation between chlorophyll components of tomato and rocket leaves, and between different antioxidant indicators of tomato fruit and rocket leaves

Plant	Variable 1	Variable 2	*R*		Lower C.I.	Upper C.I.
Tomato ($n=45$) leaf	Chl_a	Chl_b	0.324	*	0.034	0.564
		Chl_sum	0.406	**	0.128	0.625
	Chl_b	Chl_sum	0.996	**	0.993	0.998
Tomato ($n=90$) fruit	DPPH	TPC	0.361	**	0.166	0.529
		FRAP	0.018	ns	− 0.190	0.224
		Lyc	0.635	**	0.493	0.745
	TPC	FRAP	0.174	ns	− 0.034	0.368
		Lyc	0.371	**	0.177	0.537
	FRAP	Lyc	− 0.147	ns	− 0.343	0.062
Rocket ($n=45$) leaf	DPPH	TPC	− 0.231	ns	− 0.491	0.067
		FRAP	− 0.393	**	− 0.616	− 0.113
		Chl_a	0.31	*	0.014	0.550
		Chl_b	0.29	ns	− 0.002	0.539
		Chl_sum	0.30	*	0.008	0.546
	TPC	FRAP	− 0.059	ns	− 0.347	0.239
		Chl_a	− 0.02	ns	− 0.309	0.278
		Chl_b	− 0.13	ns	− 0.409	0.168
		Chl_sum	− 0.09	ns	− 0.377	0.205
	FRAP	Chl_a	− 0.01	ns	− 0.303	0.284
		Chl_b	− 0.06	ns	− 0.350	0.234
		Chl_sum	− 0.05	ns	− 0.335	0.251
	Chl_a	Chl_b	0.933	**	0.880	0.963
		Chl_sum	0.971	**	0.947	0.984
	Chl_b	Chl_sum		**	0.986	0.996

*Correlation is significant at the 0.05 level (2-tailed)

**Correlation is significant at the 0.01 level (2-tailed)

the species-dependent responses of the plants investigated in the present study.

Although in this study, a positive effect of higher suspension concentration on FRAP values was experienced in the case of both rocket and tomato plants, the treatments resulted in lower values than the control. The observed insignificant decrease of total polyphenols may indicate that the lower FRAP results may indicate the loss of other components, since the FRAP assay evaluates water-soluble components with radical scavenging ability, such as polyphenols and vitamin C. Since the amount of vitamin C shows a positive correlation with the amount of sunlight (Dumas et al. 2003; Lee and Kader 2000), it is suggested, that foliar application of suspensions may have influenced the synthesis of vitamin C by improving the leaf density of plants shading the fruits. The same effect was observed in pepper plants in terms of plant height, stem diameter, number of leaves, and leaf area (Salloom et al. 2023). The increase in vitamin C content was experienced in marjoram by Zlotek (2017), while the phenolic content remained unchanged.

The influence of the yeast suspension concentration on the chlorophyll values of tomato and rocket plants seems to be related to the other two factors. The IY-related pattern shows similarities with the results of Zlotek and Swieca (2016), who applied single and double spraying on lettuce leaves, although the difference between treatments was insignificant. In contrast, Abou El-Yazied and Mady (2011) and Abdelmoteleb et al. (2022) found a constant slope increase with concentration in tomato chlorophyll parameters after single application of 0, 2, and 4 g/L suspensions.

Effect of Spraying Frequency on Tomato and Rocket Nutritional Traits

In this study, more frequent spraying did not necessarily lead to better nutritional results; in the case of tomato, lycopene was the only parameter that was increased with more frequent application of yeast suspensions. In the case of DPPH and FRAP results of rocket, different coherences were observed within concentrations: triple application of 0.1% and single application of 1% suspensions were better. This is in contrast to the results of Zlotek and Swieca (2016), who found an opposite trend, i.e., the best combinations are double spraying with 1% and single spraying with 0.1% suspensions. However, similar to our results, it also supports

that there might be some interrelation between application frequency and concentration. Mannino et al. (2020a; 2020b) found insignificant differences in lycopene, carotenoid, tocopherol, polyphenol, and ascorbic acid levels in tomato, when the triple treatment with a yeast- and seaweed-based biostimulant was repeated. They added that although quantitative changes were not detected, qualitative changes may have occurred in terms of polyphenols and tocopherols. In addition, the use of yeast suspensions had no positive effect on the reducing power of marjoram extracts but improved the antiradical activity of the plants (Zlotek 2017).

Effect of Yeast Source on Tomato and Rocket Nutritional Traits

Simple biostimulants that can be prepared without special expertise or tools can be effective in small-scale applications. The study by El Sheikha et al. (2022) on field bean showed that yeast is able to influence chlorophyll content. Schiattone et al. (2021) found that a solution based on yeast and brown algae can increase the chlorophyll content and decrease the antioxidant status of wild rocket plants.

In this study, there is no trend difference between IY and NCAIM regarding the antioxidant data of tomato. Overall, it seems that the applied materials did not substantially support the increase of antioxidant properties.

Since polyphenol levels are good indicators of the extent of abiotic stress factors affecting plants (Almuayrifi 2013), it is suggested that the applied treatments did not increase plant stress, since TPC did not show a tendentious increase either crop. Zlotek (2017) also found no significant increase in TPC in marjoram leaves. The main players in yeast suspensions are cytokinins, which are phytohormones that regulate cell division in plants. The applied treatments may have triggered vegetative growth of plants and at the same time decreased the production of plant secondary metabolites (Rühmann et al. 2002). Although there are some results showing a decrease in crop yield after elicitation (de Román et al. 2011), the majority of studies suggest an increase after foliar spraying with yeast (Vioratti Telles de Moura et al. 2023).

The Impact of Treatments (Material × Concentration × Frequency) on the Nutritional Traits of Tomato and Rocket Samples

Biostimulants can possibly have a negative impact on the investigated traits, as experienced by Grabowska (2015) in their tomato experiment. In the present study, the applied yeast suspensions had no or slightly negative effects on the investigated antioxidant parameters (DPPH, TPC, FRAP, lycopene) of tomato plants. A slight increase in DPPH results of both tomato and rocket after yeast treatments is in agreement with the results of Abdallah et al. (2016) and Zlotek and Swieca (2016) reported on quinoa seeds and lettuce, respectively. Regarding TPC, our results are in contrast with the findings of Yan et al. (2006), Neseim et al. (2014), and Abdallah et al. (2016); they found an increase after yeast treatments on red sage, sugar beet, and quinoa, respectively. However, Mahmoud et al. (2016) had insignificant and inconsistent TPC results on lupine, as did Zlotek (2017) on marjoram. Grabowska (2015) experienced a moderate increase in lycopene content of two tomato cultivars after using different biostimulants.

Mannino et al. (2020a; 2020b) mentioned that the application of certain spectrophotometric investigations was not able to quantify individual components and, therefore, did not provide information on qualitative changes caused by the treatments. They suggest that regardless of any quantitative changes detected in tomato, qualitative changes in the composition of the traits studied occurred. This statement can also be valid in the case of the present study, in terms of antioxidant compounds (FRAP, DPPH, TPC).

Since an insignificant change in TPC results was observed, it is suggested that yeast treatments may also affect other compounds in plants with antioxidant properties, i.e., those that contribute to the results of the FRAP assay. Abd-Alrahman and Aboud (2021) found that the vitamin C content of tomato was positively affected by yeast spraying. Abou el Yazied and Mady (2011) found the same in sweet pepper plants.

Conclusions

Foliar application of yeast suspensions can be effective in increasing antioxidant and other phytochemical levels of crop plants. In addition to its beneficial effects on nutritional traits, yeast is considered to be a cost-effective material for elicitation, plant protection, and nutrient recycling. Although the hypothesis was not fully justified by the results, the present study found that double-sprayed 1% and single-sprayed 0.1% extracts were the most effective treatments in terms of phytonutrient content, indicating the need for further comparative studies with different concentrations and application frequencies to elucidate the underlying biochemical processes. When comparing a fruit and leafy vegetable, species-dependent responses were found for the nutritional traits studied highlighting the need for targeted technological developments.

Author Contributions Conceptualization: AT and LCs; Methodology: AT and ML; Formal analysis and investigation: AT, DK, ML, and

LCs; Writing—original draft preparation: LCs, ML, and AT; Writing—review and editing: LM, DK, AT, and LCs.

Funding Open access funding provided by Hungarian University of Agriculture and Life Sciences. No funding was received for conducting this study. The authors have no relevant financial or non-financial interests to disclose.

Data Availability All data generated or analyzed during this study are included in this published article.

Declarations

Conflict of interest The authors report no conflict of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

References

Abd El Galil A, Abou El-Salehein E, El Hamady M (2021) Effect of foliar spray with urea and dry yeast extract on head lettuce production. J Productivity and Dev 26(4):1071–1086. https://doi.org/10.21608/jpd.2021.211864

Abdallah M, El Habbasha ES, Sebai T (2016) Comparison of yeast extract and nicotinaminde foliar applications effect on quinoa plants grown under sandy soil condition. Int J PharmTech Res 9:24–32

Abd-Alrahman HA, Aboud FS (2021) Response of sweet pepper plants to foliar application of compost tea and dry yeast under soilless conditions. Bull Natl Res Centre 45(1):119. https://doi.org/10.1186/s42269-021-00578-y

Abd-Elbaky AA, Yousef H, Abd El-Maged MS (2021) Effect of foliar application of yeast (*Saccharomyces cescervisiae*) on controlling downy mildew disease and yield production of onion. Middle East J Agric Res 10(02):629–638

Abdelmoteleb A, Gonzalez-Mendoza D, Mohamed Elbaalawy A (2022) Azospirillum brasilense and Saccharomyces cerevisiae as alternative for decrease the effect of salinity stress in tomato (*Lycopersicon esculentum*) growth. Phyton 91(1):21–32. https://doi.org/10.3204/phyton.2022.016227

Abou El-Yazied A, Mady MA (2011) Effect of naphthalene acetic acid and yeast extract on growth and productivity of tomato (*Lycopersicum esculentum* Mill.) plants. Res J Agric Biol Sci 7(2):271–281

Agamy R, Hashem M, and Alamri S (2013) Effect of soil amendment with yeasts as bio-fertilizers on the growth and productivity of sugar beet. https://www.semanticscholar.org/paper/Effect-of-soil-amendment-with-yeasts-as-on-the-and-Agamy-Hashem/d9ff1d921e1d9fece36e5c604d2145e1f3794b4c

Alali F, Alabboud M, and Mohi-Alden K (2017) The effect of foliar spray of yeast extract on the vegetative growth and productivity in tomato.

Ali MY, Sina AAI, Khandker SS, Neesa L, Tanvir EM, Kabir A, Khalil MI, Gan SH (2021) Nutritional composition and bioactive compounds in tomatoes and their impact on human health and disease: a review. Foods. https://doi.org/10.3390/foods10010045

Al-Mharib MZK, Al-Ubaidy RM, Mohammed MM (2022) Effect of spraying with folic acid and yeast extract on the growth, yield and calcium oxalate concentration of spinach (*Spinacia oleracea* L.). Appl EcoL Environ Res 20(3):2763–2768. https://doi.org/10.1566/aeer/2003_27632768

Almuayrifi MSB (2013) *Effect of fertilisation, crop protection, pre-crop and variety choice on yield of phenols content diseases severity and yield of winter wheat* [Ph.D., University of Newcastle Upon Tyne]. http://theses.ncl.ac.uk/jspui/handle/10443/2196

Benzie IFF, Strain JJ (1996) The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. Anal Biochem 239(1):70–76. https://doi.org/10.1006/abio.1996.0292

Bianchi AR, Vitale E, Guerretti V, Palumbo G, De Clemente IM, Vitale L, Arena C, De Maio A (2023) Antioxidant characterization of six tomato cultivars and derived products destined for human consumption. Antioxidants. https://doi.org/10.3390/antiox12030761

Blekkenhorst LC, Bondonno CP, Lewis JR, Woodman RJ, Devine A, Bondonno NP, Lim WH, Zhu K, Beilin LJ, Thompson PL, Prince RL, Hodgson JM (2017) Cruciferous and total vegetable intakes are inversely associated with subclinical atherosclerosis in older adult women. J Am Heart Assoc 7(8):e008391. https://doi.org/10.1161/JAHA.117.008391

Canene-Adams K, Campbell JK, Zaripheh S, Jeffery EH, Erdman JW Jr (2005) The tomato as a functional food. J Nutr 135(5):1226–1230. https://doi.org/10.1093/jn/135.5.1226

Chaudhary P, Sharma A, Singh B, Nagpal AK (2018) Bioactivities of phytochemicals present in tomato. J Food Sci Technol 55(8):2833–2849. https://doi.org/10.1007/s13197-018-3221-z

Csambalik L, Tóbiás A (2018) Application of Saccharomyces cerevisiae for nutritional value enhancement in agricultural plants: a review. Acta Biol Szegediensis 62(2):146–157

de Román M, Fernández I, Wyatt T, Sahrawy M, Heil M, Pozo MJ (2011) Elicitation of foliar resistance mechanisms transiently impairs root association with arbuscular mycorrhizal fungi. J Ecol 99(1):36–45. https://doi.org/10.1111/j.1365-2745.2010.01752.x

Dumas Y, Dadomo M, Di Lucca G, Grolier P (2003) Effects of environmental factors and agricultural techniques on antioxidantcontent of tomatoes. J Sci Food Agric 83(5):369–382. https://doi.org/10.1002/jsfa.1370

El Sheikha AF, Allam AY, Taha M, Varzakas T (2022) How does the addition of biostimulants affect the growth, yield, and quality parameters of the snap bean (*Phaseolus vulgaris* L.)? How Is this reflected in its nutritional value? Appl Sci. https://doi.org/10.3390/app12020776

El-Desouky SA, Ismaeil FH, Wanas AL, Fathy ESL, Abd El-All MM (2011) Effect of yeast extract, amino acid and citric acid on physioanatomical aspects and productivity of tomato plants grown in late summer season. Minufiya J Agric Res 36(4):859–884

El-Naggar AHM, Hassan MRA, Shaban EH, Mohamed MEA (2015) Effect of organic and biofertilizers on growth, oil yield and chemical composition of the essential oil of *Ocimum basilicum* L. plants. Alex J Agric Res 60(1):1–16

FAOSTAT (2021) https://www.fao.org/faostat/en/#home

Fish WW, Perkins-Veazie P, Collins JK (2002) A quantitative assay for lycopene that utilizes reduced volumes of organic solvents. J Food Compos Anal 15(3):309–317. https://doi.org/10.1006/jfca.2002.1069

Fouad Fawzy Z (2010) Increasing productivity of head lettuce by foliar spraying of some bio and organic compounds. Mesop J Agric 38:20–28. https://doi.org/10.3399/magrj.2010.33649

Francesca S, Arena C, Hay Mele B, Schettini C, Ambrosino P, Barone A, Rigano MM (2020) The use of a plant-based biostimulant improves plant performances and fruit quality in tomato plants grown at elevated temperatures. Agronomy. https://doi.org/10.3390/agronomy10030363

Gawlik-Dziki U, Świeca M, Dziki D, Sugier D (2013) Improvement of nutraceutical value of broccoli sprouts by natural elicitors. Acta Sci Pol Hortorum Cultus 12(1):129–140

Ghoname AA, El-Nemr MA, Abdel-Mawgoud AMR, El-Tohamy WA (2010) Enhancement of sweet pepper crop growth and production by application of biological, organic and nutritional solutions. Res J Agric Biol Sci 6(3):349–355

Giovannucci E (1999) Tomatoes, tomato-based products, lycopene, and cancer: review of the epidemiologic literature. JNCI: J Natl Cancer Inst 91(4):317–331. https://doi.org/10.1093/jnci/91.4.317

Grabowska A (2015) The effect of biostimulants on the quality parameters of tomato grown for the processing industry. Agrochimica. https://doi.org/10.1271/0021857201531

Hammad SA (2008) Physiological and anatomical studies on drought tolerance of pea plants by application of some natural extracts. Annf Agric Sci (cairo) 53(2):285–305

Hammad SAR, Ali OAM (2014) Physiological and biochemical studies on drought tolerance of wheat plants by application of amino acids and yeast extract. Ann Agric Sci 59(1):133–145. https://doi.org/10.1016/j.aoas.2014.06.018

Hedayati N, Naeini MB, Nezami A, Hosseinzadeh H, Wallace Hayes A, Hosseini S, Imenshahidi M, Karimi G (2019) Protective effect of lycopene against chemical and natural toxins: a review. BioFactors 45(1):5–23. https://doi.org/10.1002/biof.1458

Huang D, Ou B, Prior RL (2005) The chemistry behind antioxidant capacity assays. J Agric Food Chem 53(6):1841–1856. https://doi.org/10.1021/jf030723c

Kowalska J, Krzymińska J, Tyburski J (2022) Yeasts as a potential biological agent in plant disease protection and yield improvement—a short review. Agriculture. https://doi.org/10.3390/agriculture12091404

Kun Y, Lule US, Xiao-Lin D (2006) Lycopene: its properties and relationship to human health. Food Rev Int 22(4):309–333

Lee SK, Kader AA (2000) Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biol Technol 20(3):207–220. https://doi.org/10.1016/S0925-5214(00)00133-2

Lichtenthaler HK, Buschmann C (2001) Chlorophylls and carotenoids: measurement and characterization by UV–VIS spectroscopy. Curr Protoc Food Anal Chem. https://doi.org/10.1002/0471142913.faf0403s01

Mahmoud H, Azzaz N, Khalifa Y, Mahmoud M (2016) Effect of foliar application with active yeast extract and benzyladenine on some vegetative growth criteria and chemical composition of lupine (*Lupinus termis*, L.) plants. Minia J. Agric Res Develop 36:193–214

Mannino G, Campobenedetto C, Vigliante I, Contartese V, Gentile C, Bertea CM (2020a) The application of a plant biostimulant based on seaweed and yeast extract improved tomato fruit development and quality. Biomolecules. https://doi.org/10.3390/biom10121662

Mannino G, Campobenedetto C, Vigliante I, Contartese V, Gentile C, Bertea CM (2020b) The application of a plant biostimulant based on seaweed and yeast extract improved tomato fruit development and quality. Biomolecules. https://doi.org/10.3390/biom10121662

Mohamed MHM, Sami R, Al-Musshin AAM, Ali MME, El-Desouky HS, Ismail KA, Khalil R, Zewail RMY (2021) Impacts of effective microorganisms, compost tea, fulvic acid, yeast extract, and foliar spray with seaweed extract on sweet pepper plants under greenhouse conditions. Plants 10(9):1927

Molyneux P (2003) The use of the stable radical diphenylpicrylhydrazyl (DPPH) for estimating antioxidant activity. Songklanakarin J Sci Technol 26(2):211–219

Mozos I, Stoian D, Caraba A, Malainer C, Horbańczuk JO, Atanasov AG (2018) Lycopene and vascular health. Front Pharmacol. https://doi.org/10.3389/fphar.2018.00521

Neseim MR, Amin AY, El-Mohammady MM (2014) Effect of potassium applied with foliar spray of yeast on sugar beet growth and yield under drought stress. Global Adv Res J Agric Sci 3:211–222

Nimsi KA, Manjusha K, Kathiresan K, Arya H (2023) Plant growth-promoting yeasts (PGPY), the latest entrant for use in sustainable agriculture: a review. J Appl Microbiol 134(2):lxac088. https://doi.org/10.1093/jambio/lxac088

Ozkan G, Günal-Köroğlu D, Karadag A, Capanoglu E, Cardoso SM, Al-Omari B, Calina D, Sharifi-Rad J, Cho WC (2023) A mechanistic updated overview on lycopene as potential anticancer agent. Biomed Pharmacother 161:114428. https://doi.org/10.1016/j.biopha.2023.114428

Parađiković N, Vinković T, Vinković Vrček I, Žuntar I, Bojić M, Medić-Šarić M (2011) Effect of natural biostimulants on yield and nutritional quality: an example of sweet yellow pepper (*Capsicum annuum* L.) plants. J Sci Food Agric 91(12):2146–2152. https://doi.org/10.1002/jsfa.4431

Pennathur S, Maitra D, Byun J, Sliskovic I, Abdulhamid I, Saed GM, Diamond MP, Abu-Soud HM (2010) Potent antioxidative activity of lycopene: a potential role in scavenging hypochlorous acid. Free Radical Biol Med 49(2):205–213. https://doi.org/10.1016/j.freeradbiomed.2010.04.003

Podsędek A (2007) Natural antioxidants and antioxidant capacity of Brassica vegetables: A review. LWT Food Sci Technol 40(1):1–11. https://doi.org/10.1016/j.lwt.2005.07.023

Rouphael Y, Colla G (2020) Editorial: biostimulants in agriculture. Front Plant Sci. https://doi.org/10.3389/fpls.2020.00040

Royston KJ, Tollefsbol TO (2015) The epigenetic impact of cruciferous vegetables on cancer prevention. Curr Pharmacol Rep 1(1):46–51. https://doi.org/10.1007/s40495-014-0003-9

Rühmann S, Leser C, Bannert M, Treutter D (2002) Relationship between growth, secondary metabolism, and resistance of apple. Plant Biol 4(2):137–143. https://doi.org/10.1055/s-2002-25727

Saad-Allah KM, Fetouh MI, Elhaak MA (2017) Induction of milk thistle (*Silybum marianum* L. Gaertn) growth and phytochemicals production by natural stimulants. J Appl Res Med Aromat Plants 6:101–110. https://doi.org/10.1016/j.jarmap.2017.02.006

Salloom YF, Mejbel MH, Obaid MH, Al-Hchami SHJ (2023) Effect of foliar spray of nano nitrogen and bread yeast on some vegetative growth of pepper plants. IOP Conf Ser: Earth Environ Sci 1214(1):012012. https://doi.org/10.1088/1755-1315/1214/1/012012

Sarhan T, and Abdullah OK (2010) Effect of Azotobacter Inoculation, Dry Bread Yeast Suspension and Varying Levels of Urea on Growth of Potato Cv. Desiree. *World Food System - A Contribution from Europe. Book of Abstracts*, 226.

Schiattone MI, Boari F, Cantore V, Castronuovo D, Denora M, Di Venere D, Perniola M, Renna M, Sergio L, Candido V (2021) Effects of nitrogen, azoxystrobin and a biostimulant based on brown algae and yeast on wild rocket features at harvest and during storage. Agronomy 11:2326. https://doi.org/10.3390/agronomy11112326

Singleton VL, and Rossi (1965) *Colorimetry of Total Phenolics with Phosphomolybdic-Phosphotungstic Acid Reagents | American Journal of Enology and Viticulture*. https://www.ajevonline.org/content/16/3/144

USDA (1991) *USDA National Nutrient Database for Standard Reference Release 28, 18375, Leavening agents, yeast, baker's, active dry*. https://ndb.nal.usda.gov/ndb/foods/show/5861?fgcd=&manu=&lfacet=&format=Full&count=&max=50&offset=&sort=default&order=asc&qlookup=18375&ds=&qt=&qp=&qa=&qn=&q=&ing=

Vioratti Telles de Moura O, Luiz Louro Berbara R, França de Oliveira Torchia D, Fernanda Oliveira Da Silva H, Augusto van Tol de Castro T, Carlos Huertas Tavares O, Fernandes Rodrigues N, Zonta E, Azevedo Santos L, and Calderín García A (2023) Humic foliar application as sustainable technology for improving the growth, yield, and abiotic stress protection of agricultural crops. A review. *Journal of the Saudi Society of Agricultural Sciences*. https://doi.org/10.1016/j.jssas.2023.05.001

Yan Q, Shi M, Ng J, Wu JY (2006) Elicitor-induced rosmarinic acid accumulation and secondary metabolism enzyme activities in *Salvia miltiorrhiza* hairy roots. Plant Sci 170(4):853–858. https://doi.org/10.1016/j.plantsci.2005.12.004

Zlotek U (2017) Effect of jasmonic acid and yeast extract elicitation on low-molecular antioxidants and antioxidant activity of marjoram (*Origanum majorana* L.). Acta Sci Pol Technol Aliment. https://doi.org/10.17306/J.AFS.0505

Zlotek U, Swieca M (2016) Elicitation effect of Saccharomyces cerevisiae yeast extract on main health-promoting compounds and antioxidant and anti-inflammatory potential of butter lettuce (*Lactuca sativa* L.). J Sci FoodAgric 96(7):2565–2572

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.