Acta Biologica Szegediensis

Volume 62(2):146-157, 2018
Acta Biologica Szegediensis
http://abs.bibl.u-szeged.hu/index.php/abs
DOI:10.14232/abs.2018.2.146-157

REVIEW

Application of *Saccharomyces cerevisiae* for nutritional value enhancement in agricultural plants – a review

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ABSTRACT This review focuses on yeast suspensions applied with the aim to enhance nutritional content of agricultural products. Seventy one publications were studied, and their details summarized in tables, according to the following plant groups: 1/ arable plants, 2/ vegetables, 3/ medicinal and ornamental plants. It was found that the experimental designs in these papers were inconsistent in most cases and, regardless to plant species used, the concentration of yeast extract, time of application, and repetitions of the treatment were fundamentally different, making evaluation of the methodologies difficult. However, all studies agreed in the positive impact of yeast extracts on nutritional parameters. Therefore, it is advisable to perform further studies to clarify the relationship of individual nutritional parameters to spraying dose, timing and repetition of yeast application. **Acta Biol Szeged 62(2):146-157 (2018)**

KEY WORDS
antioxidants
cytokinins
elicitation
hypersensitive reaction
phytonutrients
yeast

ARTICLE INFORMATION
Submitted
19 October 2018.
Accepted
12 November 2018.
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Introduction

Although, yeast suspensions are considered as natural biostimulants in both vegetative and generative stages of plants (Ibraheim 2014), there are few in-depth studies available about the application of yeast suspensions as elicitors. According to Zlotek and Swieca (2016), there are differences in the extent of elicitation among plant species; therefore, at least species-level research is needed in this field.

With the use of scientific search engines and bibliography databases, as well as electronic libraries of universities, numerous publications related to the topic are accessible. However, these publications – especially those which connected to open field experiments and assessed by relatively simple instrumental measurements – appeared in local journals with not a real impact to the scientific field, therefore their results remained hidden. Most of the experiments reviewed in this paper were conducted in Egypt and Iraq, coordinated by agricultural universities and research stations of these countries. Soil nutrition has a critical role in successful agricultural production of these regions as sandy soil types are low in organic matter and of high percentage of degraded and reclaimed soils. Research on the use of nutrient supplementation is intensive in this region with the aim of minimizing environmental impact and production costs. Every literary source highlights the natural origin of yeast-based products as an advantage. Gawlik-Dziki and co-workers (2016) encourage the application of yeast extracts for elicitation and thus for more favorable nutritional content of the products instead of transgenic foods which have very low consumer acceptance.

Cytokinins are phytohormones having various regulatory roles in many plant processes (Kousalya et al. 2016; Macalalad et al. 2016; Parić et al. 2017). Several literature sources mention them as the key component of yeast extracts responsible for their effectiveness. As plant hormones they are used widespread in micropropagation, however, the use of the pure compounds for large scale agricultural purposes would be circumstantial and expensive. At the same time yeasts, could be good alternative sources of cytokinins and other useful constituents.

The aim of the present review was to summarize and evaluate the methodological approaches of experiments where yeast-based preparations were used for nutritional enhancement of agricultural crops.

Experimental design

Two types of basic experimental designs with focus on produce nutritional value can be distinguished, the first

investigates the effect of yeast suspensions at various concentrations, while the other compares the impact yeast suspension of with that of different materials such as natural substances (royal jelly: Fathy and Farid 1996b; methyl jasmonate: Sánchez-Sampedro et al. 2005; urea: Sarhan and Abdullah 2010; *Salix* bark extract: Gawlik-Dziki et al. 2013), plant hormones (salicylic acid: Amer 2004), vitamins (vitamin E: El-Tohamy and El-Greadly 2007; vitamin C: El-Tohamy et al. 2008; vitamin B group: Fathy and Farid 1996b; Naguib and Khalil 2002), amino acids (Hammad and Ali 2014), minerals (boron: Abou-El-Yazied and Mady 2012; zinc: Ahmed et al. 2011), fertilizers (Amino-Green: Nour and Eisa 2009; chitosan: Tartoura 2001). In the latter case, maximum two concentrations of yeast suspensions are applied, and yeast is rather a reference point, which novel products are compared to. Combinations of such materials and yeast are also assessed in most cases.

In case of open field trials, the experimental duration is generally two years in order to overcome weather extremities. Soybean (Mekki and Ahmed 2005), sugar beet (Agamy et al. 2013), and lupine (Khalil and Ismael 2010) were investigated in greenhouse pot experiments. Abbas (2013) designed his research with green bean also in greenhouse. *In vitro* experiments have also been conducted on flax cell cultures (Shams-Arkhani et al. 2005) and on broccoli sprouts (Gawlik-Dziki et al. 2013). Sánchez-Sampedro et al. (2005) used *Silybum marianum* cell cultures for assessing silymarin accumulation in relation to foliar spraying of yeast extracts. *In vitro* hairy root cultures of red sage (Yan et al. 2006) and wormwood (Putalun et al. 2007), treated with yeast extract, were analyzed for bioactive substances.

Table 1. Application of yeast solutions on arable plants.

Plant species	Variety	Application	Concentration	No. of seasons	Frequency of treatment	Reference
Beta vulgaris subsp. *vulgaris* convar. *vulgaris* var. *altissima* / Sugar beet[2]	'Hind'	greenhouse, pot, soil	50, 100 ml/pot *10^8 cfu/ml	2	When sown, repeated every third week	Agamy et al. 2013
	'Pleo'	open field, plant, foliar	10, 14 g/l	2	30, 45, 60 DAS	Neseim et al. 2014
Chenopodium quinoa / Quinoa	n.a.	open field, plant, foliar	5, 10, 15 g/l	2	45, 60 DAS	Abdallah et al. 2016
Glycine max / Soybean[1]	n.a.	greenhouse, pot, foliar	1 g/l	2	45, 60 DAS	Mekki and Ahmed 2005
	'OAC Champion'	open field, plant, foliar	1, 2, 3, 4 g/l	n.a.	R3 and R4 stages	Al-Tawaha and Al-Tawaha 2017
Linum usitatissimum / Flax	n.a.	in vitro culture	0.25, 0.8 g/l	n.a.	n.a.	Shams-Ardakani et al. 2005
Lupinus albus / Lupine	'Balady'	greenhouse, pot, foliar and/or soil	8 g/l	2	45, 59 DAP	Khalil and Ismael 2010
	'Giza-1', 'Giza-2', 'Giza-3', 'Giza-1'	open field, plant, foliar or soil	90 ml/l	2	45, 60 DAS	Mahmoud et al. 2016
Triticum aestivum / Wheat	'Bogatka', 'Mulan', 'Muszelka'	seeds, incubator	10 g/l	n.a.	4 days after germination	Gawlik-Dziki et al. 2016
	'Sakha 94'	open field and pot, plant, foliar	3, 6 g/l	2	25, 40, 55 DAS	Hammad and Ali 2014
Vicia faba / Faba bean	'Giza 2', 'Giza 3', 'Giza 843', 'Sakha 1', 'Sakha 4'	open field, plant, foliar	5, 10 g/l	2	35 DAS, 50 DAS	El-Shafey et al. 2016
	'Giza 3'	open field, plant, foliar	25, 50 ml/l	2	30, 50, 70 DAS	Mady 2009
	'Cyprus'	open field, plant, foliar	3, 6 g/l	2	35, 50 DAS	Marzauk et al. 2014
	'Super Aquadulse'	open field, plant, foliar	2.5, 5 ml/l	2	35, 50, 65 DAS	Abou El-Yazied and Mady 2012
Vigna unguiculata / Cowpea	'Creem-7'	open field, plant, foliar	25, 50 ml/l	n.a.	n.a.	Fathy and Farid 1996a
Zea mays / Maize	'TWC 352'	seeds, germination test	0.1 g/l	n.a.	Soaked for 6, 12, 18 hours	Kandil et al. 2015

The applied strains were: [1]*Candida tropicalis*; [2]*Kluyveromyces walti*, *Pachytrichospora transvaalensis*, *Saccharomycopsis cataegensis*.
DAS: days after sowing. DAP: days after planting. n.a.: not applicable/available. cfu: colony forming unit.

Plant species

Articles focusing only on vegetative growth were also excluded as the positive effect of yeast extracts on plant development seems to be obvious; the explanations in most cases refer to the cytokinin, vitamin, enzyme, and mineral content of such extracts.

With regards to arables (Table 1), the most frequent plant subgroups used were leguminous ones: faba bean, soybean, lupine, and cowpea. Leguminous plants are important vegetables in Egypt (Abdel-Hakim et al. 2012), for human consumption and as animal forage as well, being cheap sources of proteins, carbohydrates, vitamins, and minerals. El-Shafey et al. (2016) compared five faba bean varieties in an open field experiment. Maize and wheat seedlings were treated by Kandil et al. (2015), and Gawlik-Dziki et al. (2016), respectively, in *in vitro* experiments.

There are 41 articles on vegetables reviewed here (Table 2), out of which 17 apply leguminous species. The most frequent one is snap bean, followed by pea, and common bean. As previously mentioned, the importance of these plants in human consumption is high, and their cultivation improves soil mineral content due to their symbiosis with *Rhizobium* bacteria. Ten studies investigated *Solanaceae* species (potato, tomato, sweet pepper, and eggplant), six experiments dealt with *Cucurbitaceae*, while four with *Alliaceae*.

Table 2. Application of yeast solutions on vegetable species.

Plant species	Variety	Application	Concentration	No. of seasons	Frequency of treatment	Reference
Allium cepa / Onion	'Giza 20', 'Super X'	open field, plant, foliar	1, 2, 3 g/l	2	every week starting 30 DAS	Fawzy et al. 2012
	'Giza 6 Mohassan'	open field, plant, foliar	0.5, 0.75, 1 g/l	2	60, 81 DAS	Abdel-Moneim et al. 2015
Allium sativum / Garlic	'Balady'	open field, plant, foliar	2 g/l	2	30, 45, 60, 75 DAS	Shalaby and El-Ramady 2014
	'Clone sids-40'	open field, plant, foliar	2, 3, 4 g/l	2	30, 45, 60, 75 DAS	Ahmed and Farm 2015
Capsicum annuum / Sweet pepper	'California wonder'	open field, plant, foliar	1, 2, 3 g/l	2	30 DAP	Ghoname et al. 2010
	'California Wonder'	open field, plant, foliar	25, 50 ml/l	n.a.	n.a.	Fathy and Farid 1996b
Cucumis melon / Ananas melon	'Ananas'	open field, plant, foliar	50, 100 ml/l	2	25, 35, 45, 55 DAS	Adb El-Aal 2012
Cucumis sativus / Cucumber	'Safa 62'	open field, plant, foliar	2 g/l	2	n.a.	Farag 2016
	'Celerbity F1'	greenhouse, plant, foliar	1, 2, 3, 4 g/l	2	25 DAT, 32, 39, 46 DAP	Shehata et al. 2012
	'KUC-102'	open field, plant, foliar	5, 10, 15, 20 g/l	2	21 DAS	Nassef and El-Aref 2017
	'Shadi'	greenhouse, plant, foliar	6 g/l	n.a.	20, 30, 40 DAS	Sarhan et al. 2011
Cucurbita pepo / Squash	'Eskandrani'	open field, plant, foliar	0.005 g/l	2	n.a.	Abou El-Nasr et al. 2001
Cynara cardunculus var. *scolymus* / Artichoke	'Fuseau'	open field, plant, foliar	5, 7 g/l	2	50, 65, 80, 95 DAE	Hafez 2013
Ipomoea batatas / Sweet potato	'Abees'	open field, plant, foliar	5, 10 g/l	2	21, 35 DAS	El-Tohamy et al. 2015
Lactuca sativa / Lettuce	'Lymor'	open field, plant, foliar	2, 4 g/l	2	28, 42 DAP	Fawzy 2010
	n.a.	growth chamber	10, 100 g/l 1.5 ml/plant	n.a.	21, 42 DAS	Zlotek and Swieca 2016
	'Balady'[1]	open field, plant, foliar	4 ml/l 5×10^6 cfu/ml	2	30, 45 DAP	Farrag et al. 2016
Phaseolus vulgaris / Common bean	'Giza 3'	greenhouse, pot, foliar	5 g/l	1	30, 45, 60, 75 DAS	Abbas 2013
	n.a.	open field, plant, foliar	0.005 g/l	1	n.a.	Fathy and Farid 1996a
	'Bronco'	open field, plant, foliar	1, 2 g/l	2	n.a.	Amer 2004

Table 2. Continued.

Plant species	Variety	Application	Concentration	No. of seasons	Frequency of treatment	Reference
Phaseolus vulgaris / Kidney bean	'Giza 6'	open field, plant, foliar	25, 50, 100, 150 ml/l	2	28, 42 DAS	Nassar et al. 2011
Phaseolus vulgaris / Snap bean	n.a.	open field, plant, foliar	2, 4 g/l	2	n.a.	Nour and Eisa 2009
	'Bronco'	open field, plant, foliar	5, 10 g/l	2	20, 34 DAE	El-Tohamy and El-Greadly 2007
	'Poulista'	open field, plant, foliar	4, 8, 12 g/l	n.a.	30, 40, 50 DAS	Abdel-Hakim et al. 2012
	'Primel'	pot,	12 g/l	n.a.	14, 28, 42, 56 DAS	Al-Amery and Mohammed 2017
	'Pulista'	open field, plant, foliar	2, 4 g/l	2	28, 42 DAS	Fawzy et al. 2010
	'Poulista'	open field, plant, foliar	3 g/l	2	three-leaves-stage, 7, 14 days later	Byan 2014
	'Bronco'	open field, plant, foliar	25, 50 ml/l	n.a.	n.a.	Fathy and Farid 1996b
Pisum sativum / Pea	n.a.	open field, plant, foliar	100, 300 g/l	2	n.a.	El-Desuki and El-Greadly 2006
	'Balmoral'	open field,plant, foliar and soil	4 g/l	2	30, 44 DAS	Elsharkawy 2013
	'Master B'	open field, plant, foliar	30 ml/l	n.a.	n.a.	Tartoura 2001
	'Master B'[2]	open field, plant, foliar	n.a.	2	n.a.	Zaghloul et al. 2015
	'Victoria Freezer'	open field, plant, foliar	2.5, 5, 7.5 g/l	2	30, 45, 60 DAS	Ibraheim 2014
	'Gaint'	open field, plant, foliar	2, 4 g/l	2	20, 33, 48 DAS	Ali and Abd-Allah 2010
Solanum lycopersicum / Tomato	'Super Strain B'	open field, plant, foliar	15, 30 g/l	2	20, 35, 50, 65, 80 DAP	El-Desouky et al. 2011
	'Castel Rock'	open field, plant, foliar	25, 50 ml/l	n.a.	n.a.	Fathy and Farid 1996b
	'Super Strain B'	open field, plant, foliar	2, 4 g/l	2	30, 45, 60 DAP	Abou El-Yazied and Mady 2011
Solanum melongena / Eggplant	'Black Beauty'	open field, plant, foliar	5, 10 g/l	2	30, 45 DAP	El-Tohamy et al. 2008
Solanum tuberosum / Potato	'Desiree'	open field, plant, foliar	2, 4, 6, 8 g/l	n.a.	30, 40 DAP	Hussain and Khalaf 2007
	'Desiree'	open field, soil	2, 4, 6 g/l 1 l/m^2	2	5, 15, 25, 35 DAE	Sarhan and Abdullah 2010
	'Riviera'	open field, soil	4, 8 g/l	1	germination stage, tuber formation stage	Kahlel 2015
	'Valor'	open field, plant, foliar	0, 1, 2, 3, 4, 5 g/l	2	30, 44, 58 DAS	Ahmed et al. 2011
Brassica oleracea convar. *botrytis* var. *italica* / Broccoli	'Cezar'	in vitro, germination test, watering, sprouts	1, 5, 10 g/l	n.a.	2, 3, 4 DAS	Gawlik-Dziki et al. 2013

The applied strains were: [1]Sc NCAIM Y 00216; [2]local isolate; [3]Vi-cor® company. DAS: days after sowing. DAE: days after emergence. DAP: days after planting. n.a.: not applicable/available. cfu: colony forming unit.

A non-comprehensive collection of fifteen articles using yeast extracts on medicinal and ornamental plants were also included into this review (Table 3) to provide an insight into advantages of this approach in this group of plants. In case of medicinal plants, the focus was on the amount and composition of the essential oils produced. Limited number of sources was found on treatment of fruit species; therefore, this plant group has been excluded from this review.

Yeast species and extracts

The raw material used for suspensions are not well defined in most cases. The names active dry yeast, or active yeast extract, brewer's yeast, bread yeast, instant yeast are generally used. The origin of the strain is not sufficiently documented either. In contrast, Agamy et al. (2013) provided the names of the three yeast strains obtained from a personal collection of South Africa. Nassar et al. (2015) used commercial yeast powder, while Sánchez-Sampedro et al. (2005) applied the aqueous extract of crude yeast. Abou El-Yazied et al. (2011) defined an American company (Vi-COR) as the source of the yeast material. Farrag et al. (2016) shared the catalog number of the strain used (Sc. NCAIM Y 00216), provided by Sakha Agricultural Research Station, Egypt (but the number proved misleading and untraceable). Zaghloul et al. (2015) used a local isolate for pea experiments. Mekki and Ahmed (2005) incorrectly identified baker yeast with *Candida tropicalis*, an opportunistic pathogenic yeast. Several articles, such as Abou El-Yazied and Mady (2012) or Khalil and Ismael (2010) cited sources (e.g., Mahmoued 2001; Nagodawithana 1991) about the compounds of yeast extract in general; but failed to provide the analysis of the actual material used. Therefore, the comparability of these experiments is questionable due to the lack of a standardized yeast material or of any nutritional parameters as base for comparison. None of the articles refer, for instance, to USDA (2016) database, where nutrient component quantities are reported. That database also defines that both names of baker's and active dry yeast can be used. The term brewer's yeast can refer to various *Saccharomyces* strains (Kurtzmann and Robnett 2003), therefore, it is inevitable to provide detailed information about the yeast material used for ensuring the repeatability and comparability of results.

Yeast suspension/ extracts preparation

In most cases, the preparation of yeast suspensions follows the same pattern: active dry yeast is suspended in a water-sugar (1:1) solution (Ahmed et al. 2011; Byan 2014). After

Table 3. Application of yeast solutions on medicinal and ornamental plant species.

Plant species	Variety	Application	Concentration	No. of seasons	Frequency of treatment	References
Artemisia absinthium / Wormwood	n.a.	growth medium, hairy roots	0.5, 1, 2 g/l	n.a.	21 DAS	Putalun et al. 2007
Borago officinalis / Borage	n.a.	open field, plant, foliar	2, 4, 6 g/l	2	150, 180 DAS	El-Din and Hendawy 2010
Carum carvi / Caraway	n.a.	open field, plant, foliar	1, 2g/l	2	40, 60 DAS	Medani and Taha 2015
Coleus blumei / Coleus	n.a.	in vitro culture, medium	0.01, 0.025, 0.05, 0.1g/l	n.a.	8 DAS	Sahu et al. 2013
Coriandrum sativum / Coriander	n.a.	open field, plant, foliar	1, 2, 3 g/l	2	n.a.	Eid 2001
Geranium sp. / Geranium	n.a.	greenhouse, pot, foliar	2, 4, 6 g/l	2	1 and 2 week(s) before cutting	El-Lethy et al. 2011
Melissa officinalis / Lemon balm	n.a.	open field, plant, soil	5, 10, 15 g/l	2	15, 36 DAP	Rashed 2012
Nigella sativa / Black cumin	n.a.	n.a.	0.002 g/l	n.a.	n.a.	Naguib and Khalil 2002
Ocimum basilicum / Basil	n.a.	open field, plant, foliar	2, 4, 6 g/l	2	30, 44 DAS, and one month after first cut	El-Nagger et al. 2015
	n.a.	open field, plant, foliar	4 g/l (2, 8, 12)	2	49, 70 DAS	Nassar et al. 2015
Salvia miltiorrhiza / Red sage	n.a.	in vitro, hairy roots	0.05, 0.1, 0.2, 0.4 g/l	n.a.	18 days after inoculation	Yan et al. 2006
Salvia officinalis / Sage	n.a.	open field, plant, foliar	0.1, 0.2, 0.3 g/l	2	n.a.	Massoud 2006
Silybum marianum / Milk thistle	'Albiflora'	open field, plant, foliar	25, 50, 100 g/l, 1100 l/ha, 5 l/plot	2	14, 75 DAS	Saad-Allah et al. 2017
	n.a.	in vitro cell culture	0.005, 0.015, 0.025, 0.05, 0.1 g/l	n.a.	n.a.	Sánchez-Sampedro et al. 2005
Stevia rebaudiana / Stevia	'Spanti', 'China-1'	open field, plant, foliar	2, 4 g/l	2	30, 60 DAS	Salama et al. 2016

DAS: days after sowing. DAP: days after planting. n.a.: not applicable/available

that an overnight period (El-Tohamy and El-Greadly 2007; Abbas 2013), or two days (Ahmed et al. 2011) is provided for the activation and growth of yeast cells.

Most of the articles – especially those from Egypt - cite and use this method. Others, *e.g.*, Abou El-Yazied and Mady (2012), Barnett et al (1990), Nassar et al (2011), Hafez (2013), Mahmoued (2001), or Saad-Allah et al. (2017), refer to Spencer et al. (1983). In these works, dry yeast powder was activated by using 6:1 ratio of carbon and nitrogen sources. According to the authors, the highest cell number of yeasts can be achieved with this method: each ml of activated yeast culture contains about 1.2 x 10^4 yeast cells. In this work of Spencer et al. (1983) various details are given (e.g., on budding and growth rate of *S. cerevisiae* in different environments), however, no information provided about how to prepare an extract from yeasts.

There are several frequently applied methods for releasing beneficial bioconstituents from yeast cells. Bartlett et al. (1990) used a medium with glucose and casein as favorable sources of C, N and other essential elements in a suitable balance, and adjusted air supply and temperature. The culture was subjected to two cycles of freezing and thawing for disruption of yeast cells, directly before use. Tween-20 detergent is added for tested treatments in the experiment of Bartlett et al. (1990). However, in Spencer et al. (1983) no method for preparing an effective yeast extract is given.

Farrag et al. (2016) followed the method of Ono et al. (1991), where Yeast Peptone Glucose (YPG; 2% glucose, 2% peptone, and 1% yeast extract) medium was used for the propagation of yeast cells. The growth temperature was 30 °C. The liquid culture was later used for foliar treatments. Yan et al. (2006) used the carbohydrate (polysaccharide) fraction of a commercial yeast extract (Y4250; Sigma, St. Louis, MO). The suspension for foliar treatments was prepared by a two-times ethanol precipitation then dissolved in 100 ml distilled water, sterilized by autoclaving (121 °C, 20 min), and stored in a refrigerator at 4-8 °C before use. The dose was expressed by the total carbohydrate content determined by the phenol-sulfuric acid method using sucrose as a standard (Yan et al. 2006).

Zlotek and Swieca (2016) followed the method of Gawlik-Dziki et al. (2013), where instant yeast is suspended in distilled water in certain concentrations, then autoclaved, with the addition of Tween-20 as surfactant.

Targeted plant part, timing and frequency of treatments

The most common application, especially in case of open field experiments, is foliar spraying. Agamy et al. (2013) did soil inoculation with yeast suspensions in a pot experiment with sugar beet. Mahmoud et al. (2016) compared foliar and soil application of yeast on five lupine varieties. Kahlel (2015), and Sarhan and Abdullah (2010) applied soil inoculation on potato test plants. Sahu et al. (2013) applied yeast extracts in the growth media for an *in vitro* experiment on *Coleus* sp. Kandil et al. (2015) soaked maize seeds and assessed certain nutritional parameters of the radicle.

With regard to arables, treatments were applied two or three times, starting about 30 days after sowing, and repeated after 15-20 days. In case of experiments with faba bean varieties, the authors (*e.g.*, Mady 2009; Marzauk et al. 2014; El-Shafey et al. 2016) did not refer to other works regarding experimental designs, while those with lupine were consistent even though the environment was different (greenhouse/open field).

In case of vegetables, the number of treatments is often increased to four, starting generally after 30 days and keeping 10-15 days intervals. Experiments performed with garlic varieties are consistent in timing and frequency of treatments. Experiments with lettuce originating from three different research groups show some similarities in performing the treatments although the conditions were different. Publications describing experiments on various bean types do not provide all details but the development of the methodology is probable; two applications of Fathy and Farid (1996a) are gradually increased to four by Al-Amery and Mohammed (2017). Experiments done with pea, tomato, and potato show limited methodological similarities within a variety.

No coherence is seen between the applied methodology and the investigated plant part; leaf vegetables are treated twice, fruit, tuber, and bulb vegetables are sprayed 2-4 times independently from foliage size or the position of marketable plant part. Out of 71 reviewed papers, only one examined the effect of the number of treatments within the same experiment: Zlotek and Swieca (2016) used single and double spraying on lettuce cultivated in growth chamber.

Agamy et al. (2013) and Zlotek and Swieca (2016) refer to preliminary experiments for selecting the concentration to be used in the main experiment. However, most articles reviewed here do not provide detailed explanation on the selection of concentrations, volumes, or treatment frequencies used.

Sampling

For pigments analysis, leaves of the test plants were collected; depending on the media, species, and other parameters of the experiment, the time of leaf sampling was done 30-150 days after sowing (DAS). In case of leaf vegetables and medicinal plants, this time was the end of the season (maturity). Mady (2009), as well as Abou-El-Yazied and Mady (2012) collected leaf samples two times, with a 15-20 days interval. Neseim et al. (2014) did not

define an exact date, only stated that leaves were fresh. El-Tohamy et al. (2015) and Khalil and Ismael (2010) defined a vegetative development stage; the second and the fourth full developed leaves of sweet potato and lupine were collected, respectively.

The plants' marketable plants were sampled, for detailed nutritional analysis, typically when ordinary harvest would have taken place. Tubers, roots, bulbs, pods, seeds, spikes, shoots, and fruits were collected in full ripening and taken to instrumental measurements.

Results

Nutritional parameters investigated on leaves or shoots

Total sugars, total soluble solids and dry matter content was found to be increased in several studies.

Analysis of macronutrients (nitrogen, phosphorus, potassium) in leaves showed a general increase (eggplant: El-Tohamy et al. 2008; tomato, pepper, bean: Fathy and Farid 1996b; lettuce: Farrag et al. 2016), and so did calcium and magnesium (tomato, pepper, bean: Fathy and Farid 1996b). Fawzy (2010) measured lower levels of nitrates and higher amounts of Fe, Mn, and Zn when used the suspensions on lettuce. The same was found by Medani and Taha (2015) in caraway shoot samples.

Following yeast treatments, free amino acid content (sugar beet: Neseim et al. 2014; quinoa: Abdallah et al. 2016), protein content (faba bean: Mady 2009; sugar beet: Agamy et al. 2013) and carbohydrate levels of the plant leaf samples (bean: Fathy and Farid 1996b; Abbas 2013; wheat: Hammad and Ali 2014; caraway: Medani and Taha 2015) showed an increase. But in treated milk thistle seedlings, decrease of amino acids concentration was measured by Saad-Allah et al. (2017).

In the case of leaf or shoot samples, chlorophyll a and b, were measured, often together with carotenoids; and a general rise was observed in comparison with untreated plants. Neseim et al. (2014) found this effect to be non-significant, as well as Agamy et al. (2013) and Zlotek and Swieca (2016) within their given experimental designs.

Fawzy (2010) measured ascorbic acid changes after yeast treatments of lettuce and found a significant rise. Zlotek and Swieca (2016) could not find a significant difference in the case of lettuce.

Hammad and Ali (2014) investigated peroxidase and phenoloxidase activity, which were higher in the case of treated wheat leaves. Yan et al. (2006) found increased tyrosine aminotransferase and lower phenylalanine ammonia lyase activity in the case of treated red sage leaves.

Saad-Allah et al. (2017) investigated milk thistle seedlings for photosynthetic efficiency, which showed a non-significant increase.

El-Tohamy and El-Greadly (2007) observed an increase of auxins (IAA) and gibberellin (GA3) in bean shoots after yeast treatments. Abdallah et al. (2016) found an increase of IAA levels on quinoa leaves. The same was found by Abbas (2013), together with increased ABA+ activity, and by El-Shafey et al. (2016), together with increased cytokinin levels. Higher levels of cytokinins were also observed by El-Tohamy and El-Greadly (2007) on bean and by El-Tohamy et al. (2008) on eggplant. Besides this, Mady (2009) found an increasing amount of auxins and a lower level of abscisic acid in treated faba bean leaves. Higher amounts of auxin, gibberellins and cytokinins and the decrease of abscisic acid was supported by the results of Abou El-Yazied and Mady (2011) and Abou El-Yazied and Mady (2012) on tomato and on broad bean, respectively. Increasing levels of chichoric acid, ferulic acid, and caffeic acid was found by Zlotek and Swieca (2016) in lettuce leaves.

An increase of total phenols was experienced by Yan et al. (2006), Neseim et al. (2014), and Abbdallah et al. (2016) on red sage, sugar beet, and quinoa, respectively. Gawlik-Dziki et al. (2013) detected changes in the phenolic profile of treated broccoli sprouts; chlorogenic and p-hydroxybenzoic acid decreased, while p-coumaric and syringic acid increased, and flavonoids content was also elevated by yeast spraying; resulting in increased antiradical activity of the broccoli sprouts. Zlotek and Swieca (2016) found a non-significant increase of lettuce flavonoids content, together with increased DPPH (2,2-diphenyl-1-picrylhydrazyl) and ABTS (2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) results.

Nutritional parameters investigated on seeds

Abdallah et al. (2013) measured carbohydrate and protein content increase of quinoa seeds treated with yeast extracts. The same was found by Khalil and Ismael (2010) in lupin, by Mady (2009), by El-Shafey et al. (2016) in faba bean, and by Hammad and Ali (2014) in wheat. The protein levels were consistently growing in two development stages of soybean (Al-Tawaha and Al-Tawaha 2017). The decrease of the total fiber content of wheat was observed by Hammad and Ali (2014).

The nitrogen, potassium and phosphorus content of seeds from arable plants seems to be increasing as the function of the treatment with yeast suspensions (Mekki and Ahmed 2005; Mady 2009; Khalil and Ismael 2010; Mahmoud et al. 2016).

In the study of Abdallah et al. (2016), the oil content of quinoa seeds rose insignificantly, but in soybean seeds, Mekki and Ahmed (2005) found a significant increase.

The alkaloid content of white lupin showed a significant decrease when treated by yeast suspensions (Khalil and Ismael 2010), while the results of Mahmoud et al.

(2016) showed a non-significant change in the same species.

DPPH and flavonoids content increase of treated quinoa seeds was insignificant (Abdallah et al. 2016). The phenolics content of wheat seeds treated by yeast and germinated for four days were increased according to Gawlik-Dziki et al. (2016). However, total phenolic content (TPC) changes were insignificant and inconsistent in the study of Mahmoud et al. (2016) on lupine.

Nutritional parameters investigated on roots, tubers and bulbs

The sucrose content of sugar beet roots increased when treated with yeast extracts (Agamy et al. 2013). Following to foliar treatments, the total soluble solids content of onion bulbs increased according to Fawzy et al. (2012), and Abdel-Moneim et al. (2015). The same was found by El-Tohamy et al. (2015) in sweet potato tubers and by Hussain and Khalaf (2007) in potato. In contrast, Kahlel (2015) found a non-significant total soluble solids (TSS) increase in the case of potato in a one-year trial.

An increase of starch percentage was observed by Ahmed et al. (2011) when yeast extracts were used on the foliage of potato.

The macronutrients as well as nitrate and nitrite content of onion bulbs showed an increase after foliar treatments (Ahmed and Farm 2015; Abdel-Moneim et al. 2015). In potatoes, level of macronutrients and Zn was elevated after yeast treatment (Ahmed et al. 2011). Fawzy et al. (2012) further found that Fe, Cu and Mn levels were also increased in the case of treated onion plants.

In treated sugar beet roots, increase in protein (Agamy et al. 2013), as well as in free amino acids and phenols (Neseim et al. 2014) was found. Increased protein level was found by Ahmed et al. (2011) in potato tubers. In onion bulbs, total carbohydrate content and volatile oil content were elevated on yeast treatments in the study of Ahmed and Farm (2015).

Nutritional parameters investigated on fruits

The foliar application of yeast extracts resulted in an increase of nitrogen, phosphorus and potassium in tomato fruits (Fathy and Farid 1996b; El-Desouky et al. 2011; Abou El-Yazied and Mady 2011). This is in agreement with the findings of Abd El-Aal (2012) in ananas melon, where calcium and magnesium levels were also elevated. Shehata et al. (2012) investigated the effect of yeast extracts on cucumber; elevation of Fe, Zn, Cu, and Mn, besides macronutrients, was recorded.

The TSS as well as total acid content (mainly responsible for taste properties of tomato) showed an increase in the study of Abou El-Yazied and Mady (2011). Besides TSS, total sugar levels were also increased in ananas melon (Abd El-Aal 2012) as well as in sweet pepper and in tomato (Fathy and Farid 1996b; Ghoname et al. 2010; El-Desouky et al. 2011). Increase of TSS was recorded by Sarhan and Abdullah (2011), Shehata et al. (2012), and by Farag (2016) in cucumber. In contrast, Nassef and El-Aref (2017) found no significant difference in TSS in the same species, but clear increase in the percentage of reducing sugars.

The protein and carbohydrate content of tomato were increased by yeast treatments according to Fathy and Farid (1996b), Abou El-Yazied and Mady (2011), and El-Desouky et al. (2011).

Application of yeast extracts positively affected also vitamin C content of tomato (Abou El-Yazied and Mady 2011) and of sweet pepper fruits (Ghoname et al. 2010).

Nutritional changes of artichoke inflorescence following yeast treatments – significantly increased total carbohydrate, inulin and Na content – was found by Hafez (2013).

Oil content of medicinal plants

All reviewed sources agree that foliar application of yeast extract has a positive impact on oil content of medicinal plants. In most cases, significant differences were measured, except e.g. in Nassar et al. (2015) in basil. The decrease of stevioside and rebaudioside-A percentage of stevia plant was reported by Salama et al. (2016). At the same time, a decrease in the number of volatile components on yeast treatment was seen by Nassar et al. (2015) in basil. Certain compounds of basil showed non-significant changes in the study of El-Nagger et al. (2015).

Discussion

Soil inoculation or foliar application?

Khalil and Ismael (2010) applied foliar and soil, as well as combined treatments on lupine plants. They found foliar application of yeast extract significantly more effective on the chlorophyll content of leaves than soil inoculation. Similarly, foliar application was more favorable than soil application in the case of nitrogen, protein, and carbohydrate content of lupine seeds. This is possible due to the hypersensitive reaction induced by yeast extracts.

Foliar and soil application of yeast suspensions on lupine plants was also investigated by Mahmoud et al. (2016) who found slight differences between the two methods in terms of measured nutritional parameters. Protein and lipid percentage, as well as TSS were higher, while alkaloids were lower in case of foliar application. These results were consistent through the dataset of three cultivars, while TPC was higher in two out of three varieties when applied on foliage.

Which is the most advantageous concentration?

In most studies, higher concentrations of yeast suspensions generally resulted in higher nutritional values, and to some extent a linear positive correlation was seen. Even the highest concentrations used in the referred studies had no deteriorative effect on the nutritional parameters of test plants. However, in some cases yeast extracts had no significant impact on the investigated characteristics, and in certain studies, non-linear correlations could be assumed. For example, El-Naggar et al. (2015) found contradictory results as to the optimal concentration regarding leaf pigments of basil leaves; in the first season, concentration of chlorophyll was the highest when 6 g/l suspensions were used, while in the next year lower concentrations gave better results. Similarly, GC-MS analysis of volatile components revealed that different concentrations were advantageous for the enhancement of each volatile. Eid (2001) found a reverse effect of yeast extract concentration on essential oil content of coriander plants; 1 g/l was more advantageous than either 2 or 3 g/l. Similarly, Sánchez-Sampedro et al. (2005) found that not the highest applied concentration was the most advantageous for enhancing silymarin content of *Silybum marianum* cell cultures.

Al-Tawaha and Al-Tawaha (2017) found that 1 g/l, the applied lowest concentration, increased crude protein levels of soybean the most, while 2 g/l enhanced fiber and oil content. Higher concentrations (3 and 4 g/l) in the same study had no such outstanding effect on these parameters. Regarding protein content, Nassar et al. (2011), Marzauk et al. (2014), and Ibraheim (2014) found similar results, i.e. not the highest applied concentrations were the most advantageous. In the study of Mady (2009) the applied lower concentration (25 g/l) was more favorable for auxin concentration, while all other measured parameters were higher when 50 g/l extract was used. The same tendency was found by Abou El-Yazied and Mady (2011) on the gibberellin content of tomato samples. Likewise, not the highest applied concentration was the most advantageous for phenolic components of broccoli sprouts (Gawlik-Dziki et al. 2013).

Putalun et al. (2007) applied three concentrations of yeast suspensions on wormwood hairy root culture, and measured artemisinin content on different days after treatment. The results showed a non-linear relationship between concentrations and artemisinin content. Similar results were seen by Yan et al. (2006) in red sage hairy root cultures.

How many times should spraying be repeated?

Within the reviewed 71 papers, only one deals comparatively with the number of treatments. Zlotek and Swieca (2016) used single and double spraying on lettuce seedlings grown in a growth chamber. Regarding antioxidant power, TPC and ABTS levels benefited from double spraying while DPPH results were higher on single application of yeast extracts. The authors concluded that double sprayed 1% and single sprayed 0.1% extract were the most effective treatments in terms of phytonutrient content, which points the necessity for further comparative studies.

Conclusions

Virtually all of the reviewed 71 studies supported the positive effect of the foliar application of yeast extracts on the nutritional parameters in altogether 38 plant crops, but the role of the actors of this process remained unclear which calls for ongoing research activity. The number of the published comparative studies is limited. As the applied methods show no or minimal commonalities, it is hard to conclude on an ideal combination of concentration, treatment timing, and repetition. At the same time, the great methodological diversity of successful treatments show the power of such interventions, which further stresses the need for basic comparative studies in the following topics, 1., ideal number of treatments to avoid financial losses, 2., ideal timing of treatment(s), and 3., the ideal concentration (and volume) for the highest effect on vegetative and nutritional parameters without any deteriorative impact on cultivated crops and nature. However, the number of *in vitro* studies is increasing; and these, with the involvement of in-depth instrumental investigations, can gradually clarify the questions outlined in this review.

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