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Influence of stress conditions on the quality of obtained sprouts – modification of their chemical composition

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REVIEW ARTICLE

Abstract

Sprouts are generally accepted as a pro-healthy food. They are consumed as a source of valuable macronutrients, antioxidants, microelements, and vitamins. Changing growth conditions of sprouts enables modification of their nutritional quality, as well as their safety. Thus, in order to achieve the most desirable composition of the produced sprouts, the conditions for their production are optimized. The aim of this review is to present methods currently used to modify the nutritional quality of plant sprouts. Most scientific works focus on stress conditions inducing the synthesis of secondary metabolites, mainly antioxidants. An increase in their content is achieved after application of physical (e.g., light illumination, temperature) or chemical factors (e.g., salinity stress, phytohormones, metal ions, etc). Though the application of these modifications on a larger scale is problematic. These problems include difficulties in predicting the effect of the stressor and an increased price of the obtained sprouts. However, since it is possible to enrich sprouts with valuable health-promoting substances, these methods are still considered very promising.

Keywords: abiotic stress; antioxidants; sprouts biofortification; sprouts nutritional value

Introduction

Sprouts are more and more common foodstuffs, present not only in traditional Asian markets but also in other parts of the world. The fashion for healthy, low-processed and exotic food, as well as interesting sensorial features of sprouts, increased their presence on our tables significantly. EU legislation defines sprouts as a product obtained from seeds germination in water or another medium (EU, 2013). In contrast to microgreens, they are consumed as shoots and rootlets – with seeds or deseeded. They are harvested before the full expansion of cotyledon leaves and before the emergence of true leaves – usually after 2–7 days of culturing (while microgreens after 7–21 days of growing) (Kyriacou *et al*., 2016; Le *et al*., 2020). Because of the growing interest in sprout consumption, studies on their quality which is understood in terms of nutritional value and their safety are widespread.

The nutritional value of sprouts has been appreciated for years. Frequently, at the time of sprouting, no drop is observed in the content of molecules used in metabolism as a source of energy (especially lipids and sugar), despite their involvement in plant development processes (Erba *et al*., 2018). However, hydrolysis of macromolecules is observed, making nutrients more bioavailable and an elevated content of free sugars and amino acids may be noted (Erba *et al*., 2018). Research on germination suggests an increase in protein content (Erba *et al*., 2018; Nissar *et al*., 2017). However, it must be remembered that the process usually takes place in water (without additional nitrogen sources). Thus, the synthesis of proteins (hydrolytic enzymes) probably results from the rearrangement of other nitrogen-containing compounds (Bau *et al.*, 1997). Many studies also suggest the impact of germination on dietary fiber fractions (Duenas, 2016; Masood *et al.*, 2014), and a decreased content or activity of anti-nutritional substances (Świeca and Baraniak, 2014).

Discussion on the results regarding changes in the sprouts' composition is concluded: the nutritional value of the obtained sprouts depends on the type of sprouted plants and applied conditions. In order to achieve the most desirable composition of the produced sprouts, the conditions for their production are optimized. Conditions that depart from the optimal usually reduce biomass production (Lim *et al.*, 2012) but may lead to a beneficial effect on sprouts. They are referred to as stress conditions and are divided into two groups: biotic and abiotic. Biotic stress is a consequence of pathogenes' attack (herbivores, fungi, bacteria, viruses, oomycetes, and nematodes). Abiotic stress, on the other hand, includes salinity, floods, droughts, radiation, extreme temperature, and presence of heavy metal ions and other contamination.

Stress conditions are important for the sprouting because the defense against most abiotic stressors starts in the roots (Gull *et al.*, 2019). The defense system depends on the kind of stressors. For instance, in the case of drought plants, it shortens the shoots and starts the synthesis of compounds, adapting the plant to new osmotic pressure. Whereas in the case of heavy metal ions, plants chelate them and increase the synthesis of antioxidant compounds to detoxify them (Gull *et al.*, 2019). Thus, due to the fact that stress induces endogenous defense mechanisms, it significantly influences the synthesis of secondary metabolites.

In the case of growing edible sprouts, which are carried with the use of special equipment (such as phytotrons or climate chambers), other methods of modifying natural conditions of plant growth are easy to apply, e.g., irradiation. At the same time, the possibility of controlled modification of growth conditions (usually by abiotic stress action) increases the interest in obtaining sprouts as a source of valuable plant metabolites. Most studies focus on decreasing anti-nutrients and the possible modification in the contents of bioactive compounds, among them antioxidants.

Influence of stress factors on sprouts growth

Modification of sprouting conditions is essential for seeds or grain germination percentage, rate, shoot and root length, fresh and dry weight, and seedling vigor (some examples are presented Table 1). These parameters depend on the seeds or grain quality, and optimum environmental conditions are variable according to their genetic nature. The most widely studied in this respect are salinity, drought, and temperature stress.

These sprouting parameters usually decrease with the increase in salinity (Carpici *et al.*, 2009; Jamil *et al.*, 2006; Promila and Kumar, 2000), although Wang *et al.* (2019) proved that low salinity (<80 mM) induced growth of broccoli sprouts.

Drought also inhibits and suppresses germination (Li *et al.*, 2013). However, this factor has little effect on the cultivation of edible sprouts, as it is usually done in hydroponic cultures.

Sprout yield and length are also influenced by temperature, which – unless optimal – can restrain germination. However, stimulation by frost or fire may be essential for some plants. Shock temperature may also promote sprouting in edible plants. And for some plants, increased temperatures may also be beneficial, as it was observed for amaranth seeds. Germination strength of the seeds improved in extreme temperatures [both in decreased (10°C) and increased (40°C)], and dried seeds tolerated ground temperature of even 70°C (Ye and Wen, 2017). It was observed that for some legumes seeds, differences in temperature between 10°C and 30°C do not affect, while the change in the temperature from ambient to 30°C increased fresh weight and sprout length of mung bean (Islam *et al.*, 2017).

Plants in nature germinate with limited light access. Sprouts' dry weight and length are higher in continuous dark conditions (Mastropasqua *et al.*, 2020). However, selected light illumination may also influence sprouts growth (Xu *et al.*, 2005).

The content of toxic elements in culture media significantly influences the efficiency of sprouting. The high concentration of many ions (especially metal ions) is usually toxic for plants; lower concentration on the other hand triggers the defense system against oxidative stress. As a consequence, reduction in germination percentage is observed, root shape and length disturbed (as it was observed during sprouting in the presence of iron, selenium, lead solutions) (Arscott and Goldman, 2012; Zielińska-Dawidziak *et al.*, 2014, 2016, 2018).

However, research on the use of stress conditions during the growth of sprouts on their chemical composition is becoming increasingly popular. The objective is to obtain valuable pro-health substances and plants with increased nutritional quality.

Table 1. Influence of stress factors on sprouts growth parameters.

Effect	Stress factor	Material	Reference
Increased			
Germination rate (at salt concentration <80 mM)	Salinity	Broccoli (*Brassica oleracea)*	Wang et al., 2019
Germination strength (at both 10°C as well as 40°C)	Temperature	Edible amaranths (*Amaranthus tricolor*)	Ye and Wen, 2017
Fresh weight Sprout length (in 30°C)		Lignosus bean (*Dipogon lignosus*)	Islam et al., 2017
Fresh weight	Light	Soybean (*Glicine max* L.)	Xu et al., 2005
Decreased			
Germination percentage Germination rate	Salinity	Maize (*Zea mays* L.)	Carpici et al., 2009
Germination percentage, Germination rate, Root and shoot lengths, Fresh root and shoot weights.		Sugar beet (*Beta vulgaris*) Cabbage (*Brassica oleracea capitata* L.), amaranth (*Amaranthus paniculatus*), pak-choi (*Brassica compestris*)	Jamil et al., 2006
Radicle, root, and hypocotyl length		Mung bean (*Vigna radiate*)	Promila and Kumar, 2000
Dry weight	Light	Soybean (*Glicine max* L.) Mung bean (*Vigna radiata* L.) Radish (*Raphanus sativus* L.) Pumpkin (*Cucurbita moschata*)	Mastropasqua et al., 2020
Biomass	Selenium	Broccoli (*Brassica oleracea*), Mung bean (*Vigna radiata*), Onion (*Allium cepa 'Red creole'*)	Arscott and Goldman, 2012
Shape, length, thickness, color	Heavy metal ion	Alfalfa (*Medicago sativa* L.) Lentil (*Lens culinaris* Medik.) Lupine (*Lupinus luteus*) Soybean (*Glicine max* L.) Wheat (*Triticum aestivum* L.)	Zielińska-Dawidziak et al., 2018 Zielińska-Dawidziak et al., 2014

Influence of stress on macronutrients composition of sprouts

There is scarce information regarding the influence of sprouting conditions on macronutrients. *De novo* protein synthesis and the activity of other proteins depend on many environmental conditions. They include temperature, humidity, the presence of metal ions (especially inducing oxidative stress), and concentration of phytohormones (abscisic acid, gibberellic acid, and salicylic acid).

Usually, abiotic stress (e.g., NaCl, polyethylene glycol) (Dell'Aquila and Spada, 1992) decreases protein synthesis. The expression pattern of 561 protein was studied in response to environmental disruption (Tan *et al*., 2013). Environmental stress induced by some metal ions also inhibits the mobilization of starch and sucrose (Scott and Jones, 1985).

Influence of stress on antioxidant activity of sprouts

Sprouts are often pointed as a source of valuable antioxidants because their high content is typical of young plants, and decreases with the age of the plant (Liu *et al*., 2016). Abiotic stress at the time of sprouting intensifies the synthesis of reactive oxygen species. Thus, it involves the overproduction of antioxidants (Przybysz *et al*., 2016; Tan *et al*., 2013; Zielińska-Dawidziak *et al*., 2018). It is obvious that antioxidant activity depends on the genus, species, and botanical variety of plants, but the content of antioxidants in sprouts may be easily modified by changing culture conditions (Table 2).

An example may be the application of a lighting system or radiation (γ, UV) (Fan *et al*., 2004; Shetty *et al*., 2002). Properly chosen light spectra enhanced the content of the total antioxidant activity, e.g., in buckwheat, Chinese kale, pea, chickpea, wheat sprouts (Nam *et al*., 2017; Ohand Rajashekar., 2009; Qian *et al*., 2016; Samuolienė *et al*., 2011; Tsurunaga *et al*., 2013), and many others. However, it is difficult to recommend the right light wavelength or predict the acting of this factor. Nevertheless, blue light is often suggested in the above cited research.

The content of antioxidants may also be increased by the application of other abiotic stressors. Studies on stress evoked by salt concentration are frequently conducted, but they rarely concern changes in plant composition. Sometimes an increase in salt concentration induces

Table 2. Influence of stress factor on the activity or content of antioxidative compounds at the end of sprouting experiments.

Effect	Stress factor	Material	Reference
Increased			
Antioxidant activity	Gamma rays	Alfalfa (*Medicago sativa* L.)	Fan et al., 2004[1]
	UV-B 300–320 nm*	Buckwheat (*Fagopyrum esculentum*)	Tsurunaga et al., 2013[2]
	Blue light	Chinese kale (*Brassica oleracea* var. *alboglabra)*	Qian et al., 2016[3]
	Light-emitting diode (LED) spectra (mixed wavelength)	Wheat *(Triticum aestivum* L.) Radish (*Raphanus sativus* L.) Lentil (*Lens esculenta* Moenh.)	Samuolienė et al., 2011[2]
	Salt (up to 200 mM NaCl treatment)	Buckwheat (*Fagopyrum esculentum*)	Lim et al., 2012[2]
	Salt	Durum (*Triticum turgidum* L.)	Stagnari et al., 2017[4]
	Temperature (chilling down to 4°C)	Alfalfa (*Medicago sativa* L.), Broccoli (*Brassica oleracea* L.) Radish (*Raphanus sativus* L.)	Oh and Rajashekar, 2009[4]
	Temperature (4°C and 40°C)	Lentil (*Lens culinaris* Medik.)	Świeca and Baraniak, 2014[4]
Phenolic compounds	UV light	Fava bean (*Vicia faba*)	Shetty et al., 2002[5]
	Blue light	Chinese kale (*Brassica oleracea* var. *alboglabra)*	Qian et al., 2016[6]
	Yellow light	Chickpea (*Cicer arietinum*)	Khattak et al., 2007[6]
	Blue light Red light	Buckwheat (*Fagopyrum esculentum*)	Nam et al., 2017[6]
	Light-emitting diode (LED) spectra (mixed wavelength)	Wheat *(Triticum aestivum* L.) Radish (*Raphanus sativus* L.) Lentil (*Lens esculenta* Moenh.)	Samuolienė et al., 2011[6]
	Salt (25 mM NaCl)	Einkorn (*Triticum monococcum* L.) Emmer (*Triticum turgidum* L.) Durum (*Triticum turgid*um L.)	Stagnari et al., 2017[6]
	Temperature (chilling down to 4°C)	Alfalfa (*Medicago sativa* L.) Broccoli (*Brassica oleracea* L.) Radish (*Raphanus sativus* L.)	Ohand Rajashekar, 2009[6]
	Temperature (4°C and 40°C)	Lentil (*Lens culinaris* Medik.)	Świeca and Baraniak, 2014[6]
	Iron concentration	Yellow lupine (*Lupinus luteus*) Blue lupine (*Lupinus angustifolius*)	Zielińska-Dawidziak et al., 2018[6]
	Iron concentration	Broccoli (*Brassica oleracea*) Radish (*Raphanus sativus*) Alfalfa (*Medicago sativa* L.) Mung bean (*Vigna radiate* L.)	Przybysz et al., 2016[7]
Flavonoids	Fluorescent light	Buckwheat (*Fagopyrum esculentum*)	Nam et al., 2017[8]
	Temperature (4°C and 40°C)	Lentil (*Lens culinaris* Medik.)	Świeca and Baraniak, 2014[8]
	Iron concentration	Yellow lupine (*Lupinus luteus*) Blue lupine (*Lupinus angustifolius*)	Zielińska-Dawidziak et al., 2018[9]
Vitamin C	Gamma rays	Alfalfa (*Medicago sativa*)	Fan et al., 2004[10]
	White light	Chinese kale (*Brassica oleracea* var. *alboglabra)*	Qian et al., 2016[10]
	Green light	Chickpea (*Cicer arietinum* L.)	Khattak et al. 2007[11]
	UV light	Soybean (*Glycine max* L.)	Xu et al., 2005[11]
	Iron concentration	Broccoli (*Brassica oleracea*) Radish (*Raphanus sativus*) Alfalfa (*Medicago sativa* L.) Mung bean (*Vigna radiate* L.)	Przybysz et al., 2016[10]
Rutin	UV-B 300–320 nm*	Buckwheat (*Fagopyrum esculentum*)	Tsurunaga et al., 2013[12]
Anthocyanin	UV-B 300–320 nm*	Buckwheat (*Fagopyrum esculentum*)	Tsurunaga et al., 2013[13]
	Blue light	Chinese kale (*Brassica oleracea* var. *alboglabra)*	Qian et al., 2016[14]

(*continues*)

Table 2. Continued

Effect	Stress factor	Material	Reference
Vitamin E	Visible light	White mustard (*Sinapis alba* L.)	Zieliński and Kozłowska, 2003[15]
	Red light	Barley sprouts (*Hordeum vulgare*)	Koga et al., 2013[15]
	Iron concentration (up to 20 mM $FeSO_4$)	Soybean (*Glycine max* L.)	Zielińska-Dawidziak and Siger, 2012[15]
Carotenoids	White light	Tartary buckwheat (*Fagopyrum tataricum*)	Tuan et al., 2013[16]
	Salt (up to 100 mM NaCl)	Buckwheat (*Fagopyrum esculentum*)	Lim et al., 2012[16]
	Iron (10 mM $FeSO_4$)	Soybean (*Glycine max* L.)	Zielińska-Dawidziak and Siger, 2012[16]
Activity of antioxidative enzymes	Iron concentration	Broccoli (*Brassica oleracea*) Radish (*Raphanus sativus*) Alfalfa (*Medicago sativa* L.) Mung bean (*Vigna radiate* L.)	Przybysz et al., 2016[17]
Decreased			
Phenolic content	Red light Blue light Green light Fluorescent light Gamma rays	Chickpea (*Cicer arietinum*)	Khattak et al., 2007[6]
No influence			
Antioxidant activity phenolic compounds and flavonoids	Iron (up to 20 mM $FeSO_4$)	Soybean (*Glycine max* L.)	Zielińska-Dawidziak et al., 2018[1,6, 9]

Methods of antioxidative compounds determination: Antioxidant activity 1\TRAP, 2\DPPH. 3\FRAP, and 4\ABTS; Phenolic content: 5\β-Carotene bleaching, 6\Folin-Ciocalteu and 7\spectrophotometric (Fast BlueBB); Flavonoids content: 8\Folin-Ciocalteu and 9\spectrophotometric ($AlCl_2$); Vitamin C: 10\HPLC and 11\spectrophotometric; Rutin: 12\HPLC; Anthocyanin: 13\spectrophotometric and 14\HPLC; Vitamin E: 15\HPLC; Carotenoids: 16\HPLC; Antioxidative enzymes activity: 17\spectrophotometric.

the production of bioactive compounds while significantly reducing the growth of sprouts (Falcinelli *et al.*, 2017). The higher content of phenolic compounds was noted for buckwheat sprouts (grown in salt concentration up to 200 mM) (Lim *et al.*, 2012), einkorn, emmer, and durum sprouts (up to 50 mM of salt) (Stagnari *et al.*, 2017).

Also, a change in the temperature causes differences in antioxidant concentration, which was observed after chilling broccoli, radish, and alfalfa sprouts (Ohand Rajashekar, 2009), as well as after application of heat for sprouting lentils (Świeca and Baraniak, 2014).

Usage of metal ions inducing oxidative stress enhances the accumulation of antioxidants, and it was observed in soybean, lupine (Zielińska-Dawidziak *et al.*, 2018), broccoli, radish, alfalfa, and mung bean sprouts (Przybysz *et al.*, 2016), among others.

Usually, phenolic compounds and flavonoids are studied, but it must be remembered that sprouts are a very good source of vitamins with a recognized high antioxidant potential (vitamin C, E, and β-carotene) (Duenas *et al.*, 2016; Fan *et al.*, 2004; Sim *et al.*, 2019; Stagnari *et al.*, 2017). The ascorbic acid content in seeds and grains is generally very low, but a different type of illumination may influence the biosynthesis of vitamin C. It was confirmed for soybean, chickpea, and kale sprouts (Khattak *et al.*, 2006; Qian *et al.*, 2016; Xu *et al.*, 2005). The content of tocopherol and β-carotene was modified by the stress induced by metal ions in soybean sprouts (Zielińska-Dawidziak and Siger, 2012). Application of light illumination influenced vitamin E content in different *Cruciferae* sprouts (Zieliński and Kozłowska, 2003), with red light for barley sprouts (Koga *et al.*, 2013). White light influenced carotenoids content in Tartary buckwheat (Tuan *et al.*, 2013).

Simultaneously, this increase in some antioxidants content may modify the tart, bitter and sour flavors of sprouts (Chen and Chang, 2015). Thus, an additional change in the sprouts' sensorial quality may be observed.

Influence of stress on the content of other interesting bioactive substances in sprouts

Modification of the growth conditions influence also the content of other interesting phytochemicals in sprouts (Table 3). Stress conditions (including heat treatment and salinity) may modify γ-aminobutyric acid (which acts as a neurotransmitter) content in sprouts (Benincasa *et al.*, 2019; Guo *et al.*, 2016; Youn *et al.*, 2011). Reducing oxygen availability (hypoxia stress) modifies the content of γ-aminobutyric acid in response to cytosolic acidosis, which was observed for soybean (Guo *et al.*, 2011, 2012), fava bean (Yang *et al.*, 2013), and rice (Aurisano *et al.*, 1995; Ding *et al.*, 2016), and Tartary buckwheat sprouts (Guo *et al.*, 2016).

Glucosinolates and their derivatives were also modulated in broccoli sprouts by the application of UV and phytohormones (Moreira-Rodríguez *et al.*, 2017), sulphur supplementation (in broccoli, cabbage, and radish sprouts) (Kestwal *et al.*, 2011), or glucose addition (in Chinese kale and pak choi sprouts) (Wei *et al.*, 2011).

Stress also has a significant influence on methionine and proline metabolism (Shetty *et al.*, 2002; Tan *et al.*, 2013), thus, on the content of that essential amino acid. The stress factor may also increase the L-DOPA synthesis (an amino acid that increases the concentration of dopamine in the nervous system) (Randhir *et al.*, 2004a; Shetty *et al.*, 2002). Red and blue light illumination doubled the content of amino acids in barley seedlings (compared to natural sunlight) (Meng *et al.*, 2015).

Influence of stress on antinutrients in sprouts

Usually, germination decreases the content of antinutrients (Boschin and Resta, 2013; Świeca and Baraniak, 2014), inhibitors among them. Some authors suggest that stress conditions activate protease inhibitors (Domash *et al.*, 2008; Świeca and Baraniak, 2014), but with no impact on protein digestibility. Świeca and Baraniak (2014) also observed an elevated activity of α-amylase, trypsin, and chymotrypsin inhibitors in response to the impact of temperature on sprouts, but with no influence on protein digestibility and no clear impact on starch bioavailability.

The decrease in the content of many antinutrients (trypsin and amylase inhibitors, phytic acids, and lectins) may be achieved after the application of some elicitors in the growing medium. This effect was observed after using chitosan, salicylic acid, and hydrogen peroxide in a medium intended for bean sprouting (Mendoza-Sánchez

Table 3. Influence of stress on the content of other interesting bioactive substances in sprouts.

Effect	Stress factor	Material	Reference
Increased content			
γ-Aminobutyric acid	Combined anaerobic and heat treatment (120–140°C) after sequential hydration	Wheat (*Triticum* L.)	Youn et al., 2011
	Dark cultures at 30°C, hypoxia stress	Tartary buckwheat (*Fagopyrum tataricum)*	Guo et al., 2016
	Dark cultures at 30°C, hypoxia stress	Soybean (*Glycine max* L.)	Guo et al., 2011 Guo et al., 2012
Glucosinolates	UVA treatment + methyl jasmonate UVB treatment +methyl jasmonate	Broccoli (*Brassica oleracea*)	Moreira-Rodríguez et al., 2017
	Sulphur supplementation	Cabbage (*Brassica oleracea*), Broccoli (*Brassica capitata*) Radish (*Raphanus sativus*)	Kestwal et al., 2011
	Glucose treatment	Chinese kale (*Brassica oleracea* var. *alboglabra)* Pak choi (*Brassica rapa* subsp. *Chinensis*)	Wei et al., 2011
Methionine	Cu^{2+}, gibberellic acid, abscisic acid, desiccation	Norway maple (*Acer platanoides* L.) Rice (*Oryza* L.) Tea (*Camellia sinensis* L.)	Tan et al., 2013
Proline	UV treatment	Fava bean (*Vicia faba*)	Shetty et al., 2002
Amino acids	Red and blue light illumination	Barley (*Hordeum* L.)	Meng et al., 2015
L-DOPA	Elicitor application (Oregano extact)		
	UV light	Fava bean (*Vicia faba*)	Shetty et al., 2002
Decreased content			
Glucosinolates (in shoots)	Visible light (white, red, blue)	Chinese kale (*Brassica oleracea* var. *alboglabra)*	Qian et al., 2016

et al., 2016). Khattak *et al.* (2007) stated the influence of blue light illumination on the decrease of phytic acid in chickpea sprouts exclusively. However, it must be remembered that the content of the phytic acid is usually lowered at the time of sprouting.

Other undesirable substances, such as alkaloids, tannins, or oligosaccharides, are leached from the seeds during soaking, owing to their water solubility. It is a traditional method of getting rid of them from seeds, especially legume seeds (e.g., lupine) (Boschin and Resta, 2013).

Examples of the observed changes in the content of anti-nutrients in sprouts growing under conditions of abiotic stress are presented in Table 4.

Influence of chemical substances and natural mixtures application on sprouts modification

Modification of sprouts' nutritional quality may also be achieved with the application of many chemicals (isolated or in mixtures) (Table 5). Examples include oregano extract, fish protein hydrolysate, peptides (e.g., lactoferrin) (Randhir *et al.*, 2004a, b), marine protein hydrolysates (Ramakrishna *et al.*, 2019), *Saccharomyces cerevisiae* and *Salix daphnoides* bark extracts (Gawlik-Dziki *et al.*, 2013), tea tree extract (Viacava and Roura, 2015), H_2O_2 (Świeca, 2015), persimmon fruit powder (Kim *et al.*, 2016), amino acids (e.g., phenylalanine, methionine, tryptophan, tyrosine) (Pérez-Balibrea *et al.*, 2011; Seo *et al.*, 2015; Świeca *et al.*, 2014), $CaCl_2$ and sucrose (Sim *et al.*, 2019), glucose (Wei *et al.*, 2011), and other saccharides (e.g., chitosan) (Lee *et al.*, 2005; Qiang *et al.*, 2005) or plant growth regulators (Abellán *et al.*, 2019; Moreira-Rodríguez *et al.*, 2017; Pérez-Balibrea *et al.*, 2011). Enrichment of the growing medium takes place at the stage of pre-sowing treatment, and also during the further stages of sprouting. However, this modification of growth condition significantly increases the price of the obtained product. Such enrichment of the medium was successfully applied to enhance accumulations of microelements, e.g., selenium, magnesium, or iron in sprouts (Przybysz *et al.*, 2015; Sugihara *et al.*, 2004; Zielińska-Dawidziak *et al.* 2012). It is a very promising method of food fortification in deficient elements (Zielińska-Dawidziak, 2015). Control of the content of toxic elements in medium applied to sprouting is essential because their presence also induces the plant's defense system and accumulation of these undesirable elements in sprout (Zielińska-Dawidziak *et al.*, 2014 a and b). The necessity to use high purity solutions for the biofortification of sprouts makes their production much more expensive.

Summary

Application of various stress conditions usually influences microbial quality, which was not discussed here. This is an extremely significant quality problem from the perspective of introducing sprouts into the market and their shelf-life. The review did not take the application of biotic stress, also studied as a method of modification of sprouts' chemical composition (Andini *et al.*, 2019).

The crucial problem connected with the application of modified conditions as a way of increasing the nutritional value of sprouts is the difficulty of predicting the effect of the factor used. This may result from the genetic variation of germinated sprouts and grains. The application of light-emitting diodes and biofortification of sprouts in deficient elements are promising methods. Each of the

Table 4. Influence of stress conditions on some antinutrient content in sprouts.

Effect	Stress factor	Material	Reference
Increased			
Trypsin and chymotrypsin inhibitor activity (with no influence on protein digestibility)	Temperature (4°C and 40°C)	Lentil (*Lens culinaris* Medik.)	Świeca and Baraniak, 2014
Trypsin inhibitor activity	Osmotic stress (NaCl)	Blue lupin (*Lupinus angustifolius* L.), Yellow lupin (*Lupinus luteus* L.), Pea (*Pisumsativum* L.), Barley (*Hordeum vulgare* L.) Rye (*Secalecereale* L.)	Domash et al., 2008
Decreased			
Content of lectins Trypsin inhibitor activity Amylase inhibitor activity Phytic acid content	Elicitors (chitosan, salicylic acid, hydrogen peroxide)	Dalia bean (*Phaseolus vulgaris* L.)	Mendoza-Sánchez et al., 2016
Phytic acid content	Blue light	Chickpea (*Cicer arietinum* L.)	Khattak et al., 2007

Table 5. Influence of chemical substances and natural mixtures application on sprouts composition.

Effect	Stress factor	Material	Reference
Increased			
Phenolic content	Fish protein hydrolysates	Fenugreek (*Trigonella foenum-graecum*)	Randhir et al., 2004a[1,4,8]
Antioxidant and antimicrobial activity	Lactoferrin		
Antioxidant activity and L-DOPA content	Oregano extract		
Antimicrobial activity	Lactoferrin	Mung beans (*Vigna radiate* L.)	Randhir et al., 2004b[4]
Antioxidant activity, antimicrobial activity	Oregano extract		
Phenolic content	Marine protein hydrolysates	Barley (*Hordeum vulgare* L.)	Ramakrishna et al., 2019[1]
Phenolic content	*Saccharomyces cerevisiae* and *Salix daphnoides* bark extracts	Broccoli (*Brassica oleracea* L.)	Gawlik-Dziki et al., 2013[1]
Vitamin C content	Chitosan	Broccoli (*Brassica oleracea* L.)	Pérez-Balibrea et al., 2011[7,9,10]
Flavonoid and indole glucosinolates content	Salicylic acid, methyl jasmonate		
Aliphatic glucosinolates content	Methionine		
Indole glucosinolates content	Tryptophan		
Antioxidant activity	Tea tree extract, Chitosan	Lettuce (*Lactuca sativa*)	Viacava and Roura, 2015[4]
Vitamin C and phenolic content, unchanged antioxidant activity	Persimmon fruit powder	Soybean (*Glycine max* L.)	Kim et al., 2016[1,4,6]
Phenolic content and antioxidant activity	H_2O_2	Lentil (*Lens culinaris* Medik.)	Święca, 2015[1,5]
Flavonoids content and antioxidant capacity	Phenylalanine	Lentil (*Lens culinaris* Medik.)	Święca et al., 2015[1,5]
Antioxidant capacity	Combined UV-tyrosine treatments		
Phenolic compounds	Phenylalanine and LED lights	Tartary buckwheat (*Fagopyrum tataricum*)	Seo et al., 2015[2]
Polyphenols, flavonoids, γ-aminobutyric acid, vitamin C, and E	$CaCl_2$ and sucrose	Buckwheat (*Fagopyrum esculentum*)	Sim et al., 2019[2,7,9]
Phenolic content	Glucose	Chinese kale (*Brassica oleracea)* Pak choi (*Brassica rapa*)	Wei et al., 2011[3]
Vitamin C	Glucose	Radish (*Raphanus sativus* L.)	Wei et al., 2011[7]
Vitamin C	Chitosan	Mung bean (*Vigna radiate* L.)	Qiang et al., 2005[6]
Iron concentration	Ferric EDTA	Broccoli (*Brassica oleracea*) Radish (*Raphanus sativus*) Alfalfa (*Medicago sativa* L.) Mung bean (*Vigna radiate* L.)	Przybysz et al., 2016[9]
Iron concentration	$FeSO_4$	Yellow lupine (*Lupinus luteus*) Blue lupine (*Lupinus angustifolius*) Soybean (*Glycine max* L.) Alfalfa (*Medicago sativa* L.) Lentil (*Lens culinaris* Medik.)	Zielińska-Dawidziak et al., 2012 Zielińska-Dawidziak et al., 2016 Zielińska-Dawidziak et al., 2018
Content of selenium	Sodium selenite	28 of plant species	Sugihara et al., 2004
Glucosinolates	Methyl jasmonate + UV light	Broccoli (*Brassica oleracea* L.)	Moreira-Rodríguez et al., 2017[3,8,10]
Decreased			
Phenolic and carotenoids content	Methyl jasmonate	Broccoli (*Brassica oleracea* L.)	Moreira-Rodríguez et al., 2017[3,8,10]

Methods of antioxidative compounds determination: Phenolic content: 1\Folin-Ciocalteu, 2\HPLC and 3\FRAP; Antioxidant activity: 4\ DPPH and 5\ABTS; Vitamin C: 6\colorimetric and 7\HPLC; 8\carotenoids – HPLC; 9\flavonoids – HPLC; 10\glucosinolates – HPLC.

attempts to induce abiotic stress will be associated with an increase in the cost of the sprouting process. However, such a method is still less expensive and more acceptable than genetic modification.

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