

Review

Global Change Factors Influence Plant-*Epichloë* Associations

Daniel A. Bastías ¹, Andrea C. Ueno ^{2,3} and Pedro E. Gundel ^{2,4,*}¹ AgResearch Limited, Grasslands Research Centre, Palmerston North 4442, New Zealand² Centro de Ecología Integrativa, Instituto de Ciencias Biológicas, Universidad de Talca, Talca 3480094, Chile³ Instituto de Investigación Interdisciplinaria (I3), Universidad de Talca, Campus Talca, Talca 3480094, Chile⁴ Facultad de Agronomía, IFEVA, CONICET, Universidad de Buenos Aires, Buenos Aires C1417DSE, Argentina

* Correspondence: gundel@agro.uba.ar or pedro.gundel@utalca.cl

Abstract: There is an increasing interest in determining the influence of global change on plant–microorganism interactions. We review the results of experiments that evaluated the effects of the global change factors carbon dioxide, ozone, temperature, drought, flooding, and salinity on plant symbioses with beneficial *Epichloë* endophytes. The factors affected the performance of both plants and endophytes as well as the frequency of plants symbiotic with the fungus. Elevated carbon dioxide levels and low temperatures differentially influenced the growth of plants and endophytes, which could compromise the symbioses. Furthermore, we summarise the plant stage in which the effects of the factors were quantified (vegetative, reproductive, or progeny). The factors ozone and drought were studied at all plant stages, but flooding and carbon dioxide were studied in just a few of them. While only studied in response to ozone and drought, evidence showed that the effects of these factors on symbiotic plants persisted trans-generationally. We also identified the putative mechanisms that would explain the effects of the factors on plant–endophyte associations. These mechanisms included the increased contents of reactive oxygen species and defence-related phytohormones, reduced photosynthesis, and altered levels of plant primary metabolites. Finally, we describe the counteracting mechanisms by which endophytes would mitigate the detrimental effects of the factors on plants. In presence of the factors, endophytes increased the contents of antioxidants, reduced the levels of defence-related phytohormones, and enhanced the plant uptake of nutrients and photosynthesis levels. Knowledge gaps regarding the effects of global change on plant–endophyte associations were identified and discussed.



Citation: Bastías, D.A.; Ueno, A.C.; Gundel, P.E. Global Change Factors Influence Plant-*Epichloë* Associations. *J. Fungi* **2023**, *9*, 446. <https://doi.org/10.3390/jof9040446>

Academic Editors: Jonathan Newman, Linda Johnson and Liangdong Guo

Received: 8 January 2023

Revised: 10 March 2023

Accepted: 17 March 2023

Published: 6 April 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Keywords: climate change; endophyte; stress; symbiosis; phytohormone; ROS; antioxidant; transgenerational effect

1. Introduction

Global change is dramatically altering natural ecosystems and biodiversity. The global mean surface temperature is expected to increase by about 1.5 °C due to the elevated emissions of greenhouse gases and pollutants such as CO₂ and ozone [1]. Climate is changing at local and regional scales, increasing the frequency and intensity of cold, heat, drought, and flooding events [1,2]. Salt contents in soil are also increasing as consequence of climate change and inadequate agricultural practices [3]. Evidence shows that the environmental factors associated with global change influence different aspects of the biology of plants including growth and reproduction [4]. Furthermore, the global change factors are challenging the production of major world-wide crops such as wheat, rice, maize, and soybean [5]. In natural and managed ecosystems, plants are normally associated with beneficial microorganisms that promote growth and plant fitness [6,7]. Given their critical role in plant fitness, there is an increasing interest to understand the effects of global change factors on the interaction of plants with beneficial microorganisms [8,9]. It is particularly interesting to determine if the global change factors alter the benefits conferred by microorganisms to their hosts and the mechanisms that underlie these alterations [7,10].

Plant–*Epichloë* associations are interesting symbioses to investigate the effects of global change on plants that interact with beneficial microorganisms. *Epichloë* fungi form endophytic associations with Pooideae grasses and inhabit intercellular spaces of green plant tissues [11]. Most of these endophytes are maternally inherited by establishing mycelia in mature seeds [12]. In these symbioses, the fitness of plants and endophytes are strongly aligned since host plant reproduction and seed stage provide the opportunity for symbionts to multiply and disperse [13]. Plants and vertically transmitted endophytes form mutualistic associations. The success of these symbioses (measured as frequency of symbiotic plants in populations) depends on both the net benefit conferred by endophytes on plants and the efficiency of vertical transmission [14,15]. *Epichloë* endophytes confer multiple benefits to their plant hosts, and the most documented is the antiherbivore protection given by endophyte-derived alkaloids [16]. *Epichloë* endophytes also alter the levels of phytohormones and induce the production of plant secondary metabolites that enhance the host tolerance against abiotic and biotic stress factors [17,18]. Additionally, the endophytes increase the contents of antioxidants in plants that help to mitigate the oxidative damage triggered by environmental stress factors [19]. Despite all these benefits, plant–*Epichloë* interactions can transiently turn into negative associations by either the action of certain stress-triggered plant responses or the limitation of plant resources (i.e., endophyte-symbiotic plants displaying lower fitness than their endophyte-free counterparts) [15,20]. As an expression of the context-dependent symbiosis outcome, global change factors are likely to affect the persistence, distribution, and abundance of plant–endophyte symbiosis in the near future.

The aim of this review is to describe some of the documented effects that global change factors exert on plant–*Epichloë* symbioses. The factors considered in the present work are carbon dioxide (CO₂), ozone, heat, cold, drought, flooding, and salinity. Most, but not all, of the listed factors can generate stress and growth reductions in plants. For instance, within certain range, the environmental temperature can stimulate the growth of plants [21]. The factors were selected due to their recognised effects on plant fitness and the available information in the plant–endophyte literature [22,23]. We summarised published results showing the effects of the selected global change factors on plant–*Epichloë* associations, and identified the putative mechanisms that would explain the effects of these factors on the associations. Furthermore, we described the counteracting mechanisms by which endophytes would mitigate the detrimental effects of the global change factors on plants. For vertically transmitted endophytes, these mechanisms would be critical for their persistence in individual plants and plant populations. Our study contributes to understanding the effects of global change factors on plants that interact with endophytes, the specific mechanisms that explain these effects, and the endophyte-conferred mechanisms that counteract and alleviate the negative effects.

2. Effects of Global Change Factors on Plant–*Epichloë* Associations

The environmental factors associated with global change affect distinct processes and functions in both plants and endophytes across the plant life cycle. Since fungal hyphae grow vegetatively in newly formed host seeds, the effects of global change factors on symbiotic plants can be trans-generationally transmitted (Figure 1).

Multiple studies have shown that atmospheres with elevated CO₂ levels influence plant–*Epichloë* associations by affecting the plant/endophyte growth and fungal production of alkaloids. High CO₂ levels increased the biomass of *Festuca arundinacea* (Schreb.) (Syn. *Schedonorus arundinaceus*) and *Lolium perenne* plants associated with endophytes, but the greenhouse gas did not affect the production of reproductive tillers or seed in symbiotic plants [24–26]. Similar beneficial effects of CO₂ on plant growth were documented in endophyte-symbiotic *Brachypodium sylvaticum* and *L. perenne* plants that grew in soils with high nutrient contents [27,28]. Experimental results showing positive effects of CO₂ on endophytes have been also reported. Elevated CO₂ levels increased the amount of endophyte mycelial biomass in *F. arundinacea* [29]. Furthermore, an increased frequency

of endophyte-symbiotic plants was documented in *F. arundinacea* populations that were exposed for several years to high CO₂ levels [30]. Only a few experimental results have shown negative effects of the greenhouse gas on plant–endophyte associations. Elevated CO₂ levels reduced the fungal production of alkaloids and eased the endophyte-based plant growth promotion in the same plant species [29–31].

Tropospheric ozone influences plant–*Epichloë* associations by affecting host morphophysiological traits and the endophyte persistence within plants and populations. Irrespective of the plant symbiotic status, high ozone levels reduced the photochemical efficiency and leaf greenness in *L. multiflorum* plants, but the oxidative damage induced by the pollutant was generally lower in endophyte-symbiotic than non-symbiotic plants [32,33]. The symbiosis increased the survival of seedlings under elevated ozone levels, but the pollutant reduced the reproductive effort of symbiotic plants (the ratio between reproductive and shoot biomass) [32–34]. Reduced seed longevity was also documented in endophyte-symbiotic plants that grew in environments with high ozone levels [35,36]. While ozone did not affect the transmission efficiency of endophytes from plant to seed, the viability of the fungus declined at a faster rate in seed produced by plants exposed to the pollutant [32,35]. Ozone did not affect either the concentration of alkaloids nor the biomass of fungal mycelia within plant green tissues or seed [32,34]. Despite the lack of effect of the ozone on alkaloids, the level of resistance to herbivores in symbiotic plants was reduced by the pollutant, and this effect persisted in the next plant generation [34,37,38].

Cool and warm temperatures affect plant–*Epichloë* associations by altering the plant/endophyte growth and fungal production of alkaloids. Cool temperatures reduced the growth of grasses associated with endophytes [39]. Low temperatures also reduced the endophyte mycelial biomass and alkaloid concentrations in *F. arundinacea*, *L. perenne*, and *L. multiflorum* [40–43]. Furthermore, low temperatures diminished the frequency of endophyte-symbiotic plants in *F. arundinacea* populations [39]. This stress also decreased the concentration of alkaloids within plants and compromised the endophyte-based resistance to insects [42,44]. In opposition to low temperatures, the fitness of endophyte-symbiotic plants was generally increased by treatments with warm temperatures. In *F. arundinacea*, the warm temperature stimulated biomass production more in endophyte-symbiotic than endophyte-free plants [45]. Moreover, enhanced concentrations of certain endophyte-derived alkaloids were documented in *F. arundinacea* and *L. perenne* plants grown in warm temperatures [45–48], but see [40]. In field experiments, concentrations of endophyte-derived alkaloids were positively correlated with the environmental temperature experienced by plants [49,50]. Furthermore, the endophyte-mediated promotion in the number of plant flowerheads was apparently influenced by the variation in the temperature in conjunction with other environmental variables in the field (e.g., soil nutrient contents, water availability) [51]. High temperatures usually exert negative effects on the endophyte presence in seeds. The endophyte viability in seed is usually reduced in environments that combine elevated temperature and moderated to high relative humidity [52]. For example, endophytes were not viable when seed were exposed for 100 days to 40 °C and 43% of relative humidity (while the seed were 100% viable) [53].

Multiple studies have evaluated the effects of drought on plant–*Epichloë* associations. The general pattern is that endophytes increase the survival and stimulate the growth of plants subjected to this stress [18,54,55]. For instance, the endophyte presence increased the tillering of *F. arundinacea* plants under drought [56]. Similarly, the endophyte also stimulated the growth (and photosynthesis rate) of *Achnatherum inebrians* plants that experienced water restriction [57]. In the case of *L. multiflorum*, symbiotic plants exhibited high water use efficiency and root conductivity under drought, but plant growth was not affected by the fungus [58]. In addition to the effects on plants, drought generally increased the concentration of endophyte-derived anti-herbivore alkaloids [56,59,60]. The endophyte presence also influenced the host seed production in certain genotypes of *L. perenne* in drought situations [61]. Few experiments have shown negative effects of endophytes on plants subjected to drought. For example, reduced water availability inhibited the germina-

tion of endophyte-symbiotic seeds more than non-symbiotic seeds [62]. These effects vary in their magnitude—but seemingly not direction—depending on the species/genotypes of both the plants and endophytes [18,63]. Furthermore, the magnitude of the benefits conferred by *Epichloë* endophytes to plants in drought situations also depends on maternal effects in the host plants [64].

Compared to drought, the effects of *Epichloë* on plants experiencing flooding stress have been less well documented. This may be due to the fact that early experimental results did not find that the endophyte presence provided advantages to plants that experienced flooding (see [65]). Another reason could be that most of the early research was performed on plant species/genotypes that are already somewhat flood-tolerant (i.e., *F. arundinacea* and *L. perenne*) [66]. However, more recent investigations have shown that distinct plant–endophyte combinations behave differently in the presence of flooding. For instance, the endophyte enhanced the growth and leaf water contents in certain genotypes of *F. arundinacea* plants that experienced the stress [67]. Furthermore, *Hordeum brevisubulatum* plants naturally associated with endophytes showed higher foliar biomass than their non-symbiotic counterparts grown in soils with excess water [68]. A similar result was documented in distinct ecotypes of *Festuca sinensis*, where endophyte-symbiotic plants accumulated more biomass under flooding conditions than endophyte-free plants [69]. Less common are experimental results showing negative effects of this stress on endophyte-symbiotic plants. Reduced foliar biomass and seed production was documented in endophyte-symbiotic *Poa leptocoma* plants in flooding conditions [70]. However, the incidence of endophyte-symbiotic plants in the population was high, suggesting that other endophyte-derived benefits outweighed this apparent cost [71].

Epichloë endophytes generally increased the biomass and seed production of plants grown in soils with high salinity contents [72–76]. Furthermore, the endophyte also enhanced the survival and germination of seeds that experienced high salinity [77,78]. High salinity also increased the concentration of endophyte alkaloids and mycelial biomass within plant tissues [59,79].

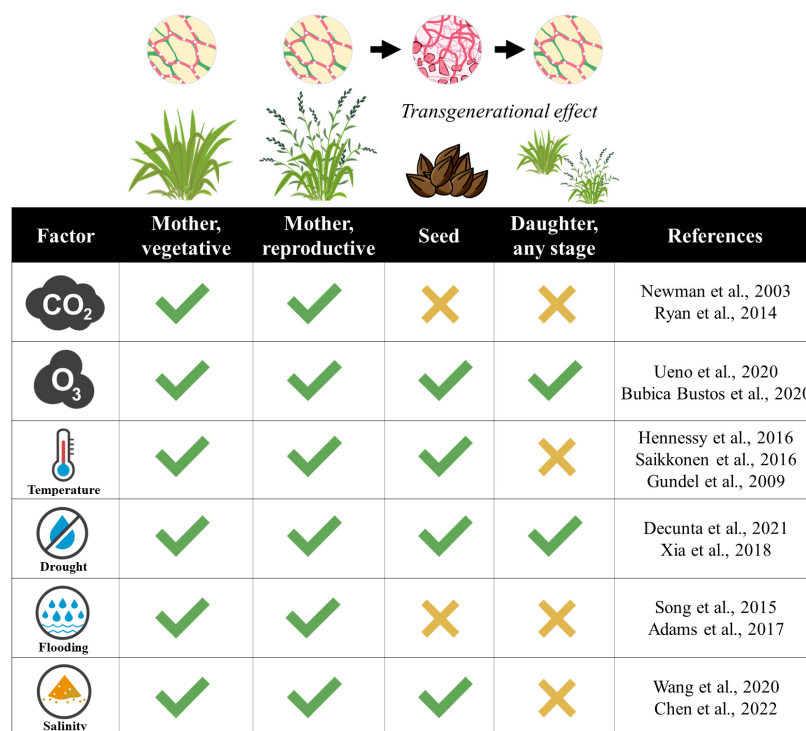


Figure 1. Summary of the presence/absence of experimental results evaluating the effects of global change factors on distinct stages of the lifecycle of plants associated with fungal endophytes.

The top diagram shows plant and endophyte lifecycles. The plant lifecycle is divided into mothers (stages vegetative or reproductive), seeds, and daughters (at any stage). The endophyte lifecycle shows the presence of the fungus within tissues of mother, seed, and daughter plants and the fungal transmission from mothers to seeds and seeds to daughters (with horizontal black arrows). The ‘transgenerational effect’ refers to those effects exerted by the factors on mothers that persist in the progeny (seeds and/or daughters). The ✓ indicates the existence of studies that evaluated the effects of a given factor on the performance of plant hosts or endophytes in a particular plant lifecycle stage, whereas the ✗ indicates a lack of studies. Plant performance refers to growth, reproduction, or survival, and endophyte performance to growth, alkaloid production, survival, transmission, or frequency in plant populations. The global change factors were not necessarily applied at the same plant stage that the plant performance was measured (e.g., factor applied at seedling stage, but performance measured at reproductive stage). The column ‘References’ refers to articles that contain experimental results associated with the effects of the factors carbon dioxide (CO₂), ozone (O₃), cold and heat/warm temperatures, drought, flooding, and salinity on plant–endophyte symbioses [18,25,29,32,37,42,51,53,64,68,70,74,79].

3. Mechanisms Underlying the Effects of Global Change Factors on Plant–*Epichloë* Associations

The environmental factors associated with global change induce certain plant responses that may affect the presence of *Epichloë* endophytes and their derived benefits in plants (Figure 2).

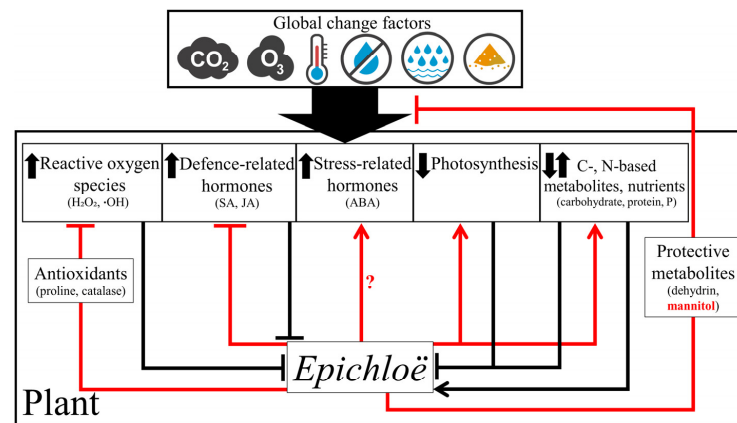


Figure 2. Mechanisms by which global change factors stimulate or inhibit endophyte fungi in plants and fungal mechanisms that counteract the negative effects. Certain factors increase the contents of carbon (C)-based primary metabolites that stimulate the endophyte growth in plants. Opposite to this, some factors enhance the amount of reactive oxygen species (ROS), defence-related hormones, and stress-related hormones, reduce photosynthesis levels, and diminish the contents of nitrogen (N)-based primary metabolites and nutrients that inhibit the growth of endophytes in plants and the fungal provision of benefits. Endophytes increase the contents of ROS-scavenging antioxidants, reduce the levels of defence-related hormones, induce photosynthesis, stimulate the plant acquisition of nutrients, and produce (or induce the plant production of) protective metabolites (e.g., dehydrin, mannitol) that potentially counteract/alleviate the detrimental effects of the factors. Arrows indicate positive regulation and truncated lines negative regulation. Black connectors show the effects of factors and plant processes on plants and endophytes. Red connectors denote endophyte effects on plant processes and plant-factor interactions. Endophyte-based metabolites are highlighted in red. The question mark indicates a putative endophyte regulation. The factors are carbon dioxide (CO₂), ozone (O₃), cold and heat/warm temperatures, drought, flooding, and salinity. Abbreviations: H₂O₂, hydrogen peroxide; ·OH, hydroxyl radical; SA, salicylic acid; JA, jasmonic acid; ABA, abscisic acid; P, phosphorus.

Grasses hosting *Epichloë* endophytes are C3 species, and it is well documented that elevated CO₂ levels stimulate the growth and photosynthesis of these species [80,81]. Higher concentrations of non-structural and soluble carbohydrates have been generally reported in C3 plants exposed to elevated CO₂ levels [82]. This CO₂-induced increase in carbohydrate contents may explain the documented growth stimulation observed in both plants and endophytes [29]. Concentrations of nitrogen compounds are usually reduced in plants grown in environments enriched with CO₂ [81,82]. Since alkaloids are nitrogen-based compounds, low concentrations of endophyte-derived alkaloids reported in plants exposed to high CO₂ levels could be explained by reduced nitrogen contents [29,83]. However, despite that the CO₂ reduced the concentration of endophytic alkaloids, the fungus still conferred protection to the plant hosts against aphids [84]. A possible explanation for this outcome could be that the reduced alkaloid levels were still above the bioactivity thresholds [85]. Alternatively, CO₂ could have reduced the quality and palatability of tissues or stimulated the accumulation of other compounds with anti-herbivory effects. In fact, plants grown in environments with elevated CO₂ levels generally showed high concentrations of antiherbivore phenolic compounds [82].

The increased concentrations of reactive oxygen species (ROS) in plants triggered by ozone may explain, at least in part, the negative effects of this stress on plant–*Epichloë* associations [19,20]. ROS at high levels damage DNA, lipids, and proteins which can lead to cell death [86]. In addition to the oxidative damage on plants caused directly by ozone, altered ROS levels reduce the growth of endophytes within plant tissues [87]. Endophytes with mutations in enzymes that produce or regulate the production of ROS exhibited unrestricted growth within plant tissues but caused stunted and sometimes lethal phenotypes in their hosts [87,88]. ROS might also limit the distribution of endophyte mycelia within plant tissues due to their effects strengthening plant cell walls [89]. Ozone can also increase the levels of defence-related phytohormones such as salicylic acid and jasmonic acid [90]. These hormones negatively affect fungal endophytes since they induce the production of antimicrobial compounds by plants, deposition of callose in plant cell walls (that block the spread of the fungus), and programmed cell death [91–94].

Temperature stresses including both cold and heat increase the levels of ROS and cause oxidative damage in plant tissues [95]. The inhibition in endophyte growth documented in situations of temperature stress may be associated with increased ROS levels [42]. The defence-related phytohormone salicylic acid is also stimulated in situations of temperature stress [95]. This hormone affected the endophyte provision of benefits to plant hosts. The exogenous application of salicylic acid on plants reduced the concentration of fungal-derived alkaloids and promoted susceptibility of symbiotic plants against insect herbivores [96,97]. Another documented effect of low temperatures in plants is the reduced photosynthetic rate [98]. Variations in photosynthate levels, due to reduced photosynthesis, could also explain the documented changes in endophyte growth and alkaloid production within plants [43,45]. Alkaloid concentrations may also be affected by temperature-based changes in the kinetics of biosynthesis and degradation [99]. Furthermore, differences between plant and endophyte may explain the effects of the stress on the fungal growth and alkaloid production. For instance, *F. arundinacea* plants presented lower minimum cardinal temperatures than their associated endophytes (i.e., the lowest temperature at which an organism can grow) which suggests that at low temperatures, both fungal mycelia and alkaloids may be ‘diluted’ within plant tissues since only plants have maintained the growth [39].

The drought tolerance conferred by endophytes to plant hosts has been well-studied and excellent reviews have summarised and discussed the mechanisms [18,54,55]. Drought usually increases ROS levels, induces defence-related phytohormone responses, and reduces chlorophyll content in plants [100,101]. Similar to other stresses, *Epichloë* endophytes might be negatively affected by these plant responses. It is worth mentioning that the magnitude of the effects of the water deficit on plant–endophyte associations depends on the intensity and length of the event [63]. As indicated, results from short-term drought

experiments showed that endophyte-symbiotic plants have a clear advantage in terms of plant performance over the non-symbiotic ones [18]. However, evidence from field surveys suggested that the plant capacity to host endophytes was impaired under extreme aridity [102,103].

Excess water in the soil causes hypoxia/anoxia in plant roots [104]. Although *Epichloë* endophytes are not found in roots, the negative consequences of flooding on host performance are likely to impair the symbiosis. Reduced chlorophyll contents, inhibited photosynthesis, and increased leaf senescence are some consequences of flooding on plants [105]. Furthermore, ethylene and ROS are generally accumulated within tissues when plants are subjected to flooding [106]. The reduction in photosynthesis rate may decrease the endophyte growth within plant tissues. Additionally, the fungal growth may be altered by the increased levels of ROS and phytohormones. Whereas no studies have evaluated the effects of flooding on the endophyte growth or its derived benefits, evidence from field studies suggest that the endophyte performance may be compromised under excess of water. For instance, a field survey found that *L. multiflorum* plants occurring in humid prairies recurrently subjected to flooding showed low endophyte transmission from plants to seed [107].

Salinity stress also increases the ROS levels in plants [108]. Similar to other stresses, altered ROS levels under salt stress may affect the growth of *Epichloë* endophytes [88,89]. The phytohormone jasmonic acid is increased in salt stress, and the induction of the defence responses associated with this hormone negatively affected the endophyte-derived benefits [109]. For instance, the exogenous application of methyl jasmonate (an activator of jasmonic acid defence responses) on symbiotic plants reduced the concentration of alkaloids and increased the susceptibility of these plants against insects [110]. Salt stress reduced the photosynthesis and photosynthates contents in plants and this reduction might also be detrimental for the endophyte growth [72,73]. The soil salinity reduced the plant acquisition of nutrients such as nitrogen and phosphorus, and low levels of these nutrients in plants can alter the endophyte growth and production of alkaloids [29,111,112]. Salt stress associated with sodium produced water deficit (due to the excessive accumulation of sodium anions within plant cells) and reduced the uptake and transport of essential ions (e.g., potassium, calcium) [113]. There is a lack of evidence showing whether the salt-mediated water deficit and altered ion exchange directly affect endophytes. Further experiments might explore this possibility.

4. Endophyte-Based Mechanisms of Plant Protection against Global Change Factors

Epichloë endophytes confer certain stress-protective mechanisms to plant hosts that may counteract the detrimental effects of the environmental factors associated with global change (Figure 2).

Epichloë endophytes can enhance the antioxidant contents in plants [19]. Antioxidants efficiently scavenge ROS and include several enzymatic and non-enzymatic compounds such as superoxide dismutase, catalase, peroxidases, glutathione, ascorbic acid, and proline [114,115]. In an experiment that included ozone as a treatment, the endophyte presence increased the content of proline antioxidants in plants, and this was associated with reduced levels of oxidate damage [116]. Similarly, under drought stress, endophytes reduced the oxidative stress in plants which was correlated with increased concentrations of several antioxidants [117]. The levels of the polyol mannitol, which can be produced by endophytes, were elevated in symbiotic plants that were subjected to drought stress [56,118]. The accumulation of mannitol (and also *Epichloë*-derived alkaloids) in drought situations may reduce the osmotic potential in plants and prevent the dehydration of cells [56]. Regarding flooding, endophytes increased the concentration of proline antioxidants in *H. brevisubulatum* plants, which was linked with low levels of oxidative stress [68]. Similar endophyte-mediated increases in proline levels were reported in certain genotypes of *F. arundinacea* plants subjected to the same stress [67]. In saline soils, the antioxidant capacity of *H. brevisubulatum* plants was enhanced by the endophyte presence [72].

Epichloë can reduce the concentration of defence-related hormones in plants. This reduction may prevent the induction of plant defence responses that inhibit the presence of endophytes within plant tissues [16]. As mentioned, plant defence responses associated with salicylic acid and jasmonic acid hormones are induced by global change stresses including ozone, temperature, and salinity (see for instance [90,95]). Experimental results have shown that *Epichloë* endophytes manipulate the concentrations of these phytohormones in the presence and absence of stresses. For instance, absent of any stress, endophytes reduced the concentration of salicylic acid in *L. multiflorum* plants [97,119]. Similarly, in the presence of stress, endophytes reduced the concentration of jasmonic acid and suppressed part of the associated signalling pathway in *A. inebrians* plants [93]. Similar suppression of defence-related phytohormones by beneficial microorganisms have been documented in other symbiotic systems such as that between plants and mycorrhizal fungi [120,121]. The study of the interaction between *Epichloë* endophytes and stress-protective hormones has commenced. Drought stress increased the levels of the stress-protective hormone abscisic acid in endophyte-symbiotic *F. arundinacea* plants (although endophyte-free plants were not included in this study) [122]. Furthermore, an exogenous application of this hormone on *A. inebrians* plants increased the observed endophyte-mediated plant growth promotion in the presence of drought [123].

In the absence of stress, *Epichloë* endophytes induce multiple molecular changes in their hosts that may render plants sensitive or tolerant to global change stresses. In *L. perenne*, endophytes increased the expression of genes involved in cold/heat responses that changed the perception of plants to temperature stresses. In the latter study, the fungus also increased the expression of plant genes associated with the biosynthesis of raffinose oligosaccharides, which are temperature-protective metabolites [91]. The antioxidant contents in plants were also increased by endophytes in the absence of stress [124]. Furthermore, endophytes enhanced the levels of photosynthesis and upregulated several genes associated with this function in *A. inebrians* plants that were not exposed to stress [57]. In the presence of stress, *Epichloë* can induce certain responses that may help alleviate (perhaps quickly) the detrimental effects of global change stresses. In response to cold stress, endophytes increased the expression of genes coding for phytochrome and ethylene receptor proteins that are involved in the acclimatization of plants to low temperatures [125]. Under drought stress, endophyte presence stimulated the expression of plant genes coding for dehydrin and heat shock proteins that are known to prevent the cellular damage caused by stresses [126–128]. Furthermore, photosynthesis levels and the expression of several genes associated with the photosynthesis process were increased by the endophyte presence in *A. inebrians* plants in response to drought stress [57]. Similar outcomes in photosynthesis rates were reported in *H. brevisubulatum* plants that grew in soil with high salt contents [72]. In this species, endophytes also reduced the plant uptake of sodium ions and improved the plant endowment of nitrogen, phosphorus, and potassium in salt stress situations [72,112]. Similarly, the uptake of sodium (and chloride) ions by *F. arundinacea* and *Festuca pratensis* plants subjected to salt stress were also decreased by their associated *Epichloë* endophytes [129]. Furthermore, endophytes increased the diameter of xylem and phloem cells in plants that experienced salt stress. These anatomical changes were correlated with reduced levels of water loss in plants [113].

5. Concluding Remarks and Future Perspectives

We summarised evidence showing that environmental factors associated with global change influenced plant–*Epichloë* symbioses through compromising plant and endophyte traits and the symbiosis as well. Under the influence of global change factors, plant responses were mostly positively regulated by endophytes. However, negative effects of these factors were also documented. For example, combinations of high temperatures with humidity were associated with reductions in endophyte viability in seeds. In other cases, the incidence of environmental factors (e.g., ozone) impaired the benefits conferred by endophytes to plants. Although most of the research has been performed at individual

level with few examples at population level (Figure 1), it is likely that global change factors exert substantial effects on the distribution and abundance of plant-endophyte symbioses in nature. This is particularly clear in situations where the factors turn beneficial symbioses into detrimental (i.e., parasitic) associations that eventually will be selected against. Additionally, there is an increasing interest in understanding whether vertically transmitted endophytes induce transgenerational effects on their plant hosts in the context of global change [130]. This has been only investigated in relation to ozone and drought, with no studies so far regarding other global change factors such as CO₂, temperature, flooding, or salinity (Figure 1). We need further long-term manipulative experiments to determine, for instance, the effects of multiple and simultaneous global change factors on both plants and endophytes at individual level, and in the dynamics of endophyte-symbiotic plants.

We posited that the induction of certain plant responses by global change factors would explain the effects of these factors on plant–*Epichloë* symbioses. These plant responses included the enhanced contents of ROS/defence-related hormones, and reduced levels of photosynthesis/nutrients (Figure 2). The direct effects of global change factors on *Epichloë* endophytes have been rarely studied. This may be because endophytes that are exclusively vertically transmitted do not present growth stages outside plants, thus the effects of environmental factors on the fungus cannot be easily separated from the effects on plants. However, the evaluation of endophyte transcriptomes and gene-edited endophytes are interesting approaches to improve the understanding of the direct effects the global change factors on the fungus [131,132]. We described the mechanisms by which endophytes may counteract the detrimental effects of the global change factors. These mechanisms included the endophyte ability to increase the plant antioxidant contents, reduce defence-related phytohormone concentrations, and increase the photosynthesis rates and plant uptake of nutrients (Figure 2). Further experiments will be necessary to evaluate if endophytes can increase the levels of stress-related phytohormones [133]. Enhanced levels of these hormones may increase the response symbiotic plants to stresses including those associated with the global change [134].

Author Contributions: D.A.B., A.C.U. and P.E.G.: conceived and wrote the study; D.A.B. and A.C.U.: designed first drafts of the figures. All authors have read and agreed to the published version of the manuscript.

Funding: D.A.B. acknowledges the research support provided by the Strategic Science Investment Fund (SSIF) from the New Zealand Ministry of Business, Innovation and Employment (MBIE). A.C.U. holds a postdoctoral research fellowship from the Universidad de Talca, Chile. The Research activities by P.E.G. are supported by the Fondo Nacional de Desarrollo Científico FONDECYT-2021-1210908) and Agencia Nacional de Investigaciones Argentina (ANPCyT) PICT-2018-01593.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We thank the anonymous reviewers for their positive and constructive comments on the manuscript. We are especially grateful with the editor for his suggestions that help us to significantly improve the writing and the last version of the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Pörtner, H.-O.; Roberts, D.; Tignor, M.; Poloczanska, E.S.; Mintenbeck, K.; Alegría, A.; Craig, M.; Langsdorf, S.; Löschke, S.; Möller, V.; et al. *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2022.

2. Forster, P.; Ramaswamy, V.; Artaxo, P.; Berntsen, T.; Betts, R.; Fahey, D.W.; Haywood, J.; Lean, J.; Lowe, D.C.; Myhre, G.; et al. Changes in Atmospheric Constituents and in Radiative Forcing. In *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*; Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, M.L., Eds.; Cambridge University Press: Cambridge, UK, 2007; pp. 129–234, ISBN 978-0-521-70596-7.
3. Hopmans, J.W.; Qureshi, A.S.; Kisekka, I.; Munns, R.; Grattan, S.R.; Rengasamy, P.; Ben-Gal, A.; Assouline, S.; Javaux, M.; Minhas, P.S.; et al. Chapter One—Critical Knowledge Gaps and Research Priorities in Global Soil Salinity. In *Advances in Agronomy*; Sparks, D.L., Ed.; Academic Press: New York, NY, USA, 2021; Volume 169, pp. 1–191, ISBN 0065-2113.
4. Parmesan, C.; Hanley, M.E. Plants and Climate Change: Complexities and Surprises. *Ann. Bot.* **2015**, *116*, 849–864. [[CrossRef](#)] [[PubMed](#)]
5. Zhao, C.; Liu, B.; Piao, S.; Wang, X.; Lobell, D.B.; Huang, Y.; Huang, M.; Yao, Y.; Bassu, S.; Ciais, P.; et al. Temperature Increase Reduces Global Yields of Major Crops in Four Independent Estimates. *Proc. Natl. Acad. Sci. USA* **2017**, *114*, 9326–9331. [[CrossRef](#)] [[PubMed](#)]
6. Trivedi, P.; Leach, J.E.; Tringe, S.G.; Sa, T.; Singh, B.K. Plant–Microbiome Interactions: From Community Assembly to Plant Health. *Nat. Rev. Microbiol.* **2020**, *18*, 607–621. [[CrossRef](#)] [[PubMed](#)]
7. Bastías, D.A.; Applegate, E.R.; Johnson, L.J.; Card, S.D. Factors Controlling the Effects of Mutualistic Bacteria on Plants Associated with Fungi. *Ecol. Lett.* **2022**, *25*, 1879–1888. [[CrossRef](#)] [[PubMed](#)]
8. Trivedi, P.; Batista, B.D.; Bazany, K.E.; Singh, B.K. Plant–Microbiome Interactions under a Changing World: Responses, Consequences and Perspectives. *New Phytol.* **2022**, *234*, 1951–1959. [[CrossRef](#)] [[PubMed](#)]
9. Bastías, D.A.; Balestrini, R.; Pollmann, S.; Gundel, P.E. Environmental Interference of Plant–Microbe Interactions. *Plant Cell Environ.* **2022**, *45*, 3387–3398. [[CrossRef](#)]
10. Batista, B.D.; Singh, B.K. Next Generation Tools for Crop–Microbiome Manipulation to Mitigate the Impact of Climate Change. *Environ. Microbiol.* **2022**, *25*, 105–110. [[CrossRef](#)]
11. Schardl, C.L.; Leuchtman, A.; Spiering, M.J. Symbioses of Grasses with Seedborne Fungal Endophytes. *Annu. Rev. Plant Biol.* **2004**, *55*, 315–340. [[CrossRef](#)]
12. Zhang, W.; Card, S.D.; Mace, W.J.; Christensen, M.J.; McGill, C.R.; Matthew, C. Defining the Pathways of Symbiotic *Epichloë* Colonization in Grass Embryos with Confocal Microscopy. *Mycologia* **2017**, *109*, 153–161. [[CrossRef](#)]
13. Gundel, P.E.; Rudgers, J.A.; Ghersa, C.M. Incorporating the Process of Vertical Transmission into Understanding of Host–Symbiont Dynamics. *Oikos* **2011**, *120*, 1121–1128. [[CrossRef](#)]
14. Gundel, P.E.; Batista, W.B.; Texeira, M.; Martínez-Ghersa, M.A.; Omacini, M.; Ghersa, C.M. *Neotyphodium* Endophyte Infection Frequency in Annual Grass Populations: Relative Importance of Mutualism and Transmission Efficiency. *Proc. R. Soc. B Biol. Sci.* **2008**, *275*, 897–905. [[CrossRef](#)] [[PubMed](#)]
15. Newman, J.A.; Gillis, S.; Hager, H.A. Costs, Benefits, Parasites and Mutualists: The Use and Abuse of the Mutualism–Parasitism Continuum Concept for *Epichloë* Fungi. *Philos. Theory Pract. Biol.* **2022**, *14*, 9. [[CrossRef](#)]
16. Bastías, D.A.; Martínez-Ghersa, M.A.; Ballaré, C.L.; Gundel, P.E. *Epichloë* Fungal Endophytes and Plant Defenses: Not Just Alkaloids. *Trends Plant Sci.* **2017**, *22*, 939–948. [[CrossRef](#)]
17. Card, S.D.; Bastías, D.A.; Caradus, J.R. Antagonism to Plant Pathogens by *Epichloë* Fungal Endophytes—A Review. *Plants* **2021**, *10*, 1997. [[CrossRef](#)]
18. Decunta, F.A.; Pérez, L.I.; Malinowski, D.P.; Molina-Montenegro, M.A.; Gundel, P.E. A Systematic Review on the Effects of *Epichloë* Fungal Endophytes on Drought Tolerance in Cool-Season Grasses. *Front. Plant Sci.* **2021**, *12*, 644731. [[CrossRef](#)]
19. Hamilton, C.; Gundel, P.E.; Helander, M.; Saikkonen, K. Endophytic Mediation of Reactive Oxygen Species and Antioxidant Activity in Plants: A Review. *Fungal Divers.* **2012**, *54*, 1–10. [[CrossRef](#)]
20. Bastías, D.A.; Gundel, P.E. Plant Stress Responses Compromise Mutualisms with *Epichloë* Endophytes. *J. Exp. Bot.* **2022**, *74*, 19–23. [[CrossRef](#)] [[PubMed](#)]
21. Acuña-Rodríguez, I.S.; Newsham, K.K.; Gundel, P.E.; Torres-Díaz, C.; Molina-Montenegro, M.A. Functional Roles of Microbial Symbionts in Plant Cold Tolerance. *Ecol. Lett.* **2020**, *23*, 1034–1048. [[CrossRef](#)]
22. Compant, S.; Van Der Heijden, M.G.A.; Sessitsch, A. Climate Change Effects on Beneficial Plant–Microorganism Interactions. *FEMS Microbiol. Ecol.* **2010**, *73*, 197–214. [[CrossRef](#)]
23. Rivero, R.M.; Mittler, R.; Blumwald, E.; Zandalinas, S.I. Developing Climate-Resilient Crops: Improving Plant Tolerance to Stress Combination. *Plant J.* **2022**, *109*, 373–389. [[CrossRef](#)]
24. Marks, S.; Clay, K. Effects of CO₂ Enrichment, Nutrient Addition, and Fungal Endophyte-Infection on the Growth of Two Grasses. *Oecologia* **1990**, *84*, 207–214. [[CrossRef](#)] [[PubMed](#)]
25. Newman, J.A.; Abner, M.L.; Dado, R.G.; Gibson, D.J.; Brookings, A.; Parsons, A.J. Effects of Elevated CO₂, Nitrogen and Fungal Endophyte-Infection on Tall Fescue: Growth, Photosynthesis, Chemical Composition and Digestibility. *Glob. Chang. Biol.* **2003**, *9*, 425–437. [[CrossRef](#)]
26. Geddes-McAlister, J.; Sukumaran, A.; Patchett, A.; Hager, H.A.; Dale, J.C.M.; Roloson, J.L.; Prudhomme, N.; Bolton, K.; Muselius, B.; Powers, J.; et al. Examining the Impacts of CO₂ Concentration and Genetic Compatibility on Perennial Ryegrass—*Epichloë festucae* Var. *lolii* Interactions. *J. Fungi* **2020**, *6*, 360. [[CrossRef](#)]

27. Meijer, G.; Leuchtman, A. The Effects of Genetic and Environmental Factors on Disease Expression (Stroma Formation) and Plant Growth in *Brachypodium sylvaticum* Infected by *Epichloë Sylvatica*. *Oikos* **2000**, *91*, 446–458. [[CrossRef](#)]
28. Hunt, M.G.; Rasmussen, S.; Newton, P.C.D.; Parsons, A.J.; Newman, J.A. Near-Term Impacts of Elevated CO₂, Nitrogen and Fungal Endophyte-Infection on *Lolium perenne* L. Growth, Chemical Composition and Alkaloid Production. *Plant Cell Environ.* **2005**, *28*, 1345–1354. [[CrossRef](#)]
29. Ryan, G.D.; Rasmussen, S.; Xue, H.; Parsons, A.J.; Newman, J.A. Metabolite Analysis of the Effects of Elevated CO₂ and Nitrogen Fertilization on the Association between Tall Fescue (*Schedonorus arundinaceus*) and Its Fungal Symbiont *Neotyphodium coenophialum*. *Plant Cell Environ.* **2014**, *37*, 204–212. [[CrossRef](#)] [[PubMed](#)]
30. Brosi, G.B.; McCulley, R.L.; Bush, L.P.; Nelson, J.A.; Classen, A.T.; Norby, R.J. Effects of Multiple Climate Change Factors on the Tall Fescue–Fungal Endophyte Symbiosis: Infection Frequency and Tissue Chemistry. *New Phytol.* **2011**, *189*, 797–805. [[CrossRef](#)] [[PubMed](#)]
31. Chen, W.; Liu, H.; Wurihan; Gao, Y.; Card, S.D.; Ren, A. The Advantages of Endophyte-Infected over Uninfected Tall Fescue in the Growth and Pathogen Resistance Are Counteracted by Elevated CO₂. *Sci. Rep.* **2017**, *7*, 6952. [[CrossRef](#)]
32. Ueno, A.C.; Gundel, P.E.; Ghersa, C.M.; Demkura, P.V.; Card, S.D.; Mace, W.J.; Martínez-Ghersa, M.A. Ontogenetic and Trans-Generational Dynamics of a Vertically Transmitted Fungal Symbiont in an Annual Host Plant in Ozone-Polluted Settings. *Plant Cell Environ.* **2020**, *43*, 2540–2550. [[CrossRef](#)]
33. Ueno, A.C.; Gundel, P.E.; Ghersa, C.M.; Agathokleous, E.; Martínez-Ghersa, M.A. Seed-Borne Fungal Endophytes Constrain Reproductive Success of Host Plants under Ozone Pollution. *Environ. Res.* **2021**, *202*, 111773. [[CrossRef](#)]
34. Ueno, A.C.; Gundel, P.E.; Omacini, M.; Ghersa, C.M.; Bush, L.P.; Martínez-Ghersa, M.A. Mutualism Effectiveness of a Fungal Endophyte in an Annual Grass Is Impaired by Ozone. *Funct. Ecol.* **2016**, *30*, 226–232. [[CrossRef](#)]
35. Gundel, P.E.; Sorzoli, N.; Ueno, A.C.; Ghersa, C.M.; Seal, C.E.; Bastías, D.A.; Martínez-Ghersa, M.A. Impact of Ozone on the Viability and Antioxidant Content of Grass Seeds Is Affected by a Vertically Transmitted Symbiotic Fungus. *Environ. Exp. Bot.* **2015**, *113*, 40–46. [[CrossRef](#)]
36. Ueno, A.C.; Gundel, P.E.; Seal, C.E.; Ghersa, C.M.; Martínez-Ghersa, M.A. The Negative Effect of a Vertically-Transmitted Fungal Endophyte on Seed Longevity Is Stronger than that of Ozone Transgenerational Effect. *Environ. Exp. Bot.* **2020**, *175*, 104037. [[CrossRef](#)]
37. Bubica Bustos, L.M.; Ueno, A.C.; Di Leo, T.D.; Crocco, C.D.; Martínez-Ghersa, M.A.; Molina-Montenegro, M.A.; Gundel, P.E. Maternal Exposure to Ozone Modulates the Endophyte-Conferred Resistance to Aphids in *Lolium multiflorum* Plants. *Insects* **2020**, *11*, 548. [[CrossRef](#)] [[PubMed](#)]
38. Gundel, P.E.; Biganzoli, F.; Freitas, P.P.; Landesmann, J.B.; Martínez-Ghersa, M.A.; Ghersa, C.M. Plant Damage, Seed Production and Persistence of the Fungal Endophyte *Epichloë occultans* in *Lolium multiflorum* Plants under an Herbivore Lepidopteran Attack and Ozone Pollution. *Ecol. Austral* **2020**, *30*, 321–330. [[CrossRef](#)]
39. Ju, H.-J.; Hill, N.S.; Abbott, T.; Ingram, K.T. Temperature Influences on Endophyte Growth in Tall Fescue. *Crop Sci.* **2006**, *46*, 404–412. [[CrossRef](#)]
40. Kennedy, C.W.; Bush, L.P. Effect of Environmental and Management Factors on the Accumulation of N-Acetyl and N-Formyl Loline Alkaloid in Tall Fescue. *Crop Sci.* **1983**, *23*, 547–552. [[CrossRef](#)]
41. Ryan, G.D.; Rasmussen, S.; Parsons, A.J.; Newman, J.A. The Effects of Carbohydrate Supply and Host Genetic Background on *Epichloë* Endophyte and Alkaloid Concentrations in Perennial Ryegrass. *Fungal Ecol.* **2015**, *18*, 115–125. [[CrossRef](#)]
42. Hennessy, L.M.; Popay, A.J.; Finch, S.C.; Clearwater, M.J.; Cave, V.M. Temperature and Plant Genotype Alter Alkaloid Concentrations in Ryegrass Infected with an *Epichloë* Endophyte and This Affects an Insect Herbivore. *Front. Plant Sci.* **2016**, *7*, 1097. [[CrossRef](#)]
43. Freitas, P.P.; Hampton, J.G.; Rolston, M.P.; Glare, T.R.; Miller, P.P.; Card, S.D. A Tale of Two Grass Species: Temperature Affects the Symbiosis of a Mutualistic *Epichloë* Endophyte in Both Tall Fescue and Perennial Ryegrass. *Front. Plant Sci.* **2020**, *11*, 530. [[CrossRef](#)]
44. Breen, J.P. Temperature and Seasonal Effects on Expression of *Acremonium* Endophyte-Enhanced Resistance to *Schizaphis graminum* (Homoptera: Aphididae). *Environ. Entomol.* **1992**, *21*, 68–74. [[CrossRef](#)]
45. Bourguignon, M.; Nelson, J.A.; Carlisle, E.; Ji, H.; Dinkins, R.D.; Phillips, T.D.; McCulley, R.L. Ecophysiological Responses of Tall Fescue Genotypes to Fungal Endophyte Infection, Elevated Temperature, and Precipitation. *Crop Sci.* **2015**, *55*, 2895–2909. [[CrossRef](#)]
46. Eerens, J.P.J.; Lucas, R.J.; Easton, S.; White, J.G.H. Influence of the Endophyte (*Neotyphodium lolii*) on Morphology, Physiology, and Alkaloid Synthesis of Perennial Ryegrass during High Temperature and Water Stress. *N. Z. J. Agric. Res.* **1998**, *41*, 219–226. [[CrossRef](#)]
47. Salminen, S.O.; Richmond, D.S.; Grewal, S.K.; Grewal, P.S. Influence of Temperature on Alkaloid Levels and Fall Armyworm Performance in Endophytic Tall Fescue and Perennial Ryegrass. *Entomol. Exp. Appl.* **2005**, *115*, 417–426. [[CrossRef](#)]
48. McCulley, R.L.; Bush, L.P.; Carlisle, A.E.; Ji, H.; Nelson, J.A. Warming Reduces Tall Fescue Abundance but Stimulates Toxic Alkaloid Concentrations in Transition Zone Pastures of the U.S. *Front. Chem.* **2014**, *2*, 88. [[CrossRef](#)]
49. Shi, Q.; Matthew, C.; Liu, W.; Nan, Z. Alkaloid Contents in *Epichloë* Endophyte-Infected *Elymus tangutorum* Sampled along an Elevation Gradient on the Qinghai-Tibetan Plateau. *Agronomy* **2020**, *10*, 1812. [[CrossRef](#)]

50. Liu, J.; Chen, Z.; White, J.F.; Chen, T.; Shi, Q.; Jin, Y.; Li, X.; Li, C. Ergot Alkaloid and Endogenous Hormones Quantities and Relationship in *Epichloë* Endophyte: Drunken Horse Grass Are Affected by Altitude. *J. Plant Growth Regul.* **2022**, 1–12. [[CrossRef](#)]
51. Saikkonen, K.; Phillips, T.D.; Faeth, S.H.; McCulley, R.L.; Saloniemi, I.; Helander, M. Performance of Endophyte Infected Tall Fescue in Europe and North America. *PLoS ONE* **2016**, *11*, e0157382. [[CrossRef](#)]
52. Welty, R.E.; Azevedo, M.D.; Cooper, T.M. Influence of Moisture Content, Temperature, and Length of Storage on Seed Germination and Survival of Endophytic Fungi in Seeds of Tall Fescue and Perennial Ryegrass. *Phytopathology* **1987**, *77*, 893–900. [[CrossRef](#)]
53. Gundel, P.E.; Martinez-Ghersa, M.A.; Garibaldi, L.A.; Ghersa, C.M. Viability of *Neotyphodium* Endophytic Fungus and Endophyte-Infected and Non-infected *Lolium multiflorum* Seeds. *Botany* **2009**, *87*, 88–96. [[CrossRef](#)]
54. Malinowski, D.P.; Belesky, D.P. Adaptations of Endophyte-Infected Cool-Season Grasses to Environmental Stresses: Mechanisms of Drought and Mineral Stress Tolerance. *Crop Sci.* **2000**, *40*, 923–940. [[CrossRef](#)]
55. Dastogeer, K.M.G. Influence of Fungal Endophytes on Plant Physiology Is More Pronounced under Stress than Well-Watered Conditions: A Meta-Analysis. *Planta* **2018**, *248*, 1403–1416. [[CrossRef](#)] [[PubMed](#)]
56. Nagabhyru, P.; Dinkins, R.D.; Wood, C.L.; Bacon, C.W.; Schardl, C.L. Tall Fescue Endophyte Effects on Tolerance to Water-Deficit Stress. *BMC Plant Biol.* **2013**, *13*, 127. [[CrossRef](#)] [[PubMed](#)]
57. Zhong, R.; Bastías, D.A.; Zhang, X.; Li, C.; Nan, Z. Vertically Transmitted *Epichloë* Systemic Endophyte Enhances Drought Tolerance of *Achnatherum inebrians* Host Plants through Promoting Photosynthesis and Biomass Accumulation. *J. Fungi* **2022**, *8*, 512. [[CrossRef](#)]
58. Manzur, M.E.; Garello, F.A.; Omacini, M.; Schnyder, H.; Sutka, M.R.; García-Parisi, P.A. Endophytic Fungi and Drought Tolerance: Ecophysiological Adjustment in Shoot and Root of an Annual Mesophytic Host Grass. *Funct. Plant Biol.* **2022**, *49*, 272–282. [[CrossRef](#)]
59. Zhang, X.; Li, C.; Nan, Z. Effects of Salt and Drought Stress on Alkaloid Production in Endophyte-Infected Drunken Horse Grass (*Achnatherum inebrians*). *Biochem. Syst. Ecol.* **2011**, *39*, 471–476. [[CrossRef](#)]
60. Lin, W.; Gao, C.; Wang, J.; Xu, W.; Wang, M.; Li, M.; Ma, B.; Tian, P. Effects of Drought Stress on Peramine and Lolitrem B in *Epichloë*-Endophyte-Infected Perennial Ryegrass. *Life* **2022**, *12*, 1207. [[CrossRef](#)]
61. Hesse, U.; Schöberlein, W.; Wittenmayer, L.; Förster, K.; Warnstorff, K.; Diepenbrock, W.; Merbach, W. Effects of *Neotyphodium* Endophytes on Growth, Reproduction and Drought-Stress Tolerance of Three *Lolium perenne* L. Genotypes. *Grass Forage Sci.* **2003**, *58*, 407–415. [[CrossRef](#)]
62. Gundel, P.E.; Maseda, P.H.; Vila-Aiub, M.M.; Ghersa, C.M.; Benech-Arnold, R. Effects of *Neotyphodium* Fungi on *Lolium multiflorum* Seed Germination in Relation to Water Availability. *Ann. Bot.* **2006**, *97*, 571–577. [[CrossRef](#)]
63. Gundel, P.E.; Irisarri, J.G.N.; Fazio, L.; Casas, C.; Pérez, L.I. Inferring Field Performance from Drought Experiments Can Be Misleading: The Case of Symbiosis between Grasses and *Epichloë* Fungal Endophytes. *J. Arid Environ.* **2016**, *132*, 60–62. [[CrossRef](#)]
64. Xia, C.; Christensen, M.J.; Zhang, X.; Nan, Z. Effect of *Epichloë gansuensis* Endophyte and Transgenerational Effects on the Water Use Efficiency, Nutrient and Biomass Accumulation of *Achnatherum inebrians* under Soil Water Deficit. *Plant Soil* **2018**, *424*, 555–571. [[CrossRef](#)]
65. Arachevaleta, M.; Bacon, C.W.; Hoveland, C.S.; Radcliffe, D.E. Effect of the Tall Fescue Endophyte on Plant Response to Environmental Stress. *Agron. J.* **1989**, *81*, 83–90. [[CrossRef](#)]
66. Di Bella, C.E.; Grimoldi, A.A.; Striker, G.G. A Quantitative Revision of the Waterlogging Tolerance of Perennial Forage Grasses. *Crop. Pasture Sci.* **2022**, *73*, 1200–1212. [[CrossRef](#)]
67. Saedi, T.; Mosaddeghi, M.R.; Sabzalian, M.R.; Zarebanadkouki, M. Effect of *Epichloë* Fungal Endophyte Symbiosis on Tall Fescue to Cope with Flooding-Derived Oxygen-Limited Conditions Depends on the Host Genotype. *Plant Soil* **2021**, *468*, 353–373. [[CrossRef](#)]
68. Song, M.; Li, X.; Saikkonen, K.; Li, C.; Nan, Z. An Asexual *Epichloë* Endophyte Enhances Waterlogging Tolerance of *Hordeum brevisubulatum*. *Fungal Ecol.* **2015**, *13*, 44–52. [[CrossRef](#)]
69. Wang, J.; Zhou, Y.; Lin, W.; Li, M.; Wang, M.; Wang, Z.; Kuang, Y.; Tian, P. Effect of an *Epichloë* Endophyte on Adaptability to Water Stress in *Festuca sinensis*. *Fungal Ecol.* **2017**, *30*, 39–47. [[CrossRef](#)]
70. Adams, A.E.; Kazenel, M.R.; Rudgers, J.A. Does a Foliar Endophyte Improve Plant Fitness under Flooding? *Plant Ecol.* **2017**, *218*, 711–723. [[CrossRef](#)]
71. Kazenel, M.R.; Debban, C.L.; Ranelli, L.; Hendricks, W.Q.; Chung, Y.A.; Pendergast, T.H., IV; Charlton, N.D.; Young, C.A.; Rudgers, J.A. A Mutualistic Endophyte Alters the Niche Dimensions of Its Host Plant. *AoB Plants* **2015**, *7*, plv005. [[CrossRef](#)]
72. Chen, T.; Johnson, R.; Chen, S.; Lv, H.; Zhou, J.; Li, C. Infection by the Fungal Endophyte *Epichloë bromicola* Enhances the Tolerance of Wild Barley (*Hordeum brevisubulatum*) to Salt and Alkali Stresses. *Plant Soil* **2018**, *428*, 353–370. [[CrossRef](#)]
73. Wang, J.; Tian, P.; Christensen, M.J.; Zhang, X.; Li, C.; Nan, Z. Effect of *Epichloë gansuensis* Endophyte on the Activity of Enzymes of Nitrogen Metabolism, Nitrogen Use Efficiency and Photosynthetic Ability of *Achnatherum inebrians* under Various NaCl Concentrations. *Plant Soil* **2019**, *435*, 57–68. [[CrossRef](#)]
74. Wang, Z.; Li, C.; White, J. Effects of *Epichloë* Endophyte Infection on Growth, Physiological Properties and Seed Germination of Wild Barley under Saline Conditions. *J. Agron. Crop Sci.* **2020**, *206*, 43–51. [[CrossRef](#)]
75. Yin, L.; Wei, M.; Wu, G.; Ren, A. *Epichloë* Endophytes Improved *Leymus chinensis* Tolerance to Both Neutral and Alkali Salt Stresses. *Front. Plant Sci.* **2022**, *13*, 968774. [[CrossRef](#)] [[PubMed](#)]

76. Liu, H.; Tang, H.; Ni, X.; Zhang, Y.; Wang, Y. Effects of the Endophyte *Epichloë coenophiala* on the Root Microbial Community and Growth Performance of Tall Fescue in Different Saline-Alkali Soils. *Fungal Ecol.* **2022**, *57–58*, 101159. [[CrossRef](#)]
77. Ahmad, R.Z.; Khalid, R.; Aqeel, M.; Ameen, F.; Li, C.J. Fungal Endophytes Trigger *Achnatherum inebrians* Germination Ability against Environmental Stresses. *S. Afr. J. Bot.* **2020**, *134*, 230–236. [[CrossRef](#)]
78. Ju, Y.; Kou, M.; Zhong, R.; Christensen, M.J.; Zhang, X. Alleviating Salt Stress on Seedlings Using Plant Growth Promoting Rhizobacteria Isolated from the Rhizosphere Soil of *Achnatherum inebrians* Infected with *Epichloë gansuensis* Endophyte. *Plant Soil* **2021**, *465*, 349–366. [[CrossRef](#)]
79. Chen, T.; Simpson, W.R.; Nan, Z.; Li, C. NaCl Stress Modifies the Concentrations of Endophytic Fungal Hyphal and Peramine in *Hordeum brevisubulatum* Seedlings. *Crop. Pasture Sci.* **2022**, *73*, 214–221. [[CrossRef](#)]
80. Laing, W.A.; Greer, D.H.; Campbell, B.D. Strong Responses of Growth and Photosynthesis of Five C3 Pasture Species to Elevated CO₂ at Low Temperatures. *Funct. Plant Biol.* **2002**, *29*, 1089–1096. [[CrossRef](#)]
81. Ainsworth, E.A.; Long, S.P. What Have We Learned from 15 Years of Free-Air CO₂ Enrichment (FACE)? A Meta-Analytic Review of the Responses of Photosynthesis, Canopy Properties and Plant Production to Rising CO₂. *New Phytol.* **2005**, *165*, 351–372. [[CrossRef](#)]
82. Robinson, E.A.; Ryan, G.D.; Newman, J.A. A Meta-Analytical Review of the Effects of Elevated CO₂ on Plant–Arthropod Interactions Highlights the Importance of Interacting Environmental and Biological Variables. *New Phytol.* **2012**, *194*, 321–336. [[CrossRef](#)]
83. Rasmussen, S.; Parsons, A.J.; Bassett, S.; Christensen, M.J.; Hume, D.E.; Johnson, L.J.; Johnson, R.D.; Simpson, W.R.; Stacke, C.; Voisey, C.R.; et al. High Nitrogen Supply and Carbohydrate Content Reduce Fungal Endophyte and Alkaloid Concentration in *Lolium perenne*. *New Phytol.* **2007**, *173*, 787–797. [[CrossRef](#)]
84. Ryan, G.D.; Shukla, K.; Rasmussen, S.; Shelp, B.J.; Newman, J.A. Phloem Phytochemistry and Aphid Responses to Elevated CO₂, Nitrogen Fertilization and Endophyte Infection. *Agric. For. Entomol.* **2014**, *16*, 273–283. [[CrossRef](#)]
85. Fuchs, B.; Krischke, M.; Mueller, M.J.; Krauss, J. Plant Age and Seasonal Timing Determine Endophyte Growth and Alkaloid Biosynthesis. *Fungal Ecol.* **2017**, *29*, 52–58. [[CrossRef](#)]
86. Raja, V.; Majeed, U.; Kang, H.; Andrabi, K.I.; John, R. Abiotic Stress: Interplay between ROS, Hormones and MAPKs. *Environ. Exp. Bot.* **2017**, *137*, 142–157. [[CrossRef](#)]
87. Kayano, Y.; Tanaka, A.; Takemoto, D. Two Closely Related Rho GTPases, Cdc42 and RacA, of the Endophytic Fungus *Epichloë festucae* Have Contrasting Roles for ROS Production and Symbiotic Infection Synchronized with the Host Plant. *PLoS Pathog.* **2018**, *14*, e1006840. [[CrossRef](#)] [[PubMed](#)]
88. Tanaka, A.; Christensen, M.J.; Takemoto, D.; Park, P.; Scott, B. Reactive Oxygen Species Play a Role in Regulating a Fungus–Perennial Ryegrass Mutualistic Interaction. *Plant Cell* **2006**, *18*, 1052–1066. [[CrossRef](#)] [[PubMed](#)]
89. Kadota, Y.; Shirasu, K.; Zipfel, C. Regulation of the NADPH Oxidase RBOHD during Plant Immunity. *Plant Cell Physiol.* **2015**, *56*, 1472–1480. [[CrossRef](#)]
90. Kangasjarvi, J.; Jaspers, P.; Kollist, H. Signalling and Cell Death in Ozone-Exposed Plants. *Plant Cell Environ.* **2005**, *28*, 1021–1036. [[CrossRef](#)]
91. Dupont, P.; Eaton, C.J.; Wargent, J.J.; Fechtner, S.; Solomon, P.; Schmid, J.; Day, R.C.; Scott, B.; Cox, M.P. Fungal Endophyte Infection of Ryegrass Reprograms Host Metabolism and Alters Development. *New Phytol.* **2015**, *208*, 1227–1240. [[CrossRef](#)]
92. Bernacki, M.J.; Rusaczek, A.; Czarnocka, W.; Karpiński, S. Salicylic Acid Accumulation Controlled by LSD1 Is Essential in Triggering Cell Death in Response to Abiotic Stress. *Cells* **2021**, *10*, 962. [[CrossRef](#)]
93. Kou, M.-Z.; Bastias, D.A.; Christensen, M.J.; Zhong, R.; Nan, Z.-B.; Zhang, X.-X. The Plant Salicylic Acid Signalling Pathway Regulates the Infection of a Biotrophic Pathogen in Grasses Associated with an *Epichloë* Endophyte. *J. Fungi* **2021**, *7*, 633. [[CrossRef](#)]
94. Redkar, A.; Sabale, M.; Zuccaro, A.; Di Pietro, A. Determinants of Endophytic and Pathogenic Lifestyle in Root Colonizing Fungi. *Curr. Opin. Plant Biol.* **2022**, *67*, 102226. [[CrossRef](#)] [[PubMed](#)]
95. Suzuki, N.; Mittler, R. Reactive Oxygen Species and Temperature Stresses: A Delicate Balance between Signaling and Destruction. *Physiol. Plant.* **2006**, *126*, 45–51. [[CrossRef](#)]
96. Simons, L.; Bultman, T.; Sullivan, T.J. Effects of Methyl Jasmonate and an Endophytic Fungus on Plant Resistance to Insect Herbivores. *J. Chem. Ecol.* **2008**, *34*, 1511–1517. [[CrossRef](#)] [[PubMed](#)]
97. Bastias, D.A.; Martínez-Ghersa, M.A.; Newman, J.A.; Card, S.D.; Mace, W.J.; Gundel, P.E. The Plant Hormone Salicylic Acid Interacts with the Mechanism of Anti-Herbivory Conferred by Fungal Endophytes in Grasses. *Plant Cell Environ.* **2018**, *41*, 395–405. [[CrossRef](#)] [[PubMed](#)]
98. Allen, D.J.; Ort, D.R. Impacts of Chilling Temperatures on Photosynthesis in Warm-Climate Plants. *Trends Plant Sci.* **2001**, *6*, 36–42. [[CrossRef](#)] [[PubMed](#)]
99. Spiering, M.J.; Lane, G.A.; Christensen, M.J.; Schmid, J. Distribution of the Fungal Endophyte *Neotyphodium lolii* Is Not a Major Determinant of the Distribution of Fungal Alkaloids in *Lolium perenne* Plants. *Phytochemistry* **2005**, *66*, 195–202. [[CrossRef](#)]
100. Gilbert, M.E.; Medina, V. Drought Adaptation Mechanisms Should Guide Experimental Design. *Trends Plant Sci.* **2016**, *21*, 639–647. [[CrossRef](#)]
101. Jogawat, A.; Yadav, B.; Chhaya; Lakra, N.; Singh, A.K.; Narayan, O.P. Crosstalk between Phytohormones and Secondary Metabolites in the Drought Stress Tolerance of Crop Plants: A Review. *Physiol. Plant.* **2021**, *172*, 1106–1132. [[CrossRef](#)]

102. Semmartin, M.; Omacini, M.; Gundel, P.E.; Hernández-Agramonte, I.M. Broad-Scale Variation of Fungal-Endophyte Incidence in Temperate Grasses. *J. Ecol.* **2015**, *103*, 184–190. [[CrossRef](#)]
103. Casas, C.; Gundel, P.E.; Deliens, E.; Iannone, L.J.; García Martínez, G.; Vignale, M.V.; Schnyder, H. Loss of Fungal Symbionts at the Arid Limit of the Distribution Range in a Native Patagonian Grass—Resource Eco-Physiological Relations. *Funct. Ecol.* **2022**, *36*, 583–594. [[CrossRef](#)]
104. Perata, P.; Armstrong, W.; Voeselek, L.A.C.J. Plants and Flooding Stress. *New Phytol.* **2011**, *190*, 269–273. [[CrossRef](#)] [[PubMed](#)]
105. Herzog, M.; Striker, G.G.; Colmer, T.D.; Pedersen, O. Mechanisms of Waterlogging Tolerance in Wheat—A Review of Root and Shoot Physiology. *Plant Cell Environ.* **2016**, *39*, 1068–1086. [[CrossRef](#)] [[PubMed](#)]
106. Fukao, T.; Barrera-Figueroa, B.E.; Juntawong, P.; Peña-Castro, J.M. Submergence and Waterlogging Stress in Plants: A Review Highlighting Research Opportunities and Understudied Aspects. *Front. Plant Sci.* **2019**, *10*, 340. [[CrossRef](#)] [[PubMed](#)]
107. Gundel, P.E.; Garibaldi, L.A.; Tognetti, P.M.; Aragón, R.; Ghersa, C.M.; Omacini, M. Imperfect Vertical Transmission of the Endophyte *Neotyphodium* in Exotic Grasses in Grasslands of the Flooding Pampa. *Microb. Ecol.* **2009**, *57*, 740–748. [[CrossRef](#)] [[PubMed](#)]
108. Sharma, P.; Jha, A.B.; Dubey, R.S.; Pessarakli, M. Reactive Oxygen Species, Oxidative Damage, and Antioxidative Defense Mechanism in Plants under Stressful Conditions. *J. Bot.* **2012**, *2012*, 217037. [[CrossRef](#)]
109. Yu, Z.; Duan, X.; Luo, L.; Dai, S.; Ding, Z.; Xia, G. How Plant Hormones Mediate Salt Stress Responses. *Trends Plant Sci.* **2020**, *25*, 1117–1130. [[CrossRef](#)]
110. Bastías, D.A.; Martínez-Ghersa, M.A.; Newman, J.A.; Card, S.D.; Mace, W.J.; Gundel, P.E. Jasmonic Acid Regulation of the Anti-Herbivory Mechanism Conferred by Fungal Endophytes in Grasses. *J. Ecol.* **2018**, *106*, 2365–2379. [[CrossRef](#)]
111. Cheplick, G.P.; Clay, K.; Marks, S. Interactions between Infection by Endophytic Fungi and Nutrient Limitation in the Grasses *Lolium perenne* and *Festuca arundinacea*. *New Phytol.* **1989**, *111*, 89–97. [[CrossRef](#)]
112. Song, M.; Chai, Q.; Li, X.; Yao, X.; Li, C.; Christensen, M.J.; Nan, Z. An Asexual *Epichloë* Endophyte Modifies the Nutrient Stoichiometry of Wild Barley (*Hordeum brevisubulatum*) under Salt Stress. *Plant Soil* **2015**, *387*, 153–165. [[CrossRef](#)]
113. Chen, T.; White, J.F.; Li, C. Fungal Endophyte *Epichloë Bromicola* Infection Regulates Anatomical Changes to Account for Salt Stress Tolerance in Wild Barley (*Hordeum brevisubulatum*). *Plant Soil* **2021**, *461*, 533–546. [[CrossRef](#)]
114. Apel, K.; Hirt, H. Reactive Oxygen Species: Metabolism, Oxidative Stress, and Signal Transduction. *Annu. Rev. Plant Biol.* **2004**, *55*, 373–399. [[CrossRef](#)]
115. Mittler, R.; Zandalinas, S.I.; Fichman, Y.; Van Breusegem, F. Reactive Oxygen Species Signalling in Plant Stress Responses. *Nat. Rev. Mol. Cell Biol.* **2022**, *23*, 663–679. [[CrossRef](#)]
116. Ueno, A.C.; Gundel, P.E.; Molina-Montenegro, M.A.; Ramos, P.; Ghersa, C.M.; Martínez-Ghersa, M.A. Getting Ready for the Ozone Battle: Vertically Transmitted Fungal Endophytes Have Transgenerational Positive Effects in Plants. *Plant Cell Environ.* **2021**, *44*, 2716–2728. [[CrossRef](#)] [[PubMed](#)]
117. Zhang, Y.; Nan, Z.B. Growth and Anti-Oxidative Systems Changes in *Elymus dahuricus* Is Affected by *Neotyphodium* Endophyte under Contrasting Water Availability. *J. Agron. Crop Sci.* **2007**, *193*, 377–386. [[CrossRef](#)]
118. Patel, T.K.; Williamson, J.D. Mannitol in Plants, Fungi, and Plant–Fungal Interactions. *Trends Plant Sci.* **2016**, *21*, 486–497. [[CrossRef](#)] [[PubMed](#)]
119. Bastías, D.A.; Martínez-Ghersa, M.A.; Newman, J.A.; Card, S.D.; Mace, W.J.; Gundel, P.E. *Sipha maydis* Sensitivity to Defences of *Lolium multiflorum* and Its Endophytic Fungus *Epichloë occultans*. *PeerJ* **2019**, *7*, e8257. [[CrossRef](#)]
120. Plett, J.M.; Kemppainen, M.; Kale, S.D.; Kohler, A.; Legué, V.; Brun, A.; Tyler, B.M.; Pardo, A.G.; Martin, F. A Secreted Effector Protein of *Laccaria bicolor* Is Required for Symbiosis Development. *Curr. Biol.* **2011**, *21*, 1197–1203. [[CrossRef](#)] [[PubMed](#)]
121. Wang, P.; Jiang, H.; Boeren, S.; Dings, H.; Kulikova, O.; Bisseling, T.; Limpens, E. A Nuclear-Targeted Effector of *Rhizophagus irregularis* Interferes with Histone 2B Mono-Ubiquitination to Promote Arbuscular Mycorrhization. *New Phytol.* **2021**, *230*, 1142–1155. [[CrossRef](#)] [[PubMed](#)]
122. Chakrabarti, M.; Nagabhyru, P.; Schardl, C.L.; Dinkins, R.D. Differential Gene Expression in Tall Fescue Tissues in Response to Water Deficit. *Plant Genome* **2022**, *15*, e20199. [[CrossRef](#)] [[PubMed](#)]
123. Cui, X.; Zhang, X.; Shi, L.; Christensen, M.J.; Nan, Z.; Xia, C. Effects of *Epichloë* Endophyte and Transgenerational Effects on Physiology of *Achnatherum inebrians* under Drought Stress. *Agriculture* **2022**, *12*, 761. [[CrossRef](#)]
124. Li, F.; Guo, Y.; Christensen, M.J.; Gao, P.; Li, Y.; Duan, T. An Arbuscular Mycorrhizal Fungus and *Epichloë festucae* Var. *Lolii* Reduce *Bipolaris sorokiniana* Disease Incidence and Improve Perennial Ryegrass Growth. *Mycorrhiza* **2018**, *28*, 159–169. [[CrossRef](#)] [[PubMed](#)]
125. Islam, M.S.; Krom, N.; Kwon, T.; Li, G.; Saha, M.C. Transcriptome of Endophyte-Positive and Endophyte-Free Tall Fescue under Field Stresses. *Front. Plant Sci.* **2022**, *13*, 803400. [[CrossRef](#)] [[PubMed](#)]
126. Dinkins, R.D.; Nagabhyru, P.; Young, C.A.; West, C.P.; Schardl, C.L. Transcriptome Analysis and Differential Expression in Tall Fescue Harboring Different Endophyte Strains in Response to Water Deficit. *Plant Genome* **2019**, *12*, 180071. [[CrossRef](#)] [[PubMed](#)]
127. Bourguin, B.; Guihur, A. Heat Shock Signaling in Land Plants: From Plasma Membrane Sensing to the Transcription of Small Heat Shock Proteins. *Front. Plant Sci.* **2021**, *12*, 710801. [[CrossRef](#)]
128. Tiwari, P.; Chakrabarty, D. Dehydrin in the Past Four Decades: From Chaperones to Transcription Co-Regulators in Regulating Abiotic Stress Response. *Curr. Res. Biotechnol.* **2021**, *3*, 249–259. [[CrossRef](#)]

129. Reza Sabzalain, M.; Mirlohi, A. *Neotyphodium* Endophytes Trigger Salt Resistance in Tall and Meadow Fescues. *J. Plant Nutr. Soil Sci.* **2010**, *173*, 952–957. [[CrossRef](#)]
130. Gundel, P.E.; Rudgers, J.A.; Whitney, K.D. Vertically Transmitted Symbionts as Mechanisms of Transgenerational Effects. *Am. J. Bot.* **2017**, *104*, 787–792. [[CrossRef](#)]
131. Miller, T.A.; Hudson, D.A.; Johnson, R.D.; Singh, J.S.; Mace, W.J.; Forester, N.T.; Maclean, P.H.; Voisey, C.R.; Johnson, L.J. Dissection of the Epoxyjanthitrem Pathway in *Epichloë* Sp. LpTG-3 Strain AR37 by CRISPR Gene Editing. *Front. Fungal Biol.* **2022**, *3*, 944234. [[CrossRef](#)]
132. Nagabhyru, P.; Dinkins, R.D.; Schardl, C.L. Transcriptome Analysis of *Epichloë* Strains in Tall Fescue in Response to Drought Stress. *Mycologia* **2022**, *114*, 697–712. [[CrossRef](#)]
133. Wang, M.; Tian, P.; Gao, M.; Li, M. The Promotion of *Festuca sinensis* Heavy Metal Stress Tolerance Mediated by *Epichloë* Endophyte. *Agronomy* **2021**, *11*, 2049. [[CrossRef](#)]
134. Aroca, R.; del Mar Alguacil, M.; Vernieri, P.; Ruiz-Lozano, J.M. Plant Responses to Drought Stress and Exogenous ABA Application Are Modulated Differently by Mycorrhization in Tomato and an ABA-Deficient Mutant (Sitiens). *Microb. Ecol.* **2008**, *56*, 704–719. [[CrossRef](#)] [[PubMed](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.