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Importing *Glomus iranicum* var. *tenuihypharum* to Norway

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A brief statement from the Norwegian Scientific Committee for Food and Environment

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Preparation of the opinion

The Norwegian Scientific Committee for Food and Environment (Vitenskapskomiteen for mat og miljø, VKM) appointed a project group to draft the opinion. The project group consisted of three VKM members and one VKM staff.

Authors of the opinion

All authors have contributed to the report in a way that fulfills the authorship principles of VKM (VKM, 2019). The principles reflect the collaborative nature of the work, and the authors have contributed as members of the project group and VKM.

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Competence of VKM experts

Persons working for VKM, either as appointed members of the Committee or as external experts, do this by virtue of their scientific expertise, not as representatives for their employers or third-party interests. The Civil Services Act instructions on legal competence apply to all work prepared by VKM.

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Summary

VKM has conducted a brief review of possible consequences of introducing the arbuscular mycorrhizal fungus *Glomus iranicum* var. *tenuihypharum* into Norway. Although there have not been any documented cases of damage caused by the introduction of similar mycorrhizal fungi, the potential impact is concerning. Most studies on similar mycorrhizal fungi have been done under greenhouse conditions, and there is limited knowledge about outdoor field conditions. The beneficial effects of *G. iranicum* var. *tenuihypharum* on plant growth have primarily been tested in southern Europe, and the tests have shown variable success in improving plant growth. The ability of the fungus to form symbiosis with multiple plant species raises concerns about its potential impact on local microbial communities. VKM stresses the high level of uncertainty and limited knowledge about possible environmental effects associated with introducing *G. iranicum* var. *tenuihypharum* into Norway.

Keywords: crop yield, environmental effects, mycorrhiza.

Sammendrag på norsk

VKM har gjort en kort gjennomgang av mulige konsekvenser av å introdusere mykorrhiza-soppen *Glomus iranicum* var. *tenuihypharum* til Norge. Selv om det ikke finnes noen dokumenterte tilfeller av negative effekter forårsaket av introduksjon av lignende mykorrhizasopper er det grunn til bekymring. De fleste studier av lignende mykorrhizasopper har blitt gjort i drivhus og det er begrenset kunnskap om forhold på friland. Effekter av *G. iranicum* var. *tenuihypharum* på planter har stort sett blitt testet i Sør-Europa, og testene har vist variabel suksess i å forbedre plantevekst. Soppens evne til å danne symbiose med flere plantearter og dens mulige effekter på det biologiske mangfoldet gir grunn til bekymring. VKM understreker at det er mye usikkerhet og begrenset kunnskap om mulige miljøeffekter av å introdusere *G. iranicum* var. *tenuihypharum* til Norge.

1 Background on mycorrhizal fungi

Mycorrhizal fungi are an important component of the soil microbial community, together with a wide variety of other organisms. Mycorrhizal fungi form symbiotic relationships with plants via the plants' fine roots. The fungi provide nutrients and water to the plants and receive carbohydrates in return. Most plant species are involved in mycorrhizal associations. Mycorrhiza promotes plant growth, and broadly speaking, this mutualistic symbiosis may be considered essential for natural terrestrial ecosystems and many forms of agriculture.

One important type of mycorrhizal symbiosis is arbuscular mycorrhizal (AM) symbiosis, which involves 75% of all terrestrial plants, including many crop species. The fungal species considered here, *Glomus iranicum* var. *tenuihypharum*, is an AM species. In AM symbiosis, fungal hyphae penetrate the root cells to form intracellular structures (arbuscules) where the nutrient exchange between fungus and plant happens. Arbuscular mycorrhiza is formed by fungi in the phylum Glomeromycota, which contains more than 200 recognized species that are almost exclusively mycorrhiza-forming.

The fact that most plant species are involved in beneficial interactions with mycorrhiza has led to the marketing of mycorrhizal products intended to increase plant growth and crop yield in agriculture, horticulture, and forestry. Despite the importance of mycorrhiza in natural systems, the use of mycorrhizal products may not always improve growth or yield in cropping systems (Hart et al., 2017). One reason is that mycorrhizal fungi do not compete well under the high phosphorous levels that exist in many agricultural soils. Another reason is that effective mycorrhizal mutualisms usually are specialized and form species-specific associations with certain plant species. Because of this species-specificity, the alleged generalist mycorrhizal species that are often included in commercial products may not be able to deliver the intended benefits.

2 Species identity, natural distribution, and host plants

The taxonomical classification of AM fungi is uncertain because the biological species concept is not meaningful for these fungi, which mainly reproduce asexually. Also, most AM species have been defined only by morphological characters. Some of these morphological species may, on closer inspection, turn out to be species complexes that consist of several genetically distinct cryptic species. It is thus unknown whether the currently recognized AM species are valid biological species. Furthermore, AM fungi do not form macroscopic fruitbodies but exist solely as hyphae in soil and plant tissues or as spores. This makes it challenging to map the geographical distribution of AM fungi.

Due to these taxonomical challenges, the geographical distribution and national species records of many mycorrhizal fungi are uncertain. Most AM fungi appear to have a wide geographic distribution, but this could be an artifact of poor species delimitations and cryptic species complexes. New AM species are continually being identified, especially with the help of molecular methods. Some AM species have been little studied, at least taxonomically, and may actually have broader distributions than what is currently indicated by the limited occurrence data. With all this uncertainty in mind, we describe the species identity and known distribution of *Glomus iranicum* var. *tenuihypharum*.

Scientific name: *Glomus iranicum* var. *tenuihypharum*

Common name: none

Norwegian name: none

Taxonomy:

Kingdom: Fungi

Division: Glomeromycota

Class: Glomeromycetes

Order: Glomerales

Family: Glomeraceae

Genus: *Glomus* / *Dominikia*

Species: *Glomus iranicum* / *Dominikia iranica*

Variety: *Glomus iranicum* var. *tenuihypharum*

Species identity: *Glomus iranicum* was first collected in a single wheat field in Iran in 1997 but was not identified and described as a new species until 2008 (Błaszkowski et al., 2010). Some years later, the species was transferred to a new genus under the name *Dominikia iranica* (Błaszkowski et al., 2015). This report will mostly refer to the fungus as *G. iranicum* since most of the (sparse) literature on the species uses this name, often specified to the variety *Glomus iranicum* var. *tenuihypharum*. According to the company marketing this variety (Symborg, 2023), "*Glomus iranicum* var. *tenuihypharum* was discovered in a hypersaline lake under extreme conditions in the Murcia region in Spain". We have not found any peer-reviewed literature describing the *tenuihypharum* variety of *G. iranicum* or the original discovery of this variety in Spain.

Natural distribution: Apart from the records from Iran and Spain there is very little information about the natural distribution of *G. iranicum / D. iranica.* Other records of *G. iranicum* (as *D. iranica*) outside Europe are from Canada (Dai et al., 2014) and Argentina (Colombo et al., 2020) (Fernandez Bibondo et al., 2018), where the fungus was associated with crops or natural plant communities. According to gbif.org, *G. iranicum* has also been recorded from Bolivia and South Africa in 2010 (as *D. iranica*) and from the Ivory Coast in 2018 (as *G. iranicum*), but it is impossible to verify whether these records are correct or not. So far, the geographical distribution of the *tenuihypharum* variety of *G. iranicum* outside greenhouses appears to be limited to Spain and Italy, based on where the product has been used in field experiments.

Host plants: According to information provided by the Symborg company, a plant in the genus *Limonium* was growing in association with *G. iranicum* var. *tenuihypharum* in Murcia, and it was assumed that this association helped the plant survive in the harsh environment. Four species of *Limonium* are registered in Norway (Artsdatabanken, 2023), but only one (*L. humile*) is indigenous to northern and western Europe. It is unknown if *L. humile* could be a host for the fungus. The other three *Limonium* species recorded in Norway (*L. bonduellei, L. lobatum*, and *L. sinuatum*) are native to southern Europe and northern Africa and have only been observed in Norway as single introductions. As all these species are present in Spain, one of them, or a similar species, could have been the host of the *G. iranicum* var. *tenuihypharum* isolate found in the Murcia region.

The full host range of *G. iranicum* is unknown, but the fungus has been shown to form mycorrhizal associations with several plant species in various experiments, including some on trees (Table 1). Most published experiments on effects of *G. iranicum* on plant growth have been conducted with *G. iranicum* var. *tenuihypharum* (Table 1). These experiments include tests with various crop plants in different countries. The fungus has been tested once as a *G. iranicum* mycorrhiza addition and showed a positive effect on grapevine in the field in Italy (Luciani et al., 2019a). In Canada, the presence of *D. iranica* was associated with reduced plant growth, contrary to all other experiments and studies with the fungus (Dai et al., 2014).

Table 1. Information from scientific papers about plants and countries associated with *Glomus iranicum*/*Dominikia iranica* or *G. iranicum* var. *tenuihypharum*. For each fungus name, the newest references are listed first. The first two rows are the original description of the fungus and its transfer to a new genus.

Fungus name used	**Type of experiment / detection spot**	**Plant species**	**Country**	**Reference**
Glomus iranicum	Cultivated field	*Triticum aestivum* (wheat)	Iran	Blaszkowski et al. 2010
	Pots	*Plantago lanceolata*	Poland	
Dominikia iranica	(New genus for species)	Mycelium in lab cultures	Poland?	Blaszkowski et al. 2015
Dominikia iranica	Soil cores, plants, pot trap cultures	River edge plant community	Argentina	Colombo et al. 2020
Glomus iranicum	Rooted cuttings in greenhouse,	*Vitis vinifera* cv. Sangiovese	Italy	Luciani et al. 2019a
	Grafted on rootstock 420A, field	(grapevine)		
Dominikia iranica	Field and containers compared	*Carya illinoinensis* (pecan trees)	Argentina	Fernandez Bibondo et al. 2018
Dominikia iranica	Organic and conventional fields	*Triticum* (wheat)	Canada	Dai et al. 2014
Glomus iranicum var. *tenuihypharum*	Field conditions	*Fragaria × ananassa* cultivars ('Brilla' (B) and 'Sibilla' strawberry)	Italy	Roccuzzo et al. 2021
Glomus iranicum var. *tenuihypharum*	Field conditions	*Cucumis melo* (melon)	Spain	Alarcón et al. 2019
Glomus iranicum var. *tenuihypharum*	Field conditions, young plants, and plantations	Citrus, different cultivars and species of citrus	Spain	Fernández et al. 2019
Glomus iranicum var. *tenuihypharum*	Field conditions (recently planted orchard)	*Corylus avellana* (hazelnut)	Italy	Luciani et al. 2019b
Glomus iranicum var. *tenuihypharum*	Greenhouse conditions	*Persea americana* (avocado)	Ecuador	Sotomayor et al. 2019
Glomus iranicum var. *tenuihypharum*	Growth chamber	*Cistus albidus*	Unknown	Ortuno et al. 2018
Glomus iranicum var. *tenuihypharum*	Pots, greenhouse	Lettuce and table grape crops	Spain	Martin et al. 2017
Glomus iranicum var. *tenuihypharum*	Field conditions	*Viburnum tinus*	Unknown, maybe Spain	Gomez-Bellot et al. 2015
Glomus iranicum var. *tenuihypharum*	Probably pots	*Viburnum tinus*	Unknown, maybe Spain	Gomez-Bellot et al. 2015
Glomus iranicum var. *tenuihypharum*	Probably field conditions	*Vitis vinifera* (Crimson grapevine)	Spain	Nicolas et al. 2015
Glomus iranicum var. *tenuihypharum*	Pots, greenhouse	Solanum (tomato)	Spain	Fernández et al. 2014
Glomus iranicum var. *tenuihypharum*	Greenhouse conditions	Lettuce	Unknown, maybe Spain	Vicente-Sanchez et al. 2014

3 Establishment and spread

Introducing new species or genetically distinct isolates of native species into new areas should always be considered carefully, because introduced species or isolates may cause unintended consequences in their new distribution range. There are no documented examples yet of damage caused by the intended or unintended introduction of mycorrhizal fungi anywhere. However, there are examples of both mycorrhizal species and saprophytic fungi that have become established and are spreading in new environments.

Introduced species can become problematic if they successfully establish, persist, and spread in a new environment (Hart et al., 2017). Most experiments with mycorrhizal fungi have been carried out in closed greenhouse systems and have limited applicability to field conditions. The few field trials that have been made provide mostly inconclusive results regarding the long-term persistence of the tested species. However, some studies have shown that mycorrhizal species may impact their host plants (Akyol et al., 2019), and persist in and improve damaged or disturbed soils (Maltz et al., 2019).

Mycorrhizal fungi must compete with other fungi in the soil for access to the plants' fine roots. In addition, many other members of the diverse soil microbial community will interact or compete with an inoculated mycorrhizal species such as *G. iranicum*. This competitive environment may reduce the likelihood of successful establishment of mycorrhizal species. On the other hand, generalist mycorrhizal species can form a symbiosis with several plant species. This may increase the probability that these fungi will survive and persist in the soil but does not guarantee successful establishment. In addition, other conditions such as temperature, humidity, and pH in the soil will influence the establishment of mycorrhizal fungi. Most of the available documentation on attempts to use mycorrhizal fungi to improve plant growth in the field shows variable inoculation success with low long-term persistence.

Successful use of a mycorrhizal product containing *G. iranicum* var. *tenuihypharum* presupposes that the fungus colonizes plant roots and forms mycorrhiza. Hence, if the product delivers as promised, it seems reasonable to assume that the fungus can become established in Norway. This should at least be true inside greenhouses and in pots that are kept at temperatures close to those prevailing in southern Europe. Survival and establishment in soil outdoors is also likely during the growth season. However, it is more uncertain if the fungus can survive Norwegian winters, but it should be noted that *D. iranica* has been isolated from wheat in Canada (Dai et al., 2014). Even if we assume that soil conditions and inoculation methods will favor the establishment of *G. iranicum* var. *tenuihypharum*, this will probably not translate into long-term persistence in outdoor environments in Norway.

Some introduced species do not remain in the area or on the hosts where they were initially introduced but spread to surrounding areas or colonize other hosts. Such spread can have unintended consequences if, for example, introduced mycorrhizal species compete with or replace local species in the soil microbial community (Engelmoer et al., 2014; Tiunov & Scheu, 2005). Introduced mycorrhizal fungi could also facilitate spread of their host plants into the natural environment, or they could form new symbiotic relationships with local plants and increase or decrease their fitness (Akyol et al., 2019). In general, AM fungi are thought to have a limited ability to spread locally since they do not form aboveground fruitbodies, unlike ectomycorrhizal fungi. However, AM fungi may be spread by animals (including birds), water or movement of soil. Spread of *G. iranicum* var. *tenuihypharum* would probably mostly occur locally via vegetative growth in the soil. Some spread over longer distances could occur by movement of colonized plants or soil with spores or other fungal propagules.

According to the company marketing the product, its recommended target plants are agricultural and horticultural crops such as potato, strawberry, carrots, different kinds of lettuce, beans, peppers, melon, onions, peas, leek, celery, and several other crop species. The list of recommended crop species is much longer than the number of plants on which the fungus has been tested (Table 1). Some recommended crops are produced in greenhouses, but several are grown in fields outside. The company does not recommend the product for use with trees or bushes in the wider environment.

4 Potential negative impacts

Fungal species that are used in mycorrhizal products are often host generalists that produce copious amounts of spores in culture. The very same characteristics that make them useful as commercial bio-stimulants may also give them the potential to become invasive (Thomsen & Hart, 2018). For example, a generalist mycorrhizal fungus that can form symbiosis with many different crop plants can also be expected to form associations with many different plant species in natural environments. In the case of *G. iranicum* var. *tenuihypharum,* the limited available evidence indicates that the fungus is associated with a single plant species in nature and under very specific (hypersaline) conditions. This does not suggest that the fungus is a generalist AM fungus with a large host and environmental range, even if it has been tested on other plant species and in various soil types. However, the limited information on the fungus does not preclude that the *tenuihypharum* variety may be a generalist.

There are few documented examples of negative effects of imported mycorrhizal fungi on local biodiversity. However, this may partly be because there are few studies and little data on this topic. Adverse impacts of introduced mycorrhizal fungi on local biodiversity could theoretically include undesirable direct consequences for host plants in managed systems, direct and indirect negative consequences for biodiversity, and negative consequences for ecosystem function (Schwartz et al., 2006).

Inoculated AM fungi have the potential to outcompete native AM fungi (Engelmoer et al., 2014; Janouskova et al., 2017; Tiunov & Scheu, 2005). One potential hazard associated with the introduction of AM fungi could thus be loss of genetic diversity and locally adapted genotypes. Another potential negative effect might be that mycorrhizal fungi improve the ability of crop species or closely related wild species to spread and establish in areas where they would not normally grow.

The total microbial diversity in soil is usually very high, and the introduction of a few extra non-pathogenic species into such complex systems is not likely to make much of a difference. For example, a single plant species can have symbiotic relationships with tens (or hundreds) of mycorrhizal fungi at the same time, and different mycorrhizal species appear to have overlapping ecological roles and to largely fulfill the same ecosystem functions. So, even if one host plant recruits a new AM fungus, this will probably not have severe effects on ecosystem functions. Provided that the introduced fungus is not extremely competitive and aggressively replaces native fungi, we generally expect introduced AM species to have no or small consequences for native species, habitats, and ecosystems.

The potential impacts of the *G. iranicum* var. *tenuihypharum* product are similar to those of the mycorrhizal products assessed by VKM previously (Thomsen et al., 2020). However, much specific information is lacking for the current product. The native range of the fungus appears to be in much warmer and drier climates than in Norway. This raises the question of whether the fungus can survive long-term outdoors in Norway. Based on the available evidence we consider it unlikely that *G. iranicum* var. *tenuihypharum* will establish in the wider environment in Norway. This conclusion comes with high uncertainty.

5 Conclusion

The potential negative impacts of the mycorrhizal product containing *Glomus iranicum* var. *tenuihypharum* appear to be similar to those of previously assessed mycorrhizal products containing AM fungi (Thomsen et al., 2020). The amount of literature and information about the uses and effects of *G. iranicum* var. *tenuihypharum* is very limited and mainly concerns studies in southern Europe. There are no indications that the fungus would have significant negative consequences for biodiversity if it was introduced into Norway. However, these conclusions come with high uncertainty due to the general lack of pertinent information. At present, we consider the available data on this species to be insufficient to carry out a full risk assessment.

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