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A Necessity to Specify the Species and Geographical Indication Tag of *Trichoderma*, a Biocontrol Agent for Soil Borne Plant Pathogens, on Commercial Packets of the Product

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Abstract

Research on *Trichoderma* species for its in vitro efficacy against soil borne fungal plant pathogens have been widely published for more than half a century and in vivo efficacy has also been reported for several species and their strains in their geographical locations of prevalence. However, the efficacy of a particular strain or an isolate of a species across the geographical location is not yet fully explored. This is the reason, why biocontrol agent *Trichoderma* has not yet achieved its impact in the agricultural production system as compared to commercial synthetic fungicides for control of plant pathogens. The available literature indicated that several environmental factors, soil ecology and geographical location specificity plays an important role in the efficacy of *Trichoderma* as biocontrol agent in the control of soil borne plant pathogens. Nevertheless, commercial formulation product of different *Trichoderma* species or unknown species are available as biocontrol agent of plant pathogens around the world, notably to be used in the organic farming system. Though different *Trichoderma* species are registered for their bio-formulation products in different countries, seldomly the name of a species of *Trichoderma* and its geographical indication tag are mentioned on the packet of commercial formulation. The geographical indication tag is available for the crop plant varieties/cvs, but not for *Trichoderma* species and strains; the crop varieties are recommended specifically for the particular geographical region or state or for whole the country based on the research trials, but this phenomenon is not in operation for release and recommendation of biocontrol agent. The *Trichoderma* species in the commercial formulation may be geographical specific for their biocontrol efficacy as evident in our research. Therefore, In the free trading era and movement of products across the regions, it becomes difficult to know that in the commercial formulation which species of *Trichoderma* is used as a biocontrol agent, its geographical indication tag and for which geographical area the biocontrol agent is recommended to work efficiently. Some species of *Trichoderma* are specific and effective for the control of certain soil borne fungal and nematode plant pathogens while other species are not effective for the same. Therefore, it seems to be important to specify the species of *Trichoderma* and its geographical indication tag on packet of commercial formulation product and the recommended geographical region for its biocontrol efficacy so as to derive the maximum advantage of the biocontrol product and the research carried out in this field.

Keywords: Biocontrol Agent; *Trichoderma*; Commercial Product; Efficacy; Geographical Indication Tag

Introduction

The fungus *Trichoderma* and its species are well known and documented biocontrol agent of soil borne fungal and nematode plant pathogens around the world [1-4]. Different species of *Trichoderma* are distributed in different ecological soil system as soil inhabitant as well as epiphytic fungus [5-7]. The genus *Trichoderma* has 104 species registered internationally [8], two dozen of which are known as biocontrol agent [9] for soil borne fungal disease pathogens. However, these species are specific in their efficacy against the disease pathogen [10,11]. Further, strain variation in the species may exist which affect the biocontrol efficacy [12]. The geographical indication of the species or strain is also an important issue in the bio-efficacy of the strain, which is not discussed earlier. Geographical indication tag is given to the land races of the crop plant species which is specific for that area and perform better in that geographical location [13,14]. Similarly, the crop varieties are release and recommended for a particular geographical area, or a state or for whole the country based on its research trials across the regions. However, for the biocontrol agent *Trichoderma,* no such issue of geographical indication tag or a release and recommendation for a geographical region or state or for entire country is yet discussed and made operational. In the present paper, the issue of specifying the species of *Trichoderma* and its geographical indication tag on the packet of commercial formulation product and the geographical area of its utilization as biocontrol agent to obtain the better results of bio-control is analysed and discussed, in the light of our own research finding, for their necessity in the larger interest of farmers and plant disease management.

Case Study

Weindling [15] demonstrated for the first time the importance of *Trichoderma* as bio-agent for other fungi. The fungus *Trichoderma* and its species have gained immense importance since last few decades due to its biocontrol ability against several plant pathogens [16,17,6] and different authors reported different species of *Trichoderma* as effective bio-agent for control of many soil borne fungi (Table 1) and the diseases caused by them.

***Trichoderma* species**	**Effective against pathogen**	**References**
T. atroviride	*Rhizoctonia solani, Pythium ultimatum.*	Brunner [18]
	Esca disease pathogen: *Armillaria mellea and A. gallica, Phaeomoniella chlamydospora, Phaeoacremonium aleophilum, Fomitiporia mediterrance.*	Savazzini [19]
T. citrinoviride	*Botrytis cinerea, Cylindrocarpon*	Park and Bue [22]
T. flavofuscum	*Pythium sp*	Patil [23]
T. hamatum	*Rhizoctonia and Pythium*	Chung & Hoitink [24]
	Fusarium.o.sp.lentis	El-Hassan [25]
	Sclerotium rolfsii.	Borkar [26]
T. koningii	*Sclerotinia sclerotiarum.Fusarium oxysporium, F. solani, Alternaria solani, Rhizoctonia solani.*	Trutmann [27]
	Pythium sp.	Shaikh & Sahera [28]
	Fusarium solani and Fusarium oxysporium.	Hadar [29] Karampour & Okhowat [30]
T. longibrachiatum	*Heterodera avenae.*	Zhang [31]
	Meloidogyne incognita.	Zhang & Xu [10]
	M. javanica.	Sokhandani [4]
	Scutellonema sp, Helicotylenchus sp.	Chanu [32]
	Rhizoctonia solani, Sclerotium rolfsii.	Sreenivasaprasad & Sreenivasaprasad [33]
T. pululiferum	No data available	
T. Polysporum	*Fusarium.o.ciceris.*	Moutassem [11]
T. pseudokoningii	*F. oxysporium, S. rolfsii.*	Cuevas [34]
	Pyricularia oryzae.	Khanzada & Shah [35]
	Fusarium wilt.	Cong [36]
	Alternaria alternata.	Thakur & Harsh [37]
T. lignorum	*No data available*	

T. aureoviride	*Fusarium oxysporium.*	Clavet [38]
T. viren	*Macrophomina phaseolina.*	Maheshwari [39]
	Rhizoctonia solani.	Kumar [40]
	Pseudomonas syringae.	Salas-Marina [41]
T. viride	*Microphomina phaseolina.*	Kehri & Chandra [42]
	Fusarium.o.sp.adzuki.	Manjunatha [43]
	Fusarium oxysporium.	John [44]
		Morshed [45]
		Osman [46]
		Sesan [1]
	Pythium debaryanum, Rhizoctonia solani, Fusarium spp.	Singh & Drivedi [47]
	Sclerotium rolfsii. Fusarium oxysporium.	Dhedi [48] Shahida [49]Kharampour & Okhowat [30]
	Fusarium solani.	Madne [50]
	Fusarium oxysporium.	Somashekhar [12]
	Fusarium udum (isolate H).	Prasad & Rangeswaran, [51] Kharakrang [52]
	Sclerotium rolfsii.	Prasad [53]
	R. solani.	Sharma [54]
	F.o.f.sp.ciceri.	Kapoor [2]
	F.o.f.sp.lini. Sclerotium rolfsii.	Ahamed & Vermette,
T. harzianum	*Phytophthora capsici.*	Mastouri
	Pythium ultimatum.	Ferrigo
	F. verticillioides, Botrytis cinera.	Kharakrang [52]
	Rhizoctonia solani.	Prasad [53]
	F.o.f.sp.ciceri.	Jayalaxmi
	F. udum.	Mayur & Deshmukh,
	Chickpea wilt.	Sharma [54]
	F.o.f.sp.lini.	Kapoor [2]
	R. solani, Pythium debaryanum, Sclerotinia minor, F. oxysporium.	Chet [55] Venkatasubbaiah [56]
	F. oxysporium, R. solani, Sclerotium rolfsii. Rhizoctonia solani.	Singh & Dwivedi [47]
	Sclerotium rolfsii.	Clavet [38] Dhedi [48] Datnoff [57] Madne [50] Karampour & Okhowat [30] Siddiqui & Mahmood [58]
	Fusarium oxysporium.	
	Fusarium udum.	Bourbos [59]
	F.o.f.sp.radicis.	Larkin & Fravel [60]
	Fusarium wilt of tomato.	Hazarika [61]
	Pythium aphanidermatum.	Prasad & Rangeswaran [51]
	Sclerotium rolfsii.	Haggag & El-Gamat [3]

T. harzianum + T.viride	*Fusarium solani, F.o.sp.ciceri, F.o.sp.radicis, R. solani.*	Haggag & El-Gamat [3] Kumar [62]
T. harzianum + T. viren	*Rhizoctonia solani.*	Kumar [62] Dubey [63]
T. harzianum+ T. viride + T. veren	*Rhizoctonia bataticola.*	Dubey [63] Shoresh [64]
T. asperellum	*Pseudomonas syringae.*	
T. parceanamosum	Data not available	

Table 1: Efficacy of *Trichoderma* species against Soil borne Plant Pathogenic Fungi and nematodes.

These species of *Trichoderma* varies not only from region to region or states to states but also from soil to soil and the substrate on which it grows [5,7,65] as evident for its distribution in India (table.2) and around the globe.

SR. No	*Trichoderma* species	State/Soils/substrate
1.	*T. atroviride*	Himalayan soils
2.	*T. citrinoviride*	Forest soils of Andhra Pradesh
3.	*T. Flavofuscum*	Rhizosphere of Oak trees in Uttaranchal
4.	*T. hamatum*	Soils of New Delhi, Southern India, and Tamil Nadu
5.	*T. harzianum*	Soils of Karnataka, Maharashtra
6.	*T. Koningii*	Soils of New Delhi, Himachal Pradesh, Jammu, Punjab, Madhya Pradesh, Chhattisgarh, Uttar Pradesh, Orissa, Assam, Meghalaya,
7.	*T. longibrachiatum*	Soils of Madhya Pradesh, Tamil Nadu, on sugarcane bagasse.
8.	*T. piluliferum*	Soils of New Delhi and South India
9.	*T. polusporum*	Soils of Kashmir
10.	*T. pseudokoningii*	Soils of Punjab and Pantnagar in Uttar Pradesh, from decomposing paddy in Kurukshetra in Haryana and on Cattle feed in Uttar Pradesh
11.	*T. viride*	Soils of Tamil Nadu, Karnataka, Andhra Pradesh, Bihar, Rajasthan, Maharashtra. Grassy soils of Varanasi, Rhizosphere of pigeon pea in central and southern states and rhizosphere of sugarcane in Maharashtra.
12.	*T. lignorum*	Soils of West Bengal, Uttar Pradesh, Assam
13.	*T. virens*	Soils of poultry farm in Jammu, Himachal Pradesh, coconut garden soils of Kerala.

Table 2: Distribution of *Trichoderma* species in Indian soils.

Thus it is evident that different geographical region within the country is dominated by certain species of *Trichoderma*. One region may be dominated by one species while other region may have different species indicating the biodiversity in the species of *Trichoderma* across the geographical region. *T. viride* was most common, followed by *T. koningii, T.harzianum* and *T. hamatum* across the Indian states.

Ma [66] reported biodiversity of *Trichoderma* from grassland and forest ecosystem in northern China. *T. harzianum* was the dominant species with 28.2% from all isolates. The principal components analysis indicated that ecosystem was the most dominant impact factor for the species diversity of *Trichoderma sp* with decreasing trend from the north to south of northern Xinjiang. Overall, *Trichoderma spp* were more frequently encountered in forest ecosystem than in grassland ecosystem.

Muniappan and Muthukumar [67] reported the influence of crop species and edaphic factor on the distribution and abundance of *Trichoderma* in alfisol of Sourth India where the population densities of two *Trichoderma* species i.e. *T.*

koningii and *T. viride* varied significantly with crop species and their abundance. The soil pH negatively influenced relative abundance of *T. koningii* whereas soil P was positively correlated with *T. viride*. Further, relative abundance of *T. koningii* was significantly and positively correlated to relative abundance of *Aspergillus fumigatus.* Recently Borkar [26] reported *Aspergillus niger* as null hyper-parasite on *Trichoderma hamatum* which restrict the growth and biocontrol activity of the *Trichoderma sp* as bio-agent. Thus besides the soil environmental and ecological factors, the presence of null hyper-parasite in the soil also affect the sustenance and biocontrol efficacy of the *Trichoderma* as bio-agent.

Al-Ani [68] reported that the environment conditions which affect *Trichoderma* growth, bioactivity and antagonism as biocontrol agent varies with the strains of *Trichoderma*. These major factors include temp, pH, nutrient substrate while minor factor includes light and humidity. The temp parameter alters the *Trichoderma*'s life phase and bioactivity. These parameters are very important in determining the efficacy of *Trichoderma* for use in controlling plant pathogens. Kredics [69] also reported the influence of environmental parameter on *Trichoderma* strains with biocontrol potentials. A series of abiotic environmental parameters including pesticides and metal ions in soil and biotic factors like presence of hyper-parasite of *Trichoderma* in the soil influence the biocontrol efficacy of *Trichoderma*. These results clearly indicate that a *Trichoderma* strain isolated and commercialized from a particular location may not prove effective in another geographical area having different soil ecological and environmental condition. Therefore, it seems to be important to have a geographical indication tag for the isolated and commercialized *Trichoderma* strain. This will clearly indicate the geographical location of its origin and its probable area of application wherein the same environment is present so that the *Trichoderma* strain may express to its fullest potential of biocontrol activity as every genetic system has effect of gene x environment interaction to express its activities [70,71]. Due to this fact only certain crop varieties and cultivars have geographical indication tag [72,73] where these express better for their yield or other beneficial characteristics.

Different species of *Trichoderma* are commercialized as biocontrol product. These may be used as a single species in biocontrol formulation or more than one species may be used in the formulation. Generally, four commercialized formulation of a single species and four commercialized formulations of more than one species are available in the market around the world (Table 3).

SR. No	*Trichoderma* species used in Bio-agent product	Country of Registration
1.	*T. asperellum*	Japan, **Brazil**, **Kenya**
2.	*T. harzianum*	**Colombia**, Australia, New Zealand, South Africa, **Kenya**, Zambia, Morocco, Tunisia, **India**, **Brazil**, Czech Republic, Ecuador, Panama, Peru, Chile, EU
3.	*T. koningii, T. harzianum* (2)	Germany, Kenya
4.	*T. koningii, T. harzianum, T. viride* (3)	**Colombia**
5.	*T. harzianum, T.viren* (2)*T. harzianum, T.viren, T.parceanamosum* (3)	Chile
6.	*T.viren*	USA
7.	*T. viride*	EU, **India**
8.	*T. viride, T.lignorum* (2)	Ukraine
9.	*Trichoderma spp*	USA, China, South Africa, Honduras, Columbia, Australia

Table 3: *Trichoderma spp* based products registered in different countries.
Source: Sajjad Hyder [9]

The market of the *Trichoderma* as biocontrol agent varies around the world. Woo [74] reported the largest distribution of *Trichoderma* bio-products in Asia, succeeded by Europe, South-Central America and North America. They further reported that the majority of the labels indicated fungicidal properties, but only 38% of the marketed merchandise are registered. Ten *Trichoderma* species are specifically indicated but many labels indicate a generic *Trichoderma sp* or *spp* mixed with list of ingredients. The 62 % un-registered products in the market (Table 4) where the genesis of the product is doubtful, makes the biocontrol technology more ambiquitous. Further where the label is not available on the *Trichoderma* product, render them worthless in its application as biocontrol agent (Figure 1).

Region	Countries	Commercial product	Registered product	% Unregistered product
Africa	South Africa, Kenya, Zambia, Morocco, Tunisia	9	9	0.0
Asia	China, India, Indonesia, Japan, Korea, Russia, Vietnam, Philippines	100	8	92.0
Europe	BE, CZ, DK, EE, ES, FI, FR, HU, IE, IT, NL, SE, SI, UK, Moldavia, Ukraine, Israel	57	21	63.15
North America	USA, Canada	29	19	34.48
Pacific	Australia, New Zealand	22	10	54.54
South Central America	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, Honduras, Mexico, Panama, Peru, Uruguay, Venezuela	40	22	45.0
Multiple region	Ca. 17	16	15	6.25
Total		273 %	104 38	

Table 4: Distribution of *Trichoderma spp* based bio-product available in worldwide market.
Source: Sajjad Hyder [9].

Figure 1: A marketed product of *Trichoderma* where the name of species and label is not mentioned.
Source: Commercial market and in public domain on internet for sale promo.

Sometimes the label mentioned on the product may not hold good if the formulated strain is used in different geographical areas for its biocontrol activity. This may be due to the environmental factors as well as the different strain of the pathogen available in the region for which it was not tested. For example, though the *Trichoderma harzianum* species is reported to be effective biocontrol agent against Sclerotium rolfsii pathogen by Venkatasubbaiah [56], Singh and Drivedi [47], and Prasad and Rangeswaran [51] whereas the *Trichoderma viride* species is reported to be effective against the same pathogen *S. rolfsii* by Singh and Drivedi [47], Prasad and Rangeswaran [51], and Kappor [2], in our experimentation both these species having geographical tag of our region failed to colonies the *S.rolfsii* pathogen and was ineffective as biocontrol agent for *S. rolfsii* indicating the importance of the geographical tag for the trichoderma formulation. In our experiment the *Trichoderm hamatum* species was found to be effective biocontrol agent against the *S. rolfsii* pathogen (Table 5) rather than *T.harzianum* or *T.viride.*

SR. No.	Intercacting microbes	Interaction Results
1.	*S. rolfsii + T. hamatum*	*T. hamatum* controlled *S. rolfsii* effectively. It could not allow *S.rolfsii* to grow and the whole space was covered with *T.hamatum*
2.	*S. rolfsii + T. longiferum*	*T.longiferum* not effective in control of *S.rolfsii. S.rolfsii* grew in the available space
3.	*S. rolfsii + T. viride*	*T. viride* not effectivre in control of *S.rolfsii. S.rolfsii* grew in available space
4.	*S. rolfsii + T. harzianum*	*T. harzianum* not effective incontrol of *S.rolfsii. S.rolfsii* grew in available space

Table 5: Efficacy of different *Trichoderma* species on groundnut foot rot pathogen *S. rolfsii* under in vitro experimentation.

These results clearly indicate that the inscription of *Trichoderma* species and the geographical tag of the biocontrol agent on the commercial formulation product is necessary to achieving the better results in the biocontrol technology [75].

Conclusion

The biocontrol agent *Trichoderma* has not yet achieved its impact in the agricultural production system in the biological management of plant diseases as compared to commercial synthetic fungicides. The available literature indicated that several environmental factors, soil ecology and geographical location specificity plays an important role in the efficacy of *Trichoderma* as biocontrol agent in the control of soil borne plant pathogens. Nevertheless, commercial formulation product of different *Trichoderma* species or combination of species are available as biocontrol agent for control of plant pathogens around the world and many of these products are unregistered doubting their worthiness in the biocontrol of plant pathogens. Though different *Trichoderma* species are registered for their bio-formulation products in different countries, seldomly the name of a species of *Trichoderma* and its geographical indication tag are mentioned on the commercial formulation packets. The *Trichoderma* species in the commercial formulation may be geographical specific for their biocontrol efficacy against a particular race or strain of the targeted pathogen. Therefore, it seems to be important to specify the species of *Trichoderma* and its geographical indicator tag on packet of commercial formulation product and the recommended geographical region for its biocontrol efficacy so as to derive the maximum advantage of the biocontrol product.

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