العنوان:	Fungal Diversity and the Occurrence of Antagonistic Fungi in Organic and Conventional Farming Systems in Oman
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1. Introduction

Oman is situated at an arid region in the eastern part of the Arabian Peninsula and in summer, the temperature can rise up to 50 °C. Most farms in Oman use traditional methods (conventional) to promote biodiversity by cultivating several crops in the same field. The majority of farms in the northern part of the country grow date palms and citrus (mainly acid lime). In addition, vegetable crops such as tomatoes and cucumbers are cultivated almost all over the country (Al-Sadi et al., 2013; Kazeeroni and Al-Sadi, 2016). Tomato is considered the top vegetable crop in terms of production, with an annual production of 111,000 tons in 2016. Cucumbers are also produced widely in the country, with an annual production of 28,000 tons (FAO, 2017). Tomatoes are usually produced in open fields, while cucumber production is mainly in greenhouses (Al-Sadi et al., 2013; Al-Sadi et al., 2014; Al-Sadi et al., 2015a; Al-Sadi et al., 2015c).

Animal manures are commonly used in farms in Oman, especially for date palms and citrus (Al-Sadi et al., 2011a; Al-Azizi et al., 2013; Al-Sadi et al., 2015b). However, potting media, composts and several organic and inorganic fertilizers are introduced and used for vegetable crops, mainly cucumbers and tomatoes (Al-Mazroui and Al-Sadi, 2015). In addition, the infection of cucumbers by pathogenic fungi necessitates frequent applications of systemic and contact fungicides (Al-Sadi, 2012; Al-Sadi et al., 2012a; Al-Sadi et al., 2015a). On the other hand, there is a shift towards organic farming in some farms in the country, but the growth rate of this sector is very slow.

Soil is a precious and complex natural resource that represents a huge reservoir of biodiversity with several billion prokaryotic and eukaryotic microorganisms (Abed et al., 2013; Al-Sadi et al., 2015c; Thomson et al., 2015; Kazeeroni and Al-Sadi, 2016; Wang et al., 2017). These microbes significantly share biomass and ecosystem functions in both natural and managed agricultural soils (Sidorenko et al., 1978). Intensive agricultural production system degrades soil quality and function and over the time causes a decline in crop yields which endanger food security and production (Eldridge et al., 2014). Fungi are the most dominant eukaryotic species in terms of biomass in soil. Fungi play important roles as decomposers, nutrient cyclers, soil aggregators, pathogens and mycorrhizal symbionts (Guo et al., 2015; Thomson et al., 2015; Stott and Taylor, 2016).

Changes in land use and agricultural practices have resulted in reduction in soil quality, fertility and productivity (Cherubin et al., 2015; Price et al., 2015). The productivity and health of soils rely to some extent on the processes of soil microbial communities (Guo et al., 2015; Heilmann-Clausen et al., 2015; Stott and Taylor, 2016). Excessive use of inorganic fertilizers and pesticides can affect soil microbial populations and result in reduction of microbial diversity or changes in microbial communities (Esmaeili Taheri et al., 2015; Filimon et al., 2015; Pose-Juan et al., 2015; Rangel et al., 2015). Microbial abundance, diversity and activity largely have implications on sustainable productivity of agricultural land and production systems. Information on the microbial communities associated with rhizospheres and their complex interrelationship is essential in the selection of sustainable crop rotations and management practices (Lenc et al., 2015; Chen et al., 2017).

Detection and quantification of fungi in soil is very important. Several methods can be used for the estimation of fungal diversity in soils. Most studies in the past focused on the use of direct culture of microorganisms (Al-Sadi et al., 2015b; Thomson et al., 2015; Kazeeroni and Al-Sadi, 2016). With the advent of next generation sequencing technologies, 454 pyrosequencing has been used for assessing fungal diversity in some studies (Esmaeili Taheri et al., 2015; Kazeeroni and Al-Sadi, 2016). It helped uncover the presence of several fungal populations, including many of the taxa that are not cultivable on synthetic media. In addition, the method helps quantify the presence of each fungal taxa.

Previous studies have shown that the population size and structure of soil flora and fauna can be affected by several factors, including the cultivation techniques, plant species, and the application of organic and inorganic fertilizers and pesticides (DeAngelis et al., 2015; Matsushita et al., 2015; Tardy et al., 2015; Van Geel et al., 2015; Coleman-Derr et al., 2016). However, little information is available concerning the effect of cultivation systems on fungal diversity in this part of the world. Information is lacking concerning the level of fungal diversity in organic farms and conventional farms in Oman.

Tomatoes and cucumbers face several challenges, with damping-off and vine decline diseases being two of the most limiting diseases, especially to cucumbers. Losses due to these diseases can reach as high as 75% of cucumber seedlings, especially because of damping-off (Al-Sadi et al., 2011c). The diseases are caused by several fungal species, the most important of which are *Pythium* and *Rhizoctonia* species. In Oman, *Pythium aphanidermatum*, *P. spinosum* and *R. solani* are the common fungal pathogens causing damping-off disease, while *Pythium* spp., *Rhizoctonia solani*, *Monosporascus* spp. and *Fusarium solani* are associated with vine decline (Al-Sadi et al., 2011c).

Management of damping-off can be attained by using a number of methods. Mefenoxam fungicide has been proven to be an effective fungicide for Pythium damping-off (Moorman and Kim, 2004; Al-Sadi et al., 2012a). Crop rotation with a non-host plant or field sanitation can be considered as alternative methods for controlling *Pythium* populations (Davis and Nunez, 1999). Although applying chemicals may help and give some degree of control, their side effects on humans and the environment are detrimental. The use of biocontrol agents is a safe alternative to the use of chemicals. Several biocontrol agents have been found effective in managing damping-off disease of cucumber. These include the use of *Trichoderma harzianum*, *Pythium oligandrum* and *Pseudomonas aeruginosa* (Al-Rawahi and Hancock, 1998; Punja and Yip, 2003; Al-Hinai et al., 2010; Blaya et al., 2013; Yu et al., 2014).

The isolation and identification of antagonistic microorganisms as potential and suppressive biocontrol strains from different sources such as soil and plant is becoming more popular (Huang et al., 2016; Siala et al., 2016; Raza et al., 2017). Biocontrol agents may suppress diseases in various ways. Their mode of action may involve the production of antimicrobial compounds, release of plant growth promoting compounds, induction of defense mechanisms in plants, and nutrient competition with pathogens (Ting et al., 2014; Arroyave-Toro et al., 2017; Collazo et al., 2017; Culebro-Ricaldi et al., 2017; Zhang et al., 2017). In Oman, little is known whether fungi present in the rhizosphere of crops could be used as potential biocontrol agents against major soil borne pathogens.

This study was conducted to investigate fungal diversity in rhizosphere soils from conventional and organic farms in Oman and to isolate potential antagonistic fungal species.

The study objectives to:

1- Compare the efficacy of direct plating and pyrosequencing in estimating fungal diversity in soil.
2- Investigate the level of fungal diversity in conventional vs organic farming systems growing cucumbers and tomatoes.
3- Investigate the potential presence of antagonistic fungal species in the rhizosphere of cucumbers and tomatoes that can be used for the management of damping-off disease caused by *Pythium* and *Rhizoctonia*.

Microbial abundance, diversity and activity largely have implications on sustainable productivity of agricultural land and production systems. Information on the microbial communities associated with rhizospheres and their complex interrelationship is essential in the selection of sustainable crop rotations and management practices (Lenc et al., 2015; Chen et al., 2017). Improving soil quality can be considered as potential way for improving food security and production.