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REVIEW PAPER

Application of *Ampellomyces quisqualis* and some Non-Chemical Measures for Managing Powdery Mildew Disease: A Review

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ABSTRACT

Powdery mildew is one of the economically important diseases. It causes huge crop losses by adversely affecting quantity as well as quality of several cereals, pulses, vegetable, ornamental, fruit crops. There are certain genera of fungal domain namely species of *Erysiphe*, *Microsphaera*, *Phyllactinia*, *Podosphaera*, *Sphaerotheca*, *Uncinula* etc. The disease primarily infects the aerial plant parts and poses a negative impact on physiological activities. It can effectively be managed through the application of antagonists especially *Ampellomyces quisqualis* and some other means of on non-chemical nature like milk, natural sulfur, potassium bicarbonate, sodium bicarbonate, metal salts, oils, neem oil, sesame oil, compost tea, and involvement of genes in disease resistance event. This review paper limelight in a precise way the various aspects related to the pathogenic and its antagonist fungi. It deals with updated information of powdery mildew genera with peculiar characteristics. History, biology, infection mechanism, life cycle, ecology, host spectrum, and occurrence of *A. quisqualis* is mentioned in detail.

HIGHLIGHTS

- Powdery mildew disease of various crops is of great importance due to causing crop losses, under organic/natural crop production system it can be managed through *A. quisqualis*, which is natural fungus that has no issues alike synthesis fungicides. Hence, it could be a safer alternate to handle this disease.

Keywords: Powdery mildew, *Ampellomyces quisqualis*, host spectrum, mode of action, ecology, non-chemical measures

Among plant diseases, powdery mildew is of global importance in terms of crop losses. Fungal phytopathogens are responsible for this disease in different crops and are mainly categorized under the genera of *Erysiphe*, *Microsphaera*, *Phyllactinia*, *Podosphaera*, *Sphaerotheca*, and *Uncinula*. This disease mainly targets wheat, barley, apple, vegetables, ornamentals, and weeds. Many resistant and

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or tolerant varieties of fruits and vegetables are available globally (Bélanger and Benyagoub 1997); although tomato and some other crops are exclusively susceptible to it (Kiss *et al.* 2001). Owing to the appearance of powdery growth of pathogen on various plant parts such as leaves, buds, shoots, fruits, and flowers, the name is given so. The number of ascus in the fruiting body (cleistothecium) and the pattern of mycelial appendages are the key features of the classification of genera responsible for the powdery mildew disease.

Powdery mildew fungal phytopathogens are obligate parasites and have a very narrow host range. High humidity is favorable for infection, nevertheless, free water is unfavorable (Huang *et al.* 2000).

Powdery mildew fungi on plant surfaces grow superficially, or epiphytically. Some of them produced hyphae on upper as well as lower leaf surfaces, although some were confined to one leaf surface only. Most of the genera produce epiphytic mycelia, however, some produce endophytic mycelia and with the help of the haustoria, they derived nutrition from plant epidermal cells.

Epiphytic and endophytic hyphae produce conidiophores. Endophytic hyphae give rise to conidiophores through leaf stomata. The conidiophores produce asexual spores (conidia) either singly or in chains. During cropping season such conidia are produced on plant surfaces as well. *E. alphitoides* was reported to infect *Euonymus japonica*, an evergreen shrub in Seoul and the Gwangju region of Korea (Lee and Nguyen 2017).

Systemic position of powdery mildew fungi

The powdery mildew fungi can systematically have positioned as Domain: Eukaryota, Kingdom: Fungi, Division: Ascomycota, Class: Leotiomycetes, Order: Erysiphales, Family: Erysiphaceae.

There are 26 genera of this pathogen viz., *Arthrocladiella, Blumeria, Brasiliomyces, Bulbomicroidium, Caespitotheca, Cystotheca, Erysiphe, Euoidium, Fibroidium, Golovinomyces, Leveillula, Microidium, Microsphaera, Neoerysiphe, Oidium, Ovulariopsis, Parauncinula, Phyllactinia, Pleochaeta, Podosphaera, Pseudoidium, Sawadaea, Setoidium, Sphaerotheca, Striatoidium* and *Uncinula.* It possesses a hundred species and six evolutionary lineages/clade (Table 1).

Characteristics of order Erysiphales

It has superficial mycelia which derives nourishment from the host plant through haustoria that penetrate the epidermal cells of the host. Usually, the teleomorphs are more distinctive and diverse than the anamorphs. Asci may be unitunicate or bitunicate. Asci are arranged in a hymenial layer in the cleistothecial. The cleistothecia (chasmothecia) are minute and its outer wall produces the appendages. The number of asci in cleistothecia varies in different genera.

The life cycle of powdery mildew fungi

Both asexual, as well as sexual spores of powdery mildew fungi, can infect the host plants. Asexual spores form on short and erect conidiophores which develop on external mycelia. The conidia are barrel-shaped and the youngest remains at the base in the chain. Fully matured spores get detached then dispersed by wind current and initiate fresh infection. The cleistothecia are produced during autumn, during winter the ascospores remain dormant, and then in spring, they germinate. Due to the expansion of asci, cleistothecial wall gets ruptured and ascospores are liberated in the air

Table 1: Evolutionary lineages/clade of powdery mildew fungal pathogen

Clade	Representative genera	Mitosporic state
1	*Erysiphe*, *Microsphaera*, *Uncinulla*	*Oidium* subgenus *Pseudoidium*
2	*Erysiphe galeopsidis*, *E. cumminsiana*	*Oidium* subgenus *Striatoidium*
3	Erysiphe species	*Oidium* subgenus *Reticuloidium*
4	*Leveillula* and *Phyllactinia*	*Oidiopsis* and *Ovulariopsis*
5	*Sphaerotheca*, *Podosphaera*, *Cystotheca*	*Oidium* subgenera *Fibroidium* and *Setoidium*
6	*Blumeria graminis*	*Oidium* subgenus *Oidium*

to re-infect host plants. Brazilian verbena (*Verbena brasiliensis*) in the southern portion of the United States revealed symptoms of powdery mildew infection on the stems and adaxial surface of the leaves with white circular powdery colonies with high numbers of aerially dispersing spores (Luecke *et al.* 2020).

Management of the disease using *A. quisqualis* and some non-chemical means

A. quisqualis has been found as one of the promising microbial candidates for the management of powdery mildew disease of crops. Certain non-chemical means also possess the capability to manage this disease in effective ways. The first emphasis has been given on the usefulness of *A. quisqualis* against this disease followed by non-chemical means.

Ampellomyces quisqualis

Brief history, biology, and mechanism of infection

A. quisqualis isolate M-10 is a fungus that fights with powdery mildew disease of crops to manage it. Biopesticides containing spores of this fungus can be employed in greenhouses and outdoors on a variety of fruits, vegetables, and ornamental plants. When it is utilized in a scientific way it is safer for individuals and the environment (Steinwand 2003). De Bary in 1870 conducted a systemic investigation on parasitism, discovering that *Ampelomyces* may develop internally in the cells of powdery mildew fungi, where it forms pycnidia in the host fungi's hyphae or conidiophores. Its biocontrol effectiveness against pathogens was later demonstrated through foliar spraying.

In 1852, *A. quisqualis* Ces. was originally discovered as a mycoparasite on grapevine leaves. It produces asexual spores exclusively, the generic name existed as *Cicinobolus* till the 1970s (Donk 1966), after this period it was named *Ampelomyces* (Speer 1978). As compared to *Phoma* species it grows slowly and produces pycnidia in powdery mildew cells intracellularly, this feature distinguishes it from *Phoma* species.

For the first time in 1932, the biocontrol efficacy of *Ampelomyces* was demonstrated for the control of clover mildew caused by *E. polygoni* DC. *Ampelomyces* do not creates poison; instead, it invades fungal phytopathogens and rapidly degenerates the hosts' cytoplasm, followed by colonization of pathogens' mycelia and destruction of pycnidia, conidiophores, and conidia (Beuther *et al.* 1981). Both organisms indulge in biotrophic interaction at first, but following the cytoplasmic invasion, they embark on necrotrophic contact.

The sporulation of host fungi is completely ceased immediately after its entry, however, mycelial growth continues (Shishkoff and McGrath 2002). *Ampelomyces* recognize powdery mildew fungi for parasitism. The conidia of host pathogenic fungi secret a water-soluble material that encourages conidial germination of parasitic fungi (Gu and Ko 1997), the parasitic fungi may also produce germ tubes to infect its host directly. Enzymatic and mechanical processes facilitate the penetration of the host cell wall. Extracellular lytic enzymes are of great significance in hyphal cell wall degradation (Philipp 1985). The role of an Exo-beta-1,3-glucanase enzyme produced by *Ampelomyces* isolates in cell wall degradation of powdery mildew fungi has been ascertained (Rotem *et al.* 1999). Its application on diseased host plants minimized pathogen's inocula, restored plant vigor and chlorophyll content in cucumber and melon (Abo-Foul *et al.* 1996; Romero *et al.* 2003).

Numerous fungal species are the antagonist of powdery mildew fungi, nevertheless, genus *Ampelomyces* is the most potent biological control agent (BCA) for crop protection strategy (Kiss 2003). Its product formulations are being marketed in various countries around the globe (Paulitz and Bélanger 2001). The tritrophic relationship between powdery mildew phytopathogen, plant, and aerial plant parts established by *Ampelomyces* is a typical example of its sort in nature (Kiss, 1998; Kiss, 2008).

As a successful BCA, the potency of *A. quisqualis* for the first time was established for the control of powdery mildew disease of *Cucumis sativus*. This success opened the avenues for its commercialization (Hofstein and Fridlender, 1994; Hofstein *et al.* 1996) in a safer way as a plant protection measure without having any risk to human health. It could reduce the powdery mildew infection on beetroot, carrot, cucurbits, mango, mulberry, peach, pepper, red clover, rose, strawberry, *zinnia* sp., etc. (Kiss *et al.* 2004b).

A. quisqualis affects the *Mirosphaera symphoricarpi* causing powdery mildew on *Symphoricarpos albus* plants and with *Sphaerotheca more-uvae* infecting the *Ribes nigrum* plants in Poland (Czerniawska et al. 2014). *A. quisqualis* can parasitize hyphae and other forms of *P. mali, P. tridactyl* var. *tridactyla* as well as *E. cichoracearum* var. *cichoracearum* (Czerniawska 2014). *A. quisqualis* parasitized *E. sordida*, *Sphaeroteca erigerontis-canadensis*, *M. hypophylla* as well as *M. palczewskii* in north-eastern Poland.

Ampelomyces: Occurrence and the host spectrum

Globally, its association has been observed over 65 species of eight fungal genera as mentioned by earlier workers (Kiss *et al.* 2004b). It has more than 65% natural parasitism of powdery mildew fungi as compared to the artificial infection; however, it could rarely infect the mycelia of *Blumeria graminis* (DC). *Ampelomyces* spp. naturally parasitized the overwintering chasmothecia of *E. necator* in conventional, organic, and untreated vineyards of northern Italy (Angeli *et al.* 2009).

The natural parasitism by *A. quisqualis* was reported on *Golovinomyces cichoracearum* and *P. xanthii* responsible for disease development in certain cucurbits plants, for instance, *Cucumis melo*, *C. sativus*, *Cucurbita pepo*, *C. maxima*, and *Citrullus lanatus* from the Czech Republic, Austria, France, Germany, Great Britain, Italy, Slovakia, Slovenia, Spain, Switzerland, the Netherlands, as well as in Turkey and Israel (Křístková *et al.* 2009).

Co-existence of *A. quisqualis* Ces. ex Schlech with *Oidium euonymi-japonica*, a fungal phytopathogen of powdery mildew of Buxus trees, *Euonymus japonica* was found in Gorgan, the Golestan province, Iran (Naseripour *et al.* 2014).

The occurrence of *E. cichoracearum* and *Sphaerotheca fuliginea*, powdery mildew phytopathogens of cucurbit in the Czech Republic were found parasitized with *A. quisqualis* (Křístková *et al.* 2017). The inclusion of *A. quisqualis* as a component of integrated disease management strategy could efficiently control the powdery mildew of the *Euonymus japonicus* plant in Kashmir valley (Ahanger *et al.* 2018).

Trichoderma spp. are well established fungal candidates to take care of fungal phytopathogens (Woo *et al.* 2014; Kumhar *et al.* 2020). Biological control of the disease using biological agents, such as *Trichoderma* spp., *Bacillus subtilis*, *A. quisqualis,* and *Pseudomonas fluorescence* for controlling foliar pathogenic fungi was recorded by researchers (Abo-foul *et al.* 1996).

Recently, plant extract and vegetable oils, such as neem (*Azadirachta indica*), (*Reynoutria sachalinensis*), ginger (*Zingiber officinale*), garlic (*Allium sativum*), onion (*Allium cepa*), clove oil (*Syzygium aromaticum*), nigella oil (*Nigella sativa*), Olive oil (*Olea europaea*) and rapeseed oil have been used to control powdery mildew fungi (Gamal Ashor Ahmed *et al.* 1998; Liu *et al.* 2010).

The mechanism of biological control of powdery mildew fungi by *A. quisqualis* has been established as hyper-parasitism as this fungus possesses the ability to colonize the mycelium of powdery mildew and produce reproductive structures (Bharat 2011).

The oak powdery mildew disease could control through the use of sulfur SC (0.5% conc) as well as by the use of *A. quisqualis* at 70 g/ha concentration (Markovic and Rajkovic 2012).

Powdery mildew of Olive incited by *Leveillula taurica* (Lev.) Arnaud. is a challenge for new, young vegetation as well as rejuvenated trees and it could be managed by applying *A. quisqualis* Ces. Schlecht. as an organic practice (Bourbos and Barbopoulou 2006).

From 2002 to 2006, in the Czech Republic, 585 leaf samples with powdery mildew symptoms were collected from cucurbits (mainly from *Cucurbita pepo*, *Cucurbita maxima*, *Cucumis sativus*) were microscopically examined for the presence of hyperparasitic fungus *A. quisqualis* Ces. (Aq). Its distribution was recorded in 52 locations of the Czech Republic, it was not restricted to limited areas, nevertheless, most of locations originated from South Moravia. In some locations its presence was recorded repeatedly, in some others it was detected only once. The majority of samples with the presence of this antagonistic fungi were collected in August and September.

A. quisqualis, revealed high levels of extracellular exo-β-1,3-glucanase activity in culture. Its culture filtrates affected powdery mildew caused by

Sphaerotheca fusca in a manner indicative of cell wall degradation. A gene encoding an exo-β-1,3-glucanase in it, designated exgA, was isolated and sequenced. The gene was expressed during the late stages of growth in culture, and transcription was induced by fungal cell wall components (Rotem *et al.* 1999).

Favorable environmental conditions for *A. quisqualis*

Generally, it works well at higher relative humidity ranging from 90-95% (Verhaar *et al.* 1999), and hence in protected cultivation its performance was satisfactory due to accessibility of appropriate RH level or free water on the foliage. However, certain additives such as paraffin oil or mineral oil surfactant increase their efficacy under low RH levels (Hofstein *et al.* 1996). For its optimum growth as well as sporulation high pH is favorable.

Economics of control measures

The successful control of disease in the field requires frequent and repeated applications (Sztejnberg *et al.* 1989), however, it increases the cost of plant protection measures. To minimize the application cost the antagonist was cultured on cotton wicks and then during the rainy season wicks were hung up in grapevine fence to facilitate natural dispersal of BCA (Falk *et al.* 1995) but it was weather dependent. The combination of both natural occurrence, as well as simulated application of *A. quisqualis*, could delay the grapevine powdery mildew in New York (Gadoury 1988). The earlier literature (Kiss *et al.* 2004a) described that *A. quisqualis* is compatible with *Trichoderma* formulations (Elad *et al.* 1998).

The dispersal of conidia of *Ampelomyces*

Its conidia can disperse to short as well as long distances. Within the canopy, the short distance dispersal from infected plant parts to healthy ones occurs through raindrop and water run-off whereas long-distance dispersal happens through airborne conidia of mycelia fragments (Sundheim, 1982). The conidia or mycelia of the antagonist parasitize the powdery mildew fungi under humid conditions. It overwinters on many host plants in various ways (Kiss *et al.* 2004b). Its resting hyphae, which have a thick wall and a brownish appearance, act as a key source of infection in the spring (Szentiványi and Kiss 2003). Woolly aphids and other sucking insects are major players in powdery mildew transmission.

Ecological aspects and the mode of action of *Ampelomyces*

The growth behavior of both *Amplomyces* and powdery mildew fungi are altogether diverse, the first one needs a higher relative humidity (Sundheim, 1982), nevertheless the second requires dry weather conditions. BCA has a shorter window with mycoparasitism basic mode of action. It destroys the powdery mildew fungi slowly by taking up to one week. Therefore, the requirement of such relative humidity is one of the constraints in the triumphant bio-control process (Verhaar *et al.* 1999; Paulitz and Be´langer, 2001). Another prerequisite of successful BCAs for this purpose is that they must be able to interact efficiently and actively in the concerned environment. This could be the reason why this environment is more unfavorable than the rhizosphere for BCA to act upon (Kiss *et al.* 2001). Aerial parts of plants such as leaves etc. have a limited life span as compared to the rhizosphere. It has been mentioned that *Ampelomyces* attack the powdery mildew fungus very late in the season because the disease appears at the end of the crop season. Owing to the mismatched occurrence timing of both fungi, the pathogenic fungi easily attained their epidemic status (Kiss, 1998). An early appearance and dissemination of mycoparasite on powdery mildew colonies on leaves and grapefruits could control disease efficiently (Falk *et al.* 1995), furthermore it is advisable to apply the mycoparasite at a low infection level of phytopathogen.

Large scale production of *A. quisqualis*

An easy and cheap fermentation method for the mass production of *A. quisqualis* was devised (Sztejnberg *et al.* 1990). Its various formulations were made and assessed on different crops which had low efficacy and hence could not be promoted furthermore (Hofstein *et al.* 1996).

Later, in 1995, an improved granule formulation 'AQ10™' got EPA registration for the use against grapevine powdery mildew. It was as equally promising as chemical fungicides when applied twice at low disease pressure during early morning and late evening to ensure adequate relative humidity. Adding mineral oil made it very successful BCA. Subsequently, it got label expansion for use in numerous fruit and vegetable crops in combination with wetting agents (Paulitz and Bélanger 2001). There are some effective microbial candidates well capable of addressing the powdery mildew problem of various crops (Table 2).

Some other potential fungal antagonists for managing powdery mildew

As potential BCA for the mitigation of cucumber powdery mildew, *Aphanocladium album* (Preuss) Gams, *Tilletiopsis albescens* Gotzhale, *Pseudozyma flocculosa*, and *Verticillium lecanii* (Zimm) Viegas has been mentioned (Kiss *et al.* 2004a). Only *V. lecanii*, out of *A. quisqualis*, *Aphanocladium album*, *Pseudozyma rugulosa*, *Tilletiopsis minor* Nyland, and *V. lecanii*, could effectively control the rose powdery mildew disease at 100% RH, but *P. flocculosa* is the best antagonist of greenhouse cucumber and rose production in realistic conditions (Paulitz and Bélanger 2001).

Non-chemical means

The disease can effectively be managed through certain non-chemical approaches such as sulfur or fish oil plus sesame oil (Keinath and DuBose 2012).

Milk, natural sulfur, potassium bicarbonate, sodium bicarbonate, metal salts, oils, and compost tea (Hacquard *et al.* 2013; Martinez *et al.* 2001; Crisp *et al.* 2006; Schilder *et al.* 2002; McGrath and Shishkoff, 1999; La Torre *et al.* 2004; Segarra *et al.* 2009) are known to provide a protective umbrella to crops against powdery mildew diseases.

Application of sulfur before disease appearance is quite effective because it checks spore germination of the pathogens. Neem oil impedes the metabolism and ceases sporulation of pathogens; this phenomenon ultimately results in successful control of disease (https://www.extension.purdue.edu/extmedia/bp/bp-69-w.pdf). The combined application of sulfur plus fish oil plus sesame oil is a promising remedial measure for the effective control of powdery mildew (Keinath and DuBose 2012).

Table 2: Management of powdery mildew through *A. quisqualis*

Crop	Powdery mildew pathogen	Promising BCA	Reference
Strawberry	*Sphaerotheca macularis*	*A. quisqualis*, *Bacillus subtilis* and *Trichoderma harzianum* T39	Pertot *et al.* 2008
Cashew	*Oidium anacardii*	*A. quisqualis*	Dominic and Marthamakobe, 2017
Cucurbit	*Podosphaera xanthii*	*A. quisqualis*	Shishkoff and McGrath, 2002
Melon	*Podosphaera fusca*	*A. quisqualis*, *Lecanicillium lecanii, B. subtilis*	Romero *et al.* 2007
Zucchini leaves	*Podosphaera xanthii*	*A. quisqualis*	Carbó *et al.* 2020
Cucumber	*Podosphaera xanthii*	*A. quisqualis*	Giotis *et al.* 2012
Grapevine	*Erysiphe necator*	*A. quisqualis, T. harzianum,* and *Saccharomyces cerevisiae*	Singh, 2017
Grapevine	*Erysiphe necator*	*A. quisqualis*	Caffi *et al.* 2013
Zucchini	*Podosphaera xanthii*	*A. quisqualis* and *B. subtilis*	Gilardi *et al.* 2008
Mango	Powdery mildew	*A. quisqualis*	M.K. Azmy, 2014
Strawberry	*Podosphaera aphanis*	*A. quisqualis*, *B. subtilis* QST713 and *T. harzianum* T39	Pertot *et al.* 2009
Cashew	*Oidium anacardii*	*A. quisqualis*	Dominic and Marthamakobe, 2017
Black gram	*Erysiphe polygoni*	*A. quisqualis*	Jayasekhar and Ebenezar, 2016
Grapevine		*A. quisqualis*	Legler *et al.* 2011
Tobacco	Powdery mildew	*A. quisqualis*	Zhao *et al.* 2012
Cucumber	*Sphaerotheca fuliginea*	*A. quisqualis*	Singh and Sahore, 2000
Fenugreek	*Erysiphe polygoni*	*A. quisqualis*	Trivedi *et al.* 2013
Rose	Powdery mildew	*A. quisqualis*, *B. subtilis*, *Verticillium lecanii* and *T. harzianum*	Kumar and Chandel, 2018

Foliar sprays of non-aerated compost tea can control powdery mildew of rose pumpkins and grapes (https://opencommons.uconn.edu/cgi/viewcontent.cgi?article=1146&context=gs_theses). The efficacy of milk is comparable with certain fungicides against the management of powdery mildew disease of summer squash (Bettiol 1999). Raw cow milk and whey were found promising in controlling cucumber powdery mildew disease incited by *Sphaerotheca fuliginea* (Schlecht.) pollacci (Kamel *et al.* 2017); nevertheless, the actual mode of action is still uncertain. It is assumed that whey protein (ferroglobin) when exposed to sunlight produces oxygen radicals which are harmful to the phytopathogenic fungus. The crop can be saved from powdery mildew through spraying the vegetable or mineral oils to a limited extent (https://s3.wp.wsu.edu/uploads/sites/403/2015/03/baking-soda.pdf).

Silicon develops the resistance against powdery mildew phytopathogens of wheat, *Blumeria graminis f. sp. tritici*, it damages pathogen's haustoria, and hence pathogen cannot infect the host plants (Bélanger *et al.* 2003).

Certain resistant genes play a vital role in managing the disease. Numerous RNAi target genes showed resistant reaction against powdery mildew fungal pathogen of wheat and barley, however, there was the overlapping of four genes (Douchkov *et al.* 2014).

There was more accumulation of salicylic acid and higher transcription for encoding defense genes such as TaLsi1 pad4 and TaLsi1 sid2 (Vivancos *et al.* 2015). In barley, gene Mlo-A1 and Mlo-B1 determined the resistance against powdery mildew; however, the Mlo-B1 gene was more powerful than the Mlo-A1 gene and hence the Mlo-based resistance could be exploited for durable protection in tetraploid wheat against powdery mildew (Ingvardsen *et al.* 2019). LEMK1 genes enhanced resistance in wheat to the powdery mildew fungus. HvLEMK1 gene is found in barley and responsible for quantitative resistance in wheat to powdery mildew fungus (Rajaraman *et al.* 2016). Grapevine MLO gene may be involved in the pathogenesis of *E. necator* (Winterhagen *et al.* 2008). More than 85 genes for powdery mildew resistance in barley have been reported and numerous avr gene loci have also been mapped (Linde and Shishkoff 2017).

Strains of *A. quisqualis* are considered to be slow-growing fungi with a radial growth rate of a few millimeters a week on solid media and their conidia are known to be difficult to produce in industrial fermenters. Nutrient composition and growth conditions had been optimized for high mycelial growth and conidiation of the ITA3 strain on a cost-effective culture medium and finalized a stable and effective dry formulation for the conidia. Plackett–Burman design and response surface methodology were employed for the optimization of new bioprocesses. In the tested culture media, a 23.2-fold increase in biomass and a 2.2×10^8 conidial yield were obtained with the optimized sugar-based medium, with a time reduction of 43% as compared to the original sugar-based medium (Angeli *et al.* 2017).

CONCLUSION

Although synthetic fungicides are more promising in controlling this disease however there are so many ill effects of them. The negative impact of excessive use of synthetic fungicides has been becoming a menace for the entire ecosystem, human beings, microbes, soil, environment, etc. under such circumstances application of *A. quisqualis* and other means will serve the purpose of managing the disease in an eco-friendly manner for crop sustainability. *A. quisqualis* and other means are readily available in nature and hence they can easily be explored as tools of disease management, particularly where organic as well as natural farming are being adopted.

List of abbreviations

BCA: Biological control agents; *A. quisqualis*: *Ampellomyces quisqualis; P. mali: Podosphaera mali; P. tridactyl: Podosphaera tridactyl; E. cichoracearum: Erysiphe cichoracearum*

REFERENCES

Abo-Foul, S., Raskin, V.I., Sztejnberg, A. and Marder, J.B. 1996. Disruption of chlorophyll organization and function in powdery mildew-diseased cucumber leaves and its control by the hyperparasite *Ampelomyces quisqualis. Phytopathology*, **86**: 195–199.

Ahanger, R.A., Qazi, N.A., Bhat, H.A. *et al.* 2018. Management of powdery mildew of *Euonymus japonicus* in Kashmir Valley. *Indian Phytopathol.*, **71**: 377–384.

Angeli, D., Pellegrini, E. and Pertot, I. 2009. Occurrence of *Erysiphe necator* chasmothecia and their natural parasitism by *Ampelomyces quisqualis. Phytopathology,* **99**: 704–710.

Angeli, D., Saharan, K., Segarra, G. *et al.* 2017. Production of *Ampelomyces quisqualis* conidia in submerged fermentation and improvements in the formulation for increased shelf-life. *Crop Prot.,* **97**: 135–144.

Bélanger, R.R., Benhamou, N. and Menzies, J.G. 2003. Cytological evidence of an active role of silicon in wheat resistance to powdery mildew (*Blumeria graminis* f. sp. tritici). *Phytopathology,* **93**: 402–412.

Bélanger, R.R. and Benyagoub, M. 1997. Challenges and prospects for integrated control of powdery mildews in the greenhouse. *Can. J. Plant Pathol.,* **19**: 310–314.

Bettiol, W. 1999. Effectiveness of cow's milk against zucchini squash powdery mildew (*Sphaerotheca fuliginea*) in greenhouse conditions. *Crop Prot.,* **18**: 489–492.

Beuther, E., Philipp, W -D. and Grossmann, F. 1981. Untersuchungen zum Hyperparasitismus von *Ampelomyces quisqualis* auf Gurkenmehltau (*Sphaerotheca fuliginea*). *J. Phytopathol.,* **101**: 265–270.

Bharat, N.K. 2011. Biological Control of Diseases of Temperate Fruit Crops. *Int. J. Sci. Nat.,* **2**: 422–431.

Bourbos, V.A. and Barbopoulou, E.A. 2006. Study of the possibility to control olive powdery mildew (*Leveillula taurica*) with the use of soft and biological fungicides. In: Biotechnology and Quality of Olive tree Products around the Mediterranean basin, pp. 143–146.

Caffi, T., Legler, S.E., Bugiani, R. and Rossi, V. 2013. Combining sanitation and disease modelling for control of grapevine powdery mildew. *Eur. J. Plant Pathol.,* **135**: 817–829.

Carbó, A., Torres, R., Usall, J. *et al.* 2020. Biocontrol potential of *Ampelomyces quisqualis* strain CPA-9 against powdery mildew: Conidia production in liquid medium and efficacy on zucchini leaves. *Sci. Hortic. (Amsterdam),* **267**.

Crisp, P., Wicks, T.J., Troup, G. and Scott, E.S. 2006. Mode of action of milk and whey in the control of grapevine powdery mildew. *Australas Plant Pathol.,* **35**: 487–493.

Czerniawska, B. 2014. *Phyllactinia mali* and *Podosphaera tridactyla* var. tridactyla – new hosts of *Ampelomyces quisqualis. Acta Mycol.,* **40**: 197–201.

Czerniawska, B., Madej, T., Adamska, I. *et al.* 2014. Erysiphales and their hyperparasite, *Ampelomyces quisqualis*, of the Drawsko Landscape Park, Poland. *Acta Mycol.,* **35**.

Dominic, M. and Marthamakobe. 2017. Biological control of cashew powdery mildew using *Ampelomyces quisqualis* Ces. *J. Biol. Control,* **30**: 226.

Donk, M.A. 1966. Cicinnobolus Bary (Fungi, Sphaeropsidales). *Taxon.,* **15**: 149–151.

Douchkov, D., Lück, S., Johrde, A. *et al.* 2014. Discovery of genes affecting resistance of barley to adapted and non-adapted powdery mildew fungi. *Genome Biol.,* **15**: 518.

Elad, Y., Kirshner, B., Yehuda, N.. and Sztejnberg, A. 1998. Management of powdery mildew and gray mold of cucumber by *Trichoderma harzianum* T39 and *Ampelomyces quisqualis* AQ10. BioControl., **43**: 241–251. https://doi.org/10.1023/A:1009919417481

Falk, S.P., Gadoury, D.M., Pearson, R.C. and Seem, R.C. 1995. Partial control of grape powdery mildew by the mycoparasite *Ampelomyces quisqualis. Plant Dis.,* **79**: 483–490.

Gadoury, D.M. 1988. Initiation, Development, Dispersal, and Survival of Cleistothecia of *Uncinula necator* in New York Vineyards. *Phytopathology,* **78**: 1413.

Gamal Ashor Ahmed, B., Mahdy Mohamed Mahdy, A. and Mahmoud Abd-El-Latef, F. 1998. Using Plant Extracts To Control Powdery Mildew Disease That Attack Cucumber Plants Under Protected Houses.

Gilardi, G., Manker, D.C., Garibaldi, A. and Gullino, M.L. 2008. Efficacy of the biocontrol agents Bacillus subtilis and *Ampelomyces quisqualis* applied in combination with fungicides against powdery mildew of zucchini. *J. Plant Dis. Prot.,* **115**: 208–213.

Giotis, C., Markellou, E., Theodoropoulou, A. *et al.* 2012. The effects of different biological control agents (BCAs) and plant defence elicitors on cucumber powdery mildew (*Podosphaera xanthii*). *Org. Agric.,* **2**: 89–101.

Gu, Y.H. and Ko, W.H. 1997. Water agarose medium for studying factors affecting germination of conidia of *Ampelomyces quisqualis. Mycol. Res.,* **101**: 422–424.

Hacquard, S., Kracher, B., Maekawa, T. *et al.* 2013. Mosaic genome structure of the barley powdery mildew pathogen and conservation of transcriptional programs in divergent hosts. Proc. Natl. Acad. Sci. U S A 110:. https://doi.org/10.1073/pnas.1306807110

Hofstein, R., Daoust, R.A. and Aeschlimann, J.P. 1996. Constraints to the development of biofungicides: The example of "AQ10", a new product for controlling powdery mildews. *Entomophaga.,* **41**: 455–460.

Hofstein, R. and Fridlender, B. 1994. Development of production, formulation and delivery systems. *In:* Brighton Crop Protection Conference, Pests and Diseases 1994. Volume 3. 1994, 1273 1280; 20 ref.

Huang, X.Q., Hsam, S.L.K., Zeller, F.J. *et al.* 2000. Molecular mapping of the wheat powdery mildew resistance gene Pm24 and marker validation for molecular breeding. *Theor. Appl. Genet.,* **101**: 407–414.

Ingvardsen, C.R., Massange-Sánchez, J.A., Borum, F. *et al.* 2019. Development of mlo-based resistance in tetraploid wheat against wheat powdery mildew. *Theor. Appl. Genet.,* **132**: 3009–3022.

Jayasekhar, M. and Ebenezar, E.G. 2016. Management of powdery mildew of black gram (<italic>Vigna mungo</italic>) caused by <italic>Erysiphe polygoni</italic>. *Agric. Sci. Dig. - A Res. J.,* **35**.

Kamel, S.M., Ketta, H.A. and Emeran, A.A. 2017. Efficacy of raw cow milk and whey against cucumber powdery mildew disease caused by *Sphaerotheca fuliginea* (Schlecht.) pollacci under plastic house conditions. *Egypt J. Biol. Pest Control,* **27**: 135–142.

Keinath, A.P. and DuBose, V.B. 2012. Controlling powdery mildew on cucurbit rootstock seedlings in the greenhouse with fungicides and biofungicides. *Crop Prot.*, **42**: 338–344.

Kiss, L. 2003. A review of fungal antagonists of powdery mildews and their potential as biocontrol agents. *Pest Manag. Sci.*, **59**: 475–483.

Kiss, L. 1998. Natural occurrence of ampelomyces intracellular mycoparasites in mycelia of powdery mildew fungi. *New Phytol.*, **140**: 709–714.

Kiss, L. 2008. Chapter 3 Intracellular mycoparasites in action: Interactions between powdery mildew fungi and Ampelomyces. *Br. Mycol. Soc. Symp. Ser.*, **27**: 37–52.

Kiss, L., Cook, R.T.A., Saenz, G.S. *et al.* 2001. Identification of two powdery mildew fungi, *Oidium neolycopersici* sp. nov. and *O. lycopersici*, infecting tomato in different parts of the world. *Mycol. Res.*, **105**: 684–697.

Kiss, L., Russell, J.C., Szentiványi, O. *et al.* 2004a. Biology and biocontrol potential of *Ampelomyces mycoparasites*, natural antagonists of powdery mildew fungi. *Biocontrol Sci. Technol.*, **14**: 635–651.

Kiss, L., Russell, J.C., Szentiványi, O. *et al.* 2004b. Biology and biocontrol potential of *Ampelomyces mycoparasites*, natural antagonists of powdery mildew fungi. *Biocontrol Sci. Technol.*, **14**: 635–651.

Křístková, E., Lebeda, A. and Sedláková, B. 2009. Species spectra, distribution and host range of cucurbit powdery mildews in the Czech Republic, and in some other European and Middle Eastern countries. *Phytoparasitica.*, **37**: 337–350.

Křístková, E., Lebeda, A., Sedláková, B. and Duchoslav, M. 2017. Distribution of cucurbit powdery mildew species in the Czech Republic. *Plant Prot. Sci.*, **38**: 415–416.

Kumhar, K.C., Babu, A., Arulmarianathan, J.P., Deka, B., Bordoloi, M., Rajbongshi, H. and Dey, P. 2020. Role of beneficial fungi in managing diseases and insect pests of tea plantation. *Egyptian J. Biolog. Pest Control*, **30**(1): 1-9.

Kumar, V. and Chandel, S. 2018. Management of rose powdery mildew (*Podosphaera pannosa*) through ecofriendly approaches. *Indian Phytopathol.*, **71**: 393–397.

La Torre, A., Spera, G. and Lolleti, D. 2004. Activity of natural products against courgette powdery mildew. *Commun. Agric. Appl. Biol. Sci.*, **69**: 671–678.

Lee, H.B. and Nguyen, T.T.T. 2017. First report of powdery mildew caused by erysiphe alphitoides on euonymus japonica in Korea. *Plant Dis.*, **101**: 385.

Legler, S.E., Caffi, T., Benuzzi, M. *et al.* 2011. New perspectives for the use of Ampelomyces-based biofungicides for effective control of powdery mildew on grapevine. *In:* AFPP – Fourth International Conference on non chemical Crop Protection Methods, pp. 1–6.

Linde, M. and Shishkoff, N. 2017. Powdery Mildew. *In:* Reference Module in Life Sciences.

Liu, F., Zhuge, Y.Y., Yang, C.Y. *et al.* 2010. Control effects of some plant extracts against cucumber powdery mildew (*Sphaerotheca fuliginea*) and their stability study. *Eur. J. Hortic. Sci.*, **75**: 147–152.

Luecke, N.C., Adams, T. and Crawford, K. 2020 First report of powdery mildew caused by *Podosphaera xanthii* on the invasive *Verbena brasiliensis* in Texas. *Plant Dis.* https://doi.org/10.1094/pdis-01-20-0022-pdn

M.K. Azmy, A. 2014. Controlling of Mango Powdery Mildew by some Salts, Growth Regulators and the Biofungicide AQ10 Compared with Punch Fungicide in *Egypt. Am. J. Life Sci.*, **2**: 33.

Markovic, M. and Rajkovic, S. 2012. *Ampelomyces quisqualis* Ces. Ex schlecht. as an alternative measure of protection. *In:* Microbes in Applied Research: Current Advances and Challenges, Malaga, Spain, 14 - 16 September 2011, pp. 8–12

Martinez, C., Blanc, F., Le Claire, E. *et al.* 2001. Salicylic acid and ethylene pathways are differentially activated in melon cotyledons by active or heat-denatured cellulase from *Trichoderma longibrachiatum*. *Plant Physiol.*, **127**: 334–344.

McGrath, M.T. and Shishkoff, N. 1999. Evaluation of biocompatible products for managing cucurbit powdery mildew. *Crop Prot.*, **18**: 471–478.

Naseripour, T., Tabarestani, M.S. and Rahnama, K. 2014. Fungi associated with the powdery mildew of Buxus trees in Gorgan landscape. *Int. J. Adv. Biol. Biomed. Res.*, **2**: 966–969.

Paulitz, T.C. and Bélanger, R.R. 2001. Biological control in greenhouse systems. *Annu. Rev. Phytopathol.*, **39**: 103–133.

Pertot, I., Fiamingo, F., Tizianel, A. *et al.* 2009. Effect of the timing of applications of control agents on podosphaera aphanis and effect of fungicides on the survival of biocontrol agents on strawberry leaves. *In:* Acta Horticulturae, pp. 733–738.

Pertot, I., Zasso, R., Amsalem, L. *et al.* 2008. Integrating biocontrol agents in strawberry powdery mildew control strategies in high tunnel growing systems. *Crop Prot.*, **27**: 622–631.

Philipp, W.D. 1985. Extracellular Enzymes and Nutritional Physiology of *Ampelomyces quisqualis* Ces., Hyperparasite of Powdery Mildew, *in vitro*. *J. Phytopathol.*, **114**: 274–283.

Rajaraman, J., Douchkov, D., Hensel, G. *et al.* 2016. An LRR/ Malectin receptor-like kinase mediates resistance to non-adapted and adapted powdery mildew fungi in barley and wheat. *Front Plant Sci.*, **7**.

Romero, D., De Vicente, A., Zeriouh, H. *et al.* 2007. Evaluation of biological control agents for managing cucurbit powdery mildew on greenhouse-grown melon. Plant *Pathol.*, **56**: 976–986.

Romero, D., Rivera, M.E., Cazorla, F.M. *et al.* 2003. Effect of mycoparasitic fungi on the development of *Sphaerotheca fusca* in melon leaves. Mycol. Res. https://doi.org/10.1017/S0953756202006974

Rotem, Y., Yarden, O. and Sztejnberg, A. 1999. The mycoparasite *Ampelomyces quisqualis* expresses *exgA* encoding an *exo*-β-1,3-glucanase in culture and during mycoparasitism. *Phytopathology*, **89**: 631–638.

Schilder, A.M.C., Gillett, J.M., Sysak, R.W. and Wise, J.C. 2002. Evaluation of environmentally friendly products for control of fungal diseases of grapes. 10th Int Conf Cultiv Tech Phytopathol Probl Org Fruit-Growing Vitic, pp. 163–167.

Segarra, G., Reis, M., Casanova, E. and Trillas, M.I. 2009. Control of powdery mildew (*Erysiphe polygoni*) in tomato by foliar applications of compost tea. *J. Plant Pathol.*, **91**: 683–689.

Shishkoff, N. and McGrath, M.T. 2002. AQ10 biofungicide combined with chemical fungicides or AddQ spray adjuvant for control of cucurbit powdery mildew in detached leaf culture. *Plant Dis.*, **86**: 915–918.

Singh, D. and Sahore, S.K. 2000. Integrated management of powdery mildew (*Sphaerotheca fuliginea*) of cucumber. Pestology, **24**: 3–8.

Singh, P.N. 2017. Biocontrol of powdery mildew of grapes using culture filtrate and biomass of fungal isolates. *Plant Pathol. Quar.*, **7**: 181–189.

Speer, E.O. 1978. Ampelomyces Cesati (Fungi, Sphaeropsidales). Taxon., **27**: 549–550.

Steinwand, B. 2003. *Ampelomyces quisqualis* isolate M-10 (021007). *In:* Pestic. Regul. Pestic. http://www.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-021007_01-Feb-00.pdf

Sundheim, L. and Krekling, T. 1982. Host-parasite relationships of the hyperparasite *Ampelomyces quisqualis* and its powdery mildew host *Sphaerotheca fuliginea* I. Scanning electron microscopy. *J. Phytopathol.*, **104**: 202–210.

Szentiványi, O. and Kiss, L. 2003. Overwintering of *Ampelomyces mycoparasites* on apple trees and other plants infected with powdery mildews. *Plant Pathol.*, **52**: 737–746.

Sztejnberg, A., Galper, S. and Lisker, N. 1990. Conditions for pycnidial production and spore formation by *Ampelomyces quisqualis. Can. J. Microbiol.*, **36**: 193–198.

Sztejnberg, A., Galper, S., Mazar, S. and Lisker, N. 1989. *Ampelomyces quisqualis* for Biological and Integrated Control of Powdery Mildews in Israel. *J. Phytopathol.*, **124**: 285–295.

Trivedi, A., Hussain, T., Sharma, S.K. and Sharma, S.K. 2013. Management of fungal root disease complex and powdery mildew in organic farming of fenugreek. *J. Mycol. Plant Pathol.*, **43**: 314–318.

Verhaar, M.A., Kerssies, A. and Hijwegen, T. 1999. Effect of relative humidity on mycoparasitism of rose powdery mildew with and without treatments with mycoparasites. *Zeitschrift fur Pflanzenkrankheiten und Pflanzenschutz*, **106**: 158–165.

Vivancos, J., Labbé, C., Menzies, J.G. and Bélanger, R.R. 2015. Silicon-mediated resistance of Arabidopsis against powdery mildew involves mechanisms other than the salicylic acid (SA)-dependent defence pathway. *Mol. Plant Pathol.*, **16**: 572–582.

Winterhagen, P., Howard, S.F., Qiu, W. and Kovács, L.G. 2008. Transcriptional up-regulation of grapevine MLO genes in response to powdery mildew infection. *Am. J. Enol. Vitic.*, **59**: 159–168.

Woo, S.L., Ruocco, M., Vinale, F., Nigro, M., Marra, R., Lombardi, N., Pascale, A., Lanzuise, S., Manganiello, G. and Lorito, M. 2014. Trichoderma-based products and their widespread use in agriculture. *The Open Mycology J.*, **8**(1).

Zhao, H.H., Xing, H.H. and Liang, C. 2012. Screening of *Ampelomyces quisqualis* isolates hyperparasite on the tobacco powdery mildew fungus. *In:* Proceedings - 2012 International Conference on Biomedical Engineering and Biotechnology, iCBEB 2012, pp. 501–502.