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Review Article

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Cultivar Mixture: Old but Impactful Plant Disease Management Strategy

Gagan Kumar[1*], Md. Mahtab Rashid[2], Basavaraj Teli[2], Raina Bajpai[2], Satyabrata Nanda[3] and Sudheer Kumar Yadav[4]

[1]Dept. of Plant Pathology, [3]Dept. of Plant Biotechnology, M. S. Swaminathan School of Agriculture, Centurion University of Technology and Management, Odisha (761 211), India

[2]Dept. of Mycology and Plant Pathology, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh (221 005), India

[4]Dept. of Agricultural Biotechnology, Narayan Institute of Agricultural Sciences, Gopal Narayan Singh University, Jamuhar, Rohtas, Bihar (821 305), India

Corresponding Author

Gagan Kumar
e-mail: gagan.kumar@cutm.ac.in

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Abstract

The two most commonly used disease management methods prevalent in agricultural package of practices are: the application of chemicals and the selection of disease-resistant cultivars through the introduction of resistance genes. Each of these preventive measures are equally susceptible to the adaptations of phytopathogens in due course of time. There are numerous records of several phytopathogens overcomimg the resistance provided by the main resistance gene through continuous evolution. In a similar fashion, the development and fixation of pesticides resistance mutations in the phytopathogens has made many pesticides to lose their effectiveness. The existingdisease management practices are presumably deficient in supporting the sustainable intensification of crop productivity due to its inadequacy of minimizing the phytopathogen evolution. Thus, comes the role of cultivar mixture which is based on the principle of supressing the evolution of phytopathogen against a specific gene or pesticide. Combinations of cultivars having several different characteristics but sufficient morphological and physiological similarities can be cultivated collectively.These cultivar mixtures do not cause any significant changes in crop production system, yet improve the yield accuracy, and decrease the use of pesticides in many cases. They are also faster and cheaper to develop and are distinctive to "multiline" which are identified as combinations of genetically identical lines of a crop species varying mostly in disease resistance gene. The use of cultivar mixtures can improve the effectiveness of disease management practices as their level of resistance vary in the same region.

Keywords: Biodiversity, cultivar, resistance, susceptible, sustainable agriculture

1. Introduction

Currently, agriculture is confronting the problem of supplying food to a growing world population while protecting the environment. The high yielding crop varieties provided us the opportunity to fulfil the demand but with intensive cultivation of such crop varieties led to emergence and/or resurgence of plant diseases (Jain, 2010; Singh et al., 2011). They also do not follow the sustainable agricultural approach as they favour the application of more synthetic fertilizers and chemicals (Arif et al., 2019). Plant diseases has thus emerged as major hinderace in meeting the food demands as they are the primary cause of yield decline in crops and their cost of management affects the economics of crop production.Since, plant diseases are such a significant factor in determination of crop yield, they require specificmanagement practices for reducing their impact (Strange and Scott, 2005; Yadav et al., 2019). The two most common plant disease management practices that are prevalent in post-green revolution era of agriculture are theuse of pesticides and the cultivation of resistant cultivars. Each of the methods have their own set of advantages as well as limitations (Rawat et al., 2021). The injudicious use of pesticides for management of plant diseases has posedseveral environmental risks along with the risk of becoming ineffective due to development of resistant population of phytopathogens following adaptation (Leroux and Walker, 2011; Cai et al., 2021). Similarly, the genetic uniformity ofcompletely resistant cultivars haslead to their breakdown of resistance by the same phenomenon of adapting phytopathogens (de Vallavieille-Pope, 2004; Rimbaud et al., 2021). The partially resistant cultivars are however exception to this as they follow a dirty-crop approach where there is no build-up of resistant population but they require additional disease managment strategies which impacts the production economics (Burdon et al., 2014; Brown et al., 2015). Thus, one alternative to this crisis of resistant cultivars is the use of agricultural biodiversity (Cooke et al., 2006; Frison et al., 2011; Zhang et al., 2018; Brooker et al., 2021).

Since the genetic uniformity makes a crop vulnerable to plant disease, one potential method of disease suppression is increasing the genetic diversity. The most simple and effective way to increase the genetic diversity is to use mixed cultivars of having varying susceptibility to a plant disease (Wolfe, 1988). It has been also proven thatcultivation of susceptible and resistant cultivars in the same field at the same time provides us with higher yields than the pure ones (de Vallavieille-Pope, 2004; Zupunski et al., 2021). Disease suppression among combinations of susceptible plant cultivars can be demonstrated through several mechanisms(Cooke et al., 2006; Girelli et al., 2021). This cultural method of mixing the cultivars can be used as an alternative to encourage the sustainable development of agricultural production, with only slight changes in agricultural methods. Cultivar mixtures are an attractive choice for the agro-ecological management of plant diseases, despite their relatively lower level of adoption in the field (Berlin et al., 2018). Agro-ecosystems are genetically more homogeneous than natural ecosystems, have a greater plant density, and have much less genomic and population diversity. It is widely recognized that these inherent characteristics, in particular the lack of genetic diversity of agro-ecosystems, render them vulnerable to disease epidemics (Wolfe, 2000; Zhan et al., 2002). For achieving the sustainable improvement of agricultural production,the development of fairly effective and sustainable disease management methods and techniques are essential. One way of building this approach is by taking a reference from fundamental characteristics of current farming practices of rendering susceptible plants to phytopathogens.

2. Disease Suppression through Cultivar Mixture

The cultivation of mixed cultivars does not control or eradicate plant diseases. The technique rather functions by reducing the level of disease development through the elimination of spores produced during the multiplication phase of phytopathogens (Table 1, Figure 1). Since there are genetic differences in the plant population, the levels of spores are diluted through their deposition on resistant plant individuals. Additionally, the infection cycle of a phytopathogen is also delayed through the activation of defense responses in susceptible plants by avirulent phytopathogens. Moreover, disease suppression is also due to the variety of epidemiological and physiological processes. The major mechanisms through which cultivar mixture causes disease suppression are categorized into four categories namely: density effect, barrier effect, induced resistance, and alteration of microclimate (Vidal et al., 2017a). The density effect is due to the increased spaceand minimized movement of spore between susceptible plants in comparison to the single cultivar stand (Burdon and Chilvers, 1982). The barrier effect is due to the interception of spores by resistant cultivars which prevents the inoculum establishment on susceptible plants (Burdon and Chilvers, 1982; Schoeny et al., 2008). The induced resistance mechanism functions by the activation of defense responses in incompatible plants due to the attack of avirulent strains or race of the phytopathogens (Pieterse et al., 2014). The alteration of the microclimate mechanism is due to the varied characteristics of mixed cultivars *i.e.,* plant height, canopy structure, etc. which

Table 1: Some examples of cultivar mixtures in different crops against various disease

Cultivar Mixtures	Crops	Diseases	References
Cultivar mixture with different resistance backgrounds	Wheat	Stripe rust	Huang et al., 2012
Two-component cultivar mixtures	Rice	Blast	Raboin et al., 2012
Three-component mixtures	Barley	Powdery Mildew	Newton and Guy, 2011
Four-way cultivar mixture	Wheat	Septoria tritici blotch	Kristoffersen et al., 2020
Four mixtures	Wheat	Septoria tritici blotch	Cowger and Mundt, 2002
Two-component mixtures	Wheat	Septoria tritici blotch	Gigot et al., 2013
Three cultivar mixture (patchy cultivar mixtures)	Barley	Different diseases	Newton and Guy, 2009
Two cultivar mixture	Wheat	Septoria tritici blotch	Vidal et al., 2017a
Two cultivar mixture	Wheat	Septoria tritici blotch	Vidal et al., 2017b
Mixture of resistant and susceptible cultivars	Pea	Powdery Mildew	Villegas-Fernandez et al., 2021
Cultivar mixtures with varying proportions of resistance	Durum wheat	Septoria tritici blotch	Ben M' Barek et al., 2020
Cultivars mixture with diversity for many traits, including plant height, flowering date, disease resistance, and yield potential	Wheat	Yellow rust	Vidal et al., 2020
Mixture of resistant and susceptible cultivars	Apple	Scab, powdery mildew	Parisi et al., 2013

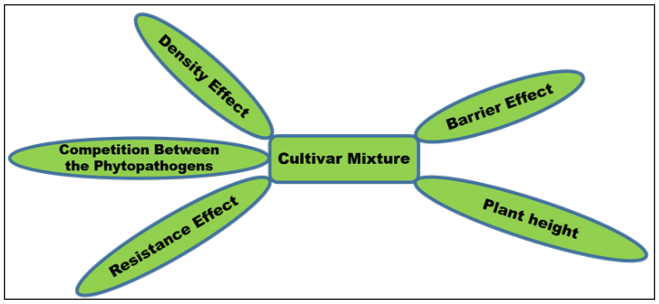

Figure 1: Diagramatic representation of various disease suppression effects of cultivar mixture

modifies the microenvironment that is not optimum for the development of plant diseases (Barot et al., 2017).

2.1. Density effect

As explained earlier, the density effect is due to the increased spacing between the susceptible plants in comparison to the single cultivar stand which leads to a minimized movement of spores between the susceptible plant (Dornbusch et al., 2011; Kiaer et al., 2012). The mechanism functions particularly in the case of the phytopathogens which are dependent on rain splashes for transmission of spores to a distance less than 1 m. In cultivar mixture crop, the diseases are reduced precisely because of fewer susceptible cultivars in comparison to a single cultivar stand comprising of only susceptible plants (Macdonald and McCartney, 1987; Ben M'Barek et al., 2020). This effect can also be confirmed by using two single susceptible cultivars stands varying only in their plant density or spacing. Reduced disease incidence would be observed in crops with wider plant spacing or reduced plant density. The reduced plant density in a combination of resistant and susceptible cultivars would however not have comparatively lower disease incidence than a single resistant cultivar stands (Chin and Wolfe, 1984; Vidal et al., 2020). The concept of "reduced density" was also forwarded for observation in case of two or more host-specific phytopathogens *i.e.*, host 1 is resistant to phytopathogen 1 but susceptible to phytopathogen 2 and vice-versa for host 2. It was observed that level of disease incidence was lower than the pure stands in cultivar mixture stands (Mikaberidze et al., 2015). The barrier effect is not included in this model as it does not specifically take the spatial impact of phytopathogen spread into consideration.

2.2. *Barrier effect*

The introduction of resistant varieties in the cultivar mixture causes hindrance in the transmission of phytopathogens to susceptible hosts, resulting in lower disease incidence (Burdon et al., 2016). Spores that land on resistant plants have little to no effect on the host and also are prevented from affecting susceptible plants. In order to optimize the reduction in disease proliferation in a cultivar mixture, a sufficient percentage of resistant cultivars are used in the cultivar mixture. In an experiment, it was observed that a cultivar mixture of wheat comprising of 75% partially resistant cultivar plants and 25% susceptible cultivar plants had upto 42% lower incidence of septoria blight disease (Gigot et al., 2013; Gigot et al., 2014).

2.3. Resistance effect

In plant epidemiological studies, partial or quantitative resistance leads to reduced disease severity rather than providing complete immunity against disease in case of total or qualitative resistance (Singh et al., 2004; Latha et al., 2012; Pilet-Nayel et al., 2017). This quantitative or partial resistance can be utilized in reducing the size of the phytopathogen's population while avoiding highly specific strain development (Zhan et al., 2002; Chen, 2005; Dong and Ronald, 2019). This is the reason why partially resistant cultivars are considered as a potential candidate in a cultivar mixture for not only controlling transmission of a plant disease but also as an adaptive strategy against dynamic and genetic diversity of a phytopathogenic population (Sommerhalder et al., 2011). However, the researches which are carried out till now both at theoretical and empirical stages are mainly focused on the use of cultivar mixtures against biotrophic phytopathogens which interact with their host plant as per the gene-for-gene hypothesis (Flor, 1956). The selection of a cultivar with major gene resistance is the most prevalent criteria in cultivar mixture even though it can cause rapid evolution in phytopathogens leading to the appearance of highly virulent strains (Mundt, 2002). The induced resistance effect is activated in plants by the attack of avirulent phytopathogens which also provide protection against other phytopathogens or other races of the same phytopathogens that cause disease infection normally in host plants (Lannou et al., 2005).

2.4. Aerial canopy effect

The canopy structure of plants directly affects microclimate and the spore dispersal, thereby influencing the spread and incidence of plant disease (Le May et al., 2009; Tivoli et al., 2012; Calonnec et al., 2013). In dense canopies, the distance between the plants is short which makes spore interception through rain splashes easier (Yang and Madden, 1993; Schoeny et al., 2008). The dense canopies also provide favourable conditions for infection of phytopathogens and the development of the disease by retaining optimum moisture (Deshpande et al., 1995; Richard et al., 2013). The architecture of aerial canopy has been also observed to affect the dispersal of phytopathogen spores by rain splashes (Yang and Madden, 1993; Madden and Boudreau, 1997; Schoeny et al., 2008). The architecture of canopy is always dependent on individual plant architecture features which complies that leaf dimensions, tillers, and internodal length determines the canopy characteristics namely leaf area index (LAI), leaf area density (LAD), and porosity (Godin, 2000; Maiti and Rodriguez, 2017). Thus, all of these characteristics affect the dispersal of spores thereby eventually influencing the development of plant disease (Tivoli et al., 2012; Calonnec et al., 2013). Therefore, the dissemination of spore is affected by the canopy structure of the cultivar mixture which is associated with the mechanism of disease management. Hence, the plant diseases dispersed by rain splashes can be controlled by designing the mixture taking into consideration plant architecture (Vidal et al., 2017b). However, very limited quantitative data is present about the importance of plant architecture in impeding the disease spread by rain splashes in cultivar mixture crop stands.

2.5. Plant height

The inoculum interception is negatively related to plant height as it was observed that interception of inoculum decreased in the plant at a height 40 cm higher than the source of inoculum. The plants having double the height than the standard height plants had 33% less inoculum than the later ones. In another case where the plant height of susceptible plants was twice that of standard height, the inoculum interception by leaves of resistant plants was increased by 40%. The large susceptible plants decrease the interception of inoculum by limiting the border of spores and it can be modified by creating variants of plant heights in cultivar mixture. All these observations suggest that through an appropriate selection of architectural characteristics of cultivars, one can modulate the effects of mixture on the dispersal of phytopathogenic spores (Vidal et al., 2018).

2.6. Competition between the phytopathogens

Plant diversity, ecological stability, and ecosystem productivity have a very eminent relationship in natural systems. Phytopathogens change these connections by hampering the health of plants and decreasing their development. This competitiveness of diseased plants can stimulate a direct force on the population and community organization of the plants (Burdon et al., 2006; Bradley et al., 2008; Maron et al., 2011; Latz et al., 2012). Studies examining the effects of biodiversity on the capacity of the environment to protect against disease are still in their experimental phase. However, until now we can conclude that improved species diversity can decrease the soil and foliar-borne diseaseswhich can ultimately improve productivity in an ecosystem (Allan et al., 2010; Maron et al., 2011). It is thus, anticipated that a mixture of host cultivars would allow pathogens to compete with plant tissues which will lead to reduced levels of disease incidence (Ohtsuki and Sasaki, 2006).

3. Conclusion

Modern pest control practices must comply with the three principles: profitability, environmental impact and community acceptance. The greatest benefit of cultivar mixture is low cost disease suppression and balance of agro-ecosystem. The greater genetic diversity of cultivar mixture makes it less likely that whole plant population will become infected from a particular disease. Resistance and competition in plants reduce disease dissemination and susceptibility, respectively. Hence, for best yield and maximized profit it is imperative to incorporate cultivar mixture in cropping system.

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