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First case of a plant pathogen resistant to three different site-specific mode-of-action fungicides used in the control of Asian soybean rust

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Data de chegada: 04/07/2017. Aceito para publicação em: 04/08/2017.

10.1590/0100-5405/182237

Asian soybean rust (ASR) caused by *Phakopsora pachyrhizi* Sydow & Sydow is considered to have great destructive potential and to cause yield losses ranging from 10 to 90% (8, 6, 9). The disease is controlled based on systemic fungicide application. However, sensitivity reduction has been detected in ASR control over the past 10 years (4). High doses of fertilizers, specially nitrogen, to obtain high yields; increased population of soybean plants per ha; planting of late season soybean varieties; high population of volunteer soybean plants in the fields combined with favorable environmental conditions and cultivation of susceptible cultivars are factors associated with the increased epidemics intensity in most soybean producing regions in Brazil. As a result, *P. pachyrhizi* uredospore population in the air has largely increased in soybean growing fields either in Brazil or in Bolivia and Paraguay. In the latter two countries, green soybean plants can be found in the field all year around. Furthermore, frequent use of fungicides with specific modes of action (triazoles and strobilurins), alone and in mixtures, at doses and numbers of application exceeding the manufacturer's recommendations, has greatly increased the selection pressure on the fungal population. As a consequence, efficiency decreases to a greater or lower degree (7). Nowadays, more than 60% systemic fungicides with specific mode of action, of the triazole and strobilurin groups, show reduced effectiveness on ASR control (3, 4). Godoy et al. (2016) published a review about ASR, showing the decreased effectiveness of fungicides in controlling *P. pachyrhizi*. In the last four years, another group of specific systemic fungicides, carboxamides, has been made available to producers. However, fungicides of this group have already presented reduced disease control efficiency for other crops (10). Even so, double and triple mixtures were registered and started to be used with these three specific fungicide groups (triazoles, strobilurins and carboxamides) (1). The question is: for how long will such formulated fungicide mixtures be specifically effective to control ASR? The answer to this question is not very difficult since reduced efficiency of the applied mixtures can already be noticed. Selection of *P. pachyrhizi* individuals resistant to the three active ingredients used in mixtures would be the first, and so far, the unique case reported in the chemical control of plant diseases. Furthermore, in disease control programs, systemic fungicides are often applied as 'curative', which facilitates the selection of resistant individuals due to the larger pathogen population. What will be the future of chemical control for ASR if, in the short and medium term, there will be no more chemical groups on the market with specific mode of action to recommend? In our view, there will be no further possibility of using fungicides with specific mode of action, either alone or in mixture with other systemic fungicides with different modes of action. To reduce the selection pressure of systemic fungicides on the pathogen, the number of application/area of these

chemicals will need to be reduced. Such fungicides should be used only when the environmental conditions favor the disease development (rain, temperature and leaf wetness). Disease forecast programs are of great importance to decide when systemic fungicides can be used to control ASR (2). Under low pressure of the disease and unfavorable environmental conditions, protectant fungicides are very important to reduce the disease selection pressure and consequently the fungal resistance. Thus, there will be a need to use generalized mode-of-action fungicides as protectant in mixtures with systemic site-specific mode-of-action fungicides, remaining the chemicals of the dithiocarbamate (mancozeb) and nitrile (chlorothalonil) groups that individually have medium to low efficiency in controlling the disease. But an additive effect of mancozeb and chlorothalonil in mixture with systemic fungicides (triazole, strobilurins and carboxamides) has been obtained during the two last crop seasons on ASR control and productivity (*Ponce & Zambolim, 2017). The great advantage of using these chemicals is that they act to reduce the chances of selecting resistant mutants among *P. pachyrhizi* population due to their generalized mode-of-action on the fungal population. Formulated mixtures or tank mixtures of systemic fungicides with mancozeb, chlorothalonil or other efficient protectant fungicides would therefore be of great importance to increase the effective life of systemic fungicides. Development of resistance to triple mixtures is probably a unique case in the world and, although this measure is recommended for ASR control, in our view it will not be durable.

ACKNOWLEDGMENTS

To Professor Eduardo Seite Gomide Mizubuti and Emerson Del Ponte, from the Department of Phytopathology, Universidade Federal de Viçosa, for critical review of the manuscript and valuable suggestions.

*Ponce, R.; Zambolim, L. Additive effect of protector fungicides in mixture with systemics and strobilurin on the control of Asian soybean rust and yield. Results obtained in 2016/2017. Not published.

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