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Potassium phosphite combined with reduced doses of fungicides provides efficient protection against potato late blight in large-scale field trials

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ABSTRACT

Potato late blight caused by the oomycete *Phytophthora infestans* is a devastating disease of potato worldwide. Most of the potato cultivars grown in conventional agriculture are susceptible, or at best moderately resistant, and require frequent applications of fungicides to avoid heavy yield losses.

In field trials spanning four years, we have investigated the effect of potassium phosphite, an inorganic salt on potato late blight. Potassium phosphite is known to induce defence responses in potato and to also have direct toxic effects on oomycetes, which in turn counteract late blight and tuber blight development. However, the use of this salt is not yet implemented and approved in European potato cultivation. We compared the effect of phosphite alone with fungicides currently used in Swedish potato cultivation. We also investigated the combined use of potassium phosphite and reduced doses of fungicides. Table potato cultivars and starch potato cultivars with different levels of resistance were used.

We found that potassium phosphite in combination with reduced doses of fungicides results in the same level of protection as treatments with the recommended full dose of fungicides. These combined treatments reduce the need of traditional fungicides and may also decrease the selection pressure for fungicide resistance development in the pathogen. In relatively resistant starch potato cultivars using phosphite alone gave sufficient protection against late blight. Furthermore, in starch potato a combination of phosphite and fungicides at two-week intervals provided similar protection to weekly applications of fungicide at the recommended dose. Foliar treatment with phosphite also gave protection against tuber blight at similar levels to that of the best-performing fungicide. Our data suggests that potassium phosphite could be used in potato cultivation in temperate regions such as in Sweden, at least in combinations with reduced rates of fungicides. The implementation of the use of phosphite in practical potato crop protection as part of an IPM strategy is discussed. Doses, intervals and combinations could be adjusted to the level of cultivar resistance.

1. Introduction

Late blight, caused by the oomycete *Phytophthora infestans*, remains the most important plant protection problem in potato in the majority of the growing areas in the world. Since most cultivars grown are susceptible or at best moderately resistant, frequent fungicide treatments are necessary to protect the crop. However, despite the frequent sprayings with fungicides late blight still causes large economic losses (Haverkort et al., 2009). With classical breeding, which is time consuming, it has been difficult to obtain durable resistance since the pathogen can adapt rapidly, overcoming introduced resistance genes. Stacking of resistance genes maybe a solution in the future, but so far cultivars containing such genes alongside all the other desirable agricultural traits are not yet available (Eriksson et al., 2016).

For environmental reasons and to meet long term consumer demands there is a need to develop alternative methods of late blight control that can be combined with fungicide treatments and

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thereby reduce the amount of fungicides necessary for efficient control of late blight. Induced resistance, i.e. exogenous application of non-toxic compounds or microorganisms that stimulate plant defence, is a control method that on its own may not be efficient enough for control of such a devastating disease as late blight but may play a role if combined with other methods such as fungicide treatment. The resistance inducer BABA (β-amino butyric acid) has for example been shown to improve defence against *Phytophthora infestans* in potato, in laboratory experiments, in the greenhouse, and under field conditions (Baider and Cohen, 2003; Bengtsson et al., 2014; Eschen-Lippold et al., 2010; Liljeroth et al., 2010). However, the efficacy under field conditions is not sufficient even if BABA may be possible to apply in combination with fungicides (Liljeroth et al., 2010). Many other inducers of immune responses have been shown to reduce potato late blight such as biosurfactants and plant extracts, e.g. sugar beet extract (Bengtsson et al., 2015; Moushib et al., 2013).

Phosphite salts, e.g. potassium phosphite, may be more promising due to their combined effects. As well as inducing defence reactions in the plant they also have a direct inhibiting effect on growth and sporulation of oomycetes (Fenn and Coffey, 1989; Grant et al., 1990; Smillie et al., 1989). However, the precise mode of action is still unclear. In some developing countries phosphite salts have been promoted and are used against late blight since they pose lower risks for human health and the environment compared to conventional fungicides (Kromann et al., 2012). An analysis of field data from several tropical countries revealed that phosphites provide control efficacy comparable to conventional contact fungicides, such as mancozeb and chlorothalonil. Furthermore, the control appeared to be relatively stable across locations (Kromann et al., 2012).

Several recent laboratory studies show that application of phosphite compounds improves plant defence (Burra et al., 2014; Eshraghi et al., 2011; Lim et al., 2013; Massoud et al., 2012). A proteomics study by Lim et al. (2013) reported that phosphite triggers complex functional changes in potato leaves, which may explain induced resistance against *P. infestans*. Among up-regulated proteins the majority were defence related and associated with the SA-dependent pathway, antimicrobial activity, the ROS pathway, the Ca^{2+} dependent pathway and the hypersensitivity reaction (HR). Since expression trends of the differentially expressed genes after phosphite treatment were rather similar to *P. infestans* infected plants at 4 days post-inoculation, it may be that pre-activation of genes by phosphite induces faster defence responses or that rather few genes are highly relevant for induced disease resistance. We previously analyzed transcriptomic and proteomic changes following response of phosphite treatment prior to pathogen infection (Burra et al., 2014). Multiple defence pathways were rapidly induced by phosphite treatment. The results indicated that phosphite influences primary metabolism and cell wall associated processes.

Besides the field studies of phosphites against late blight in tropical agriculture (Kromann et al., 2012) there are only a few reports of the field efficacy of phosphites against late blight in other parts of the world. The effect on foliar late blight was demonstrated by Cooke and Little (2002) but this study did not directly compare phosphite efficacy with the efficacy of traditional fungicides. Mayton et al. (2008) reported that potassium phosphite protected against both foliar late blight and tuber blight at least as well as the fungicide chlorothalonil. Wang-Pruski et al. (2010) also reported a significant protecting effect of phosphite, which was enhanced when it was used in combination with chlorothalonil. No other comparisons with modern fungicides have been reported in scientific literature. To evaluate if the use of modern fungicides in different potato growing regions could be reduced by combined use of potassium phosphite/fungicide treatments, field trials of such strategies are needed.

In this study we have investigated the effect of potassium phosphite and modern fungicides on late blight development in full-scale field trials spanning 4 years in Sweden. Food potato and starch potato cultivars with different levels of partial resistance were investigated and phosphite was applied either alone or in combination with commonly used fungicides. Our data strongly suggests that using phosphite in combination with reduced doses of fungicides gives good protection against potato late blight. The possible integration of phosphite into practical potato crop protection strategies and potential drawbacks are discussed.

2. Materials and methods

2.1. Field experiments

All field trials were carried out by the 'Swedish Rural Economy and Agricultural Societies' in Mosslunda south of Kristianstad, Sweden. In each year a different field was used, situated no more than 2 km from other fields. The field trials were performed according to Good Experimental Practice (GEP) consistent with EU directive 93/71, KIFS 2004:4, STAFS 2001:1 and Standard Operative Procedures, SLU 2004.

2.1.1. Experimental design

At each place the trials were performed with a randomized block design containing four blocks. Each plot was 5 rows of 10 m length, from which the middle 3 rows were harvested. Between block 1 and 2 and between block 3 and 4, three rows of untreated plants were grown, serving as infector plants. No *P. infestans* inoculations were carried out.

In the first three years (2011–2013) both table potato cultivars and starch potato cultivars with different levels of resistance were used. In 2014 two table potato cultivars were used. The susceptible cultivar Bintje was used throughout all years and was compared with different partially resistant food potato cultivars. The starch potato cultivars Seresta and Merano were used between 2011 and 2013.

The treatments against late blight were applied once a week, starting at the end of June when the canopy covered the rows and continuing until crop maturation. This resulted in a total of 11–13 application times (T1-T13). Occasionally, a single day deviation from this scheme happened due to unfavourable weather conditions for spraying. Fungicides (Shirlan, a.i. fluazinam; Ranman Top, a.i. cyazofamid; Revus, a.i. mandipropamid; Epok, a.i. metalaxyl-M + fluazinam; Infinito a.i. fluopicolide + propamocarb), β-amino-butyric acid (BABA; Sigma, Stockholm, Sweden) and Proalexin (LMI AB Sweden, Helsingborg, Sweden; a.i. potassium phosphite) were applied at different doses and in different combinations as described below.

2.1.2. Experiments 2011

Two experiments were carried out with two table potato cultivars (Bintje and Ovatio) in the first experiment and two starch potato cultivars (Merano and Seresta) in the second one. Besides the untreated control different treatments were applied. Shirlan at standard recommended dose was compared with reduced dose and combinations with BABA and Proalexin according to Table 1.

2.1.3. Experiments 2012

Four experiments with similar treatments were carried out. In two of the experiments table potato (cvs. Bintje and Ovatio) and in the other two experiments starch potato (cvs. Seresta and Merano) were used (Table 2). A fungicide strategy commonly used by