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Short communication

Control of loose smut (*Ustilago nuda* and *U. tritici*) infections in barley and wheat by foliar applications of systemic fungicides

Peter Jones
Department of Plant Science, University College, Cork, Ireland (Fax: (+353) 21 274420; E-mail: p.jones@ucc.ie)

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Abstract

Foliar application of a number of broad-spectrum systemic fungicides (particularly conazole fungicides) to loose smut-infected plants of wheat and barley in a 3-spray programme resulted in a marked reduction in the percentage of plants producing infected ears. Such foliar fungicides may have a previously unseen role in reducing the levels of loose smut infection in wheat and barley.

Introduction

Ustilago nuda (Jens.) Rostr. and *Ustilago tritici* (Pers.) Rost. are two closely-related seed-borne fungi, which are the causative organisms of the diseases loose smut of barley and wheat, respectively. The fungi colonise the embryo and move (largely intercellularly) within the infected plant, being found particularly in the nodes and the ear (Batts and Jeater, 1958). During the period from glume differentiation to the start of floret differentiation, the growth rate of the fungal mycelium increases significantly (Malik and Batts, 1960; Dean, 1964), the fungus develops intracellularly as well as intercellularly (Dean, 1964) and penetrates all spikelet tissues except the rachis and the awns (Shinohara, 1976). The development of sporiferous hyphae starts early in ear development (Batts and Jeater, 1958; Shinohara, 1976); by the time the ear of an infected plant emerges from the leaf sheath, the infected tissues have been transformed into a mass of olive-brown spores.

Once major diseases wherever wheat and barley were grown, the loose smuts are now minor problems in European cereal-growing regions, including Ireland (Dhitaphichit and Jones, 1991). Control has been based primarily on seed-certification schemes (Doling, 1966; Anonymous, 1980) and the use of systemic seed fungicides. The first such chemicals were the Basidiomycete-specific carboxins (Edgington et al., 1966; von Schmeling and Kulka, 1966), followed by several carboxamides, including fenfuram (Martin and Edgington, 1980). In the 1980's, broad-spectrum systemic seed fungicides, including azoles (such as triadimenol, fenapanil, imazalil and flutriafol), and morpholines (e.g. fenpropimorph), were introduced. Aimed primarily at the early control of foliar diseases such as powdery mildews, the high cost of these fungicides has restricted their use in loose smut control programmes to Breeder's, pre-Basic and Basic seed, and to Certified seed where an embryo test has indicated an above-threshold level of infection (Wray and Pickett, 1985).

The use of foliar applications of fungicides to eliminate the fungus from infected plants was first observed (for carboxin) by von Schmeling and Kulka (1966). Jones (1997) demonstrated that foliar application of tradimefon (structurally similar to the seed fungicide, triadimenol, with activity against loose smut; Worthing and Hance, 1991), especially during the early stages of stem extension, could greatly reduce the levels of loose smut infection in wheat and barley plants grown from infected seed, while late application of this chemical also reduced reinfection of ovaries. The fact that several other active ingredients used in broad-spectrum seed fungicides, including flutriafol, are also widely used in cereal crop sprays to control major foliar diseases, such as powdery mildews and rusts, lead to the current investigation of how widespread is the phenomenon of loose smut elimination by the use of foliar fungicides.

Methods

Naturally-infected seed of winter barley cv. Panda (24.2% infection, as determined by the embryo test; Rennie and Seaton, 1975) and spring wheat cv. Chinese Spring (21.3% infection) was used. Seed was drilled in 4 m $\times$ 1 m microplots at densities of 350 seeds m^{-2} in autumn (for barley) and 300 seeds m^{-2} in spring (wheat). Nitrogen was applied at rates of 150 kg ha^{-1} (barley) and 120 kg ha^{-1} (wheat) in two splits: seed bed (40 kg ha^{-1}) and GS31 (remainder). Each fungicide was applied at GS 31, 39 and 59 (Zadoks et al., 1974). Each fungicide (Table 1) was applied (using a back-pack sprayer) at full strength, according to the manufacturer's recommendations, at 160 ml m^{-2}, four times the maximum recommended spray volume (but insufficient to cause significant run-off) because of the small areas involved. Applications of fungicides to infected wheat and barley seed was achieved by shaking carboxin (as 'Murganic RPB' (Murphy Chemical), 160 g 100 kg^{-1} seed) or triadimenol (as 'Baytan' (Bayer), 40 g 100 kg^{-1} seed) in a sealed bag with 500 g of seed for 2 min. Each fungicide treatment was replicated four times, with the trial set out in a replicated randomised block design.

Infection levels were scored as percentage plant infection; any plant with one or more smutted ears (completely or partially smutted) was recorded as infected. The experimental data were analysed by parametric analysis of variance and multiple comparisons were conducted using Fisher's Protected Least Significant Difference.

Results and discussion

Eradicant activity was restricted to fungicides with systemic action (Table 1). Microplots sprayed with either of the two contact fungicides tested, dinocap and sulphur, exhibited infection levels similar to the embryo test infection values (Table 1). Seven of the fifteen foliar-applied fungicides tested resulted in very marked (at least 60%) significant reductions in the expression

Table 1. Effect of foliar- and seed-applied fungicide treatments on percentage plant loose smut infection levels in barley and wheat

Tissue treated	Fungicide (class)	Wheat cv. Chinese Spring[a]	Barley cv. Panda[b]
Foliage	Flutriafol (azole)	5.0	3.9
	Imazalil (azole)	18.5	20.1
	Propiconazole (azole)	3.6	5.3
	Tebuconazole (azole)	2.3	4.1
	Triadimefon (azole)	1.9	2.3
	Fenpropimorph (morpholine)	15.9	18.9
	Tridemorph (morpholine)	18.9	23.3
	Fenpropidin (morpholine)	22.4	21.7
	Benomyl (benzimidazole)	16.3	15.5
	Carbendazim (benzimidazole)	8.5	13.1
	Fenfuram (carboxamide)	2.3	2.5
	Iprodione (dicarboximide)	23.5	21.9
	Dinocap (dinitrophenol)	20.8	24.6
	Guazatine (guanidine)	6.5	14.8
	Sulphur	22.0	22.5
Seed	Carboxin (carboxamide)	1.2	3.8
	Triadimenol (azole)	0.5	1.6
	LSD (*P* 0.05)	4.6	

[a]Seed infection level: 21.3%.
[b]Seed infection level: 24.2%.

of loose smut infection, compared to the seed infection levels estimated by the embryo test and the plant infection levels in plots treated with contact fungicides (Table 1). Wheat and barley reacted very similarly to the fungicides; a highly significant positive correlation was obtained between the plant infection levels exhibited by wheat and barley crops treated with foliar fungicides ($r = +0.973, n = 15, P < 0.001$). Differences did occur, however; both guazatine and carbendazim were significantly less effective ($P < 0.05$) in barley than in wheat, while the difference for tridemorph was significant at the $P < 0.10$ level.

Treatment with five of the foliar fungicides resulted in such large reductions in infection levels, that they were not significantly different from those obtained from carboxin- (or triadimenol-) treated seeds for both wheat and barley. Four of these chemicals were of the azole class of demethylation inhibitors (tebuconazole, propiconazole, flutriafol and triadimefon), the fifth (fenfuram) being a carboxamide fungicide; surprisingly, a fifth foliar-applied azole fungicide, imazalil, was inactive against both species. Lower significant levels of control of both species were obtained with guazatine (a guanidine fungicide), fenpropimorph (a morpholine fungicide) and the two benzimidazole chemicals carbendazim and benomyl (Table 1).

The activity towards seed-borne *Ustilago* spp. of several of the fungicides identified is not unexpected. Tebuconazole, flutriafol, guazatine and fenfuram are also commonly used as seed fungicides, with tebuconazole and guazatine having proven activity towards members of the Ustilaginales (Worthing and Hance, 1991), although guazatine has only low activity against *U. nuda* when used as a seed treatment (D. Bartlett, personal communication, 1997).

In Ireland and the UK, prophylactic fungicide application strategies in cereals involve two- (GS39 and GS59) or three-spray programmes (GS31, GS39 and GS59; Anonymous, 1986) using broad-spectrum systemic fungicides such as those used in this study. The results of this research suggest that these treatments may, in addition to their intended effects on foliar pathogens, also reduce levels of loose smut (Jones, 1997). This study expands on earlier work (Jones, 1997) and indicates that the eradicant effect of systemic foliar fungicides on loose smut infection is achieved by a range of chemicals. Jones (1997) demonstrated that, in terms of loose smut elimination, the earliest application of tradimefon (at GS31) was the most effective; this is the application most commonly omitted when a 2-spray prophylactic programme is used. These studies should be extended to other seed-borne pathogenic fungi which develop systemically within the infected plant (e.g. *Pyrenophora graminea*, *Tilletia caries* and members of the *Fusarium* ear blight complex). Significant reductions in these important pathogens may make the inclusion of an early (GS31) fungicide spray economically viable in the control of both foliar and seed-borne pathogens. It is not suggested that seed fungicides should be replaced by foliar fungicides to control seed-borne pathogens; the former method is less expensive and more effective than the latter. Rather, in countries like Ireland and the UK where there is a tradition of sowing untreated farm-saved cereal seed, decisions as to whether a prophylactic foliar fungicide application should be made at approximately GS31 to control foliar diseases, should also take into account the impact of the fungicide on systemic seed-borne pathogens.

References

Anonymous (1980) The Cereal Seed Regulations, 1980. Her Majesty's Stationery Office, London

Anonymous (1986) Use of fungicides and insecticides on cereals, Booklet 2257. MAFF Publications, Alnwich, UK

Batts CCV and Jeater A (1958) The development of loose smut (*Ustilago tritici*) in susceptible varieties of wheat, and some observations on field infections. Transactions of the British Mycological Society 41: 115–125

Dean WJ (1964) Some effects of temperature and humidity on loose smut of wheat. PhD thesis. University of Nottingham, Nottingham, UK

Dhitaphichit P and Jones P (1991) Virulent and fungicide-tolerant races of loose smut (*Ustilago nuda* and *U. tritici*) in Ireland. Plant Pathology 40: 508–514

Doling DA (1966) Loose smut in wheat and barley. Agriculture, London 73: 523–527

Edgington LV, Walton GS and Miller PM (1966) Fungicides selective for Basidiomycetes. Science 153: 307–308

Jones P (1997) Control of loose smut (*Ustilago nuda* and *U. tritici*) infections in barley and wheat plants by foliar application of triadimefon. Plant Pathology 46: 946–951

Malik MMS and Batts CCV (1960) The development of loose smut (*Ustilgo nuda*) in barley plants, with observations on spore formation in nature and in culture. Transactions of the British Mycological Society 43: 126–131

Martin RA and Edgington IV (1980) Effect of temperature on efficiency of triadimenol and fenapanil to control loose smut in barley. Canadian Journal of Plant Pathology 2: 201–204

Rennie WJ and Seaton RD (1975) Loose smut of barley. The embryo test as a means of assessing loose smut infection in seed stocks. Seed Science and Technology 3: 697–709

Shinohara M (1976) Behaviour of *Ustilago nuda* (Jens.) Rostrup and *U. tritici* (Pers.) Rostrup in their host tissues. Review of Plant Protection Research 9: 124–142

von Schmeling B and Kulka M (1966) Systemic fungicidal activity of 1,4-oxathiin derivatives. Science 152: 659–660

Worthing CR and Hance RJ (1991) The Pesticide Manual. A World Compendium, Ninth Edition. British Crop Protection Council, UK

Wray MW and Pickett AA (1985) Trends in loose smut (*Ustilago nuda*) infections in certified seed of barely in England and Wales 1976 to 1983. Journal of the National Institute of Agricultural Botany 17: 31–40

Zadoks JC, Chang TT and Konzak CF (1974) A decimal code for the growth stage of cereals. Weed Research 14: 415–421