Session 1
Symposium Opening

Chairman and
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SEED TREATMENT - A PANACEA FOR PLANT PROTECTION?

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ABSTRACT

Milestones in seed dressing development, main products and uses, characteristics of the market (by products, crops, regions) and untapped potentials/chances are described.

INTRODUCTION

Before discussing the question raised in the title a brief overview will be given highlighting the past development, present status and some market aspects of seed treatment. At the same time, this general introduction is intended to set the scene for the following papers dealing with concrete contributions to this topic.

Worldwide, around 90% of all food crops are propagated by seed. The seed, besides being the carrier of the genetic potential of the plant developing from it, is an involuntary carrier of propagation units of pathogens and pests and an excellent food basis for the structures emerging from them. The seedling/plantlet is the most vulnerable stage of plant development, susceptible to adverse growing conditions in general and specifically to parasitic organisms. Thus, seed treatment, that is, the application of bioactive chemicals, or antagonistic or symbiotic micro-organisms to the seed prior to sowing may aim at:

- the protection against seed- and soil-borne pathogens and animal pests (Hewett and Griffiths, 1986)
- the protection of the seedling from damage by herbicides by safening agents (Hatzious and Hoagland, 1989)
- physical treatments (heat) to control deep-seated seed-borne pathogens (Appel and Gassner, 1907) including viruses
- the stimulation of germination and/or enhancement of growth during the seedling stage by application of nutrients
- the speedy establishment of beneficial micro-organisms on the roots, for fixing nitrogen, enhancing nutrient uptake (VAM), or stimulating growth of seedlings (bacteria)
- the facilitation of sowing by standardising the shape of seeds by pelleting techniques.

The many-fold advantages and benefits of seed treatment as a major crop protection measure in comparison to soil application or foliar sprays have been described by several authors (Graham-Bryce, 1973; Powell and Matthews, 1988; Suett, 1988; Taylor and Harman, 1990), therefore, they will not be repeated here. However, by briefly describing the history and main characteristics of seed treatment they will become evident.

SEED TREATMENT CHRONICLE

The history of chemical seed treatment, the oldest practice in plant protection, has been documented in a range of reviews (Keitt, 1959; Frohberger, 1969; Neergard, 1977; Ainsworth, 1981; Jeffs, 1986). Major milestones in this development are summarised in Table 1.

TABLE 1. Selected milestones in the development of chemical seed treatments (compiled from Ainsworth, 1981; Frohberger, 1969; Jeffs, 1986; Neergard, 1977).

Since 1755	First proof of contagious nature of wheat bunt based on field trials (Tillet, 1755) and of activity of copper sulfate against it (Schulthess, 1761; Tesier, 1779).
Since 1800	Use of various inorganic salts against bunt and smuts.
Since 1807	Increasing use of copper sulphate against cereal smuts/ bunts, based on scientific work by Prévost, 1807, and Kühn, 1873.
1895-1897	Formalin against smuts/bunt (Geuther, 1895; Bolley, 1897).
Since 1914	Organic mercury compounds against bunt, snow mould etc. become dominating based on pioneering work of Wesenberg (1938) and Riehm (1914).
1942	Thiram (Tisdale and Flenner), broad spectrum fungicide.
1945	γ-hexachlorocyclohexane (γ-HCH) (Slade, 1945), first organic insecticidal seed treatment.
1945	Introduction of hexachlorobenzene (Yersin *et al*) against cereal bunt.
1952	Captan as a broad spectrum fungicide (Kittleson).
1962	Methiocarb (Unterstenhöfer), insecticide/bird repellent.
1965	Carbofuran (McEwen and Davis), broad spectrum systemic insecticide.
1966	Carboxin, first systemic fungicide against cereal smuts (von Schmeling and Kulka).
1968	Guazatine, broad spectrum fungicide (Jackson *et al,* 1973).
1969	Ethirimol, first systemic fungicide against powdery mildew by seed treatment (Bebbington *et al*).
1973	Imazalil against seed-borne *Helminthosporium* spp (Bartlett and Ballard, 1973).
1977	Metalaxyl, first systemic fungicide against downy mildews (Schwinn *et al*).
1978	Triadimenol, broad spectrum systemic fungicide, including control of powdery mildew by seed treatment (Frohberger).
1981	Furathiocarb, systemic insecticide for maize, sugar beet, oilseed rape, vegetables (Bachmann and Drabek).
1981	Pencycuron, residual fungicide against *Rhizoctonia* on potatoes (Frohberger and Grossmann).
1982-1992	Ban of mercury-based products in EC countries.
1986	Tefluthrin, insecticide for sugar beet and maize (Jutsum *et al*).
1988	Fenpiclonil, broad spectrum residual fungicide (Koch and Leadbeater, 1992).
1990	Imidacloprid, broad spectrum insecticide (Elbert *et al*).

From the beginning, it focused on small grain cereals as the most important staple crop in Europe which had to be protected from attack by fungal pathogens. Without covering the centuries since Roman times during which cereal seed was treated with products of questionable performance against unspecified problems, Table 1 shows the stepwise development from treatments with inorganic salts against bunt since the 19th century, to formalin as the first organic compound and the first to control smut (replacing hot water treatment), to the organo-mercuries, which dominated the scene from the 1920s to the 1980s, the introduction of Gamma-BHC as the first insecticidal treatment in the late 1940s and finally to the introduction of novel residual and apoplastically systemic fungicides (the latter against deep-seated pathogens) and to a lesser extent, insecticides, since the 1960s. The systemic fungicides (for literature see Davidse and de Waard, 1984) opened the door to a novel approach to disease control, that is, the control of foliar and systemic pathogens by seed treatment. This is a highly attractive approach particularly from the viewpoint of efficacy, targeted application and environmental aspects. Ethirimol and triadimenol against cereal powdery mildew and metalaxyl against systemic downy mildews were the pioneers in this field. However, there are three limiting factors to this approach:

1. The risk of resistance development. We know, from broad experience, that the duration of exposure of a pathogen population to selection pressure by a fungicide, is a major risk factor for resistance-prone chemicals such as the single-site systemic fungicides. Despite cases of resistance to residual seed-applied fungicides, starting with hexachlorobenzene/bunt (Kuiper, 1965) and leading on to mercury compounds/*Pyrenophora graminicola* (Jones *et al*, 1989) and benzimidazoles *Gerlachia nivalis* (Hartke and Buchenauer, 1981; Locke *et al*, 1987), respectively, the risk has become much more serious with the introduction of systemic compounds. Fortunately, in contrast to foliar diseases, resistance in seed- and soil-borne pathogens still is comparatively rare. In order to stay on the safe side, industry and advisory services have to find the balance between the farmer's interest in long-lasting control and their responsibility for avoiding resistance and offering a practicable compromise to the user. With regard to the control of foliar pathogens by seed treatment, the solution could mean a use restriction to spring cereals and/or winter cereals in mild climates without an extended dormant phase of the crop.

2. The persistence of the fungicide, which on the one hand should be limited in order to avoid residues in the edible parts of the crop; on the other hand, longevity of the molecule expands the period of protection, making the product more attractive to the farmer.

3. Crop tolerance, that is, inhibition/retardation of germination and/or seedling growth which may be an inherent feature of such compounds.

ANALYSIS OF SEED TREATMENT USE

Seed treatment started (Table 1) in small grain cereals in temperate zones for their protection against fungal pathogens, firstly bunt and smut, later snow mould and other seed- and soil-borne pathogens (for literature see Bateman *et al*, 1986).

Since then and till now they have held the leading position in the fungicide seed treatment market (Table 2). However, considering the vast variety of biological problems and the marginal role of seed treatment in many parts of the world, there are untapped market potentials in bulk crops like rice and cotton and many speciality crops. In contrast to fungicides, for insecticidal seed treatments maize, followed by sugar beets, cotton and rice, are the dominating crops.

TABLE 2. The seed-dressing market by crops (figures represent percentage of total). 1991 figures.

Crop	Total	Fungicides		Insecticides	
Small-grain cereals	54	64	(1)	3	(5)
Potatoes	11	15	(2)	-	
Maize	7	2	(6)	44	(1)
Rice	6	7	(3)	14	(4)
Cotton	6	5	(4)	16	(3)
Oilseed rape	3	?		?	
Sugar beet	2	-		17	(2)
Legumes	2	3	(5)	1	(6)
Soybeans	2	2	(6)	-	
Vegetables	?	1	(7)	3	(5)
Total	93	99		98	

( ) = ranking within fungicides/insecticides. Source: Ciba-Geigy.

Fungicides clearly lead the seed treatment market, as shown in Table 3. The various chemical classes were compiled by Martin and Woodcock, (1983), in comparison, insecticide treatments play a minor role, they are used in combination with fungicides as much as they are used alone. Safeners and PGR's are only used on a very limited scale, although they may play a significant role in certain crops under specific growing conditions. There is ample room for much broader use.

The market shares of the different chemicals are shown in Table 4. It reveals a strong position of the top two products in all three categories. In addition, it shows in the case of fungicides the enormous number of active ingredients, and the present insignificance of mercury-based treatments after more than seventy years of dominance. It also illustrates the limited importance of the 51 chemicals not specified here, despite their significant role in certain niche crops and uses. They range from old products like thiram, maneb/mancozeb, quintozene and guazatine to novel types like bitertanol, metalaxyl, oxadixyl, and prochloraz. It can be assumed that these will increase in importance with the decrease and eventual removal of the old products from the market.

TABLE 3. The seed treatment market by product segments in % of total . 1991 figures.

Product group	% market share
Fungicides (F)	68
Insecticides (I)	11
Dual treatments (F + I)	11
Safeners	1
Plant growth regulators	1
Various	7
Total	99

Source: Ciba-Geigy

TABLE 4. Seed treatment market 1991. Ranking of products by market share.

Fungicides (F)		Insecticides (I)		Mixtures (F + I)	
Carboxin + mixtures; Triadimenol + mixtures	~ 40%	Carbofuran, Methiocarb	~ 70%	γ- BHC + fungicides; Tefluthrin + Oxine-Cu	~ 90%
Oxine-Cu + mixtures, Pencycuron, Captan, Benomyl, TBZ, Mercury.	~ 30%	Thiodicarb, Acephate, Disulfoton, Chlorpyrifos	~ 25%	Rest (= 6 products)	~ 5%
Rest (= 51 products)	~ 30%	Rest (= 14 products)	~ 5%		

Source: Ciba-Geigy

Just two insecticidal compounds, namely carbofuran and methiocarb, cover 70% of the market, both introduced some 30 years ago. Likewise the remaining insecticides in Table 4 were introduced 20 to 30 years ago. Thus, in contrast to fungicides, no novel chemical groups have entered the market or reached a sizeable position in the market. Newcomers like furathiocarb, imidacloprid or fipronil may change this picture within the next few years.

Even more surprising is the situation in the segment of dual mixtures. The 10% share of the total seed treatment market they hold is dominated by Gamma-BHC plus a wide range of commodity fungicide mixture partners, followed by tefluthrin plus oxine-Cu, both holding some 90% of this segment.

A glimpse at the geographical pattern of the seed treatment market shows the strong position of Western Europe (Table 5) with France and Germany as the leading countries. This is not surprising in view of the high market value of cereal crops in this part of the world, and, correspondingly, the high inputs the farmer grants them. To what extent this will change in connection with the new agricultural policy (CAP) of the EC remains to be seen. What can be said already, apart from the decrease in cultivated acreage, is that the cost pressure both on the farmer and the agrochemical industry is increasing, a trend which can only make seed treatments even more attractive, particularly if they manage to control early season stem and foliar diseases. Table 5 also underlines the importance of the CIC and the USA, with markets in the order of the leading Western European countries. If the productivity of cereal growing in these countries improves, there would be tremendous potential for more sophisticated seed treatments.

TABLE 5. World seed treatment market by regions (1991 figures) and ranking of countries within them.

Region/Countries	% market share
Western Europe (France, Germany, UK, rest)	40
Rest of the world (CIC [= ex USSR], USA, Canada, Brazil Central/Eastern Europe, Japan, rest)	60

Source: Ciba-Geigy

When considering the percentage of treated seed within crop species in the highest developed market (the EC), sugar beet and oilseed rape rank highest with more than 90% (Table 6). Over 80% of all other crops are treated with fungicides, with the exception of potatoes, but less than 20% receive insecticidal seed treatments alone.

Looking briefly at the development of application technology, a line can be drawn from powder formulations for dry seed treatment via water dispersible powders for slurry treatment to ready-to-use liquid formulations such as emulsions, flowables or solutions and micro-encapsulated active ingredients. In speciality crops such as sugar beet and vegetables, seed pelleting is common practice providing uniform seed shape for precision sowing and offering room for multiple chemical treatments, leading to lower quantities of seed/surface units. Film coating with special binders added to the chemical formulations provides good product adherence during handling, and protection from mechanical damage to the seed. Novel approaches in seed technology, like seed priming and precision sowing in crops other than sugar beet and vegetables will have an impact on seed treatments (for literature see Clayton, 1988; Taylor and Harman, 1990). This aspect will be dealt with in Session 7 of this meeting.

TABLE 6. Ranking of crops with regard to quantities and percentage treated in the EC.

By quantities (in t)	Percentage of seed treated with Fungicides		Insecticides	
wheat	sugar beet)		sugar beet)	> 90%
barley	oilseed rape)	> 90%	oilseed rape)	
potatoes	maize)		wheat)	
maize	barley)		maize)	
peas	wheat)	> 80%	barley)	< 20%
oilseed rape	peas)		peas)	
sugar beet	potatoes	- 40%	potatoes)	

Source: Ciba-Geigy

Depending on the seed species, treatments are carried out by breeders, seed propagators, seed processors or farmers. In the case of sugar beet, maize and vegetables the end user buys the treated seed, whereas in small grain cereals there is a trend towards on-farm treatments, a trend which may have implications with regard to formulation and the safety profile of the product. On-farm treatment is the method of choice in potatoes, tropical millet, sorghum and maize against the systemic downy mildews in developing countries where home saved seed predominates. In this segment, industry is selling special sachets and containers for mixing small seed quantities assuring simple and safe product use.

The development of seed treatment machinery would be a topic of its own right with many interesting aspects including those pointing at opportunities for further improvement with regard to uniformity of seed loading, economy of product use etc. In addition it would show the urgent need for improvement in many countries outside Western Europe which holds a leading position in this field. Some aspects of seed treatment techniques will be covered in Session 7.

In summarising, it can be seen that the history of seed treatment began with the development of non-defined agents, then inorganic molecules followed by non-selective organic biocides, mainly mercury-based molecules, then organic selective residual and lately systemic chemicals. New molecules are under development in industry such as phenylpyrroles, methoxyacrylates (ICIA 5504 and BAS 490 F), triticonazole, MON 24000 and triazoxide.

As a new element, biological products are about to enter the scene. They are preparations of living bacteria or fungi, antagonistic to seed- and soil-borne pathogens. After a long lead time, the first products of this type are now being introduced into the market, such as Kodiak, a *Bacillus subtilis* preparation or Blue Circle, a *Ps. cepacia* preparation against damping-off and nematodes respectively. There is a lot of potential for such products (for literature see Becker and Schwinn, 1993) and we will see more of them coming along provided the active principles are competitive with regard to biological performance, applicability, storage lifetime and cost. An interesting approach in this context is their combination with chemicals. Session 6 will deal with this topic in more detail.

Cereals as a crop and fungicides as treatments clearly dominate the scene both from the diversity of pathogens (for literature see Hewett and Griffiths, 1986), and variety of chemical solutions available (Tables 1, 2, 3). They also have a high potential outside the developed countries, and in other crops, such as, tropical graminaceous species, soybeans, and cotton.

Insecticidal seed treatments are only 11% of the fungicide market in size probably due to the fact that development of novel molecules was insignificant until recently. Turning this argument around, it means that their importance can increase with the development of more potent chemicals. This would hold particularly true if such novel compounds could replace the granular soil-applied insecticides. Considering the superiority of seed versus soil-application in terms of targeting, required dose and environmental side effects this development would be highly desirable.

Seed treatment is a small part of both the seed and the plant protection industry (Table 7). In addition, it is a highly diverse segment of their markets in terms of crops and products, scattered over a wide range of regions and price levels. Till now, the main markets are in Western Europe, the USA and Canada. In terms of application technology and price level Western Europe leads the seed treatment stakes. There is large potential outside these countries and in many more crops.

TABLE 7. Share of seed treatments in the plant protection and seed industry market (1991 figures) worldwide.

Market segment	Value in billion US $	% of total
Plant protection	25	100
of which seed treatments	0.88	3.5
Fungicides	5.2	100
of which seed treatments	0.5	10
Seed industry	10	100
of which seed protection	0.5	5

Source: Ciba-Geigy

Whereas small grain cereals, potatoes and maize are bulk crops (Table 7) which are still seed treated with relatively simple machinery in many countries, seed treatment of sugar beet and vegetables has reached a much higher level of sophistication.

As long as the cheap and biologically highly active, broad range organic mercury compounds dominated the cereal seed treatment market, this segment had low priority in the plant protection industry's research and development activities. It is interesting to reflect that the development of more selective, toxicologically and environmentally safer products was blocked for decades by the low price and excellent cost/benefit ratio of the existing products, despite their high acute toxicity. They required considerable safety measures at the application sites and created occasional problems in developing countries, when treated surplus seed was consumed by livestock or humans. The ban of mercury-based products has resulted in significant changes; the immediate need for toxicologically and environmentally safer, biologically sound replacements, at the expense of a significant increase in treatment costs, or, conversely, a more attractive price level for industry. All in all, these changes strongly stimulated industry's interest in this market segment. The development of alternative products also increased the trend away from professional seed treaters to on-farm application and towards new developments in formulation and machinery. Thus, the ban of mercury-based products, imposed in Germany as the first European country in 1982, in the UK only recently, marked the transition of seed treatment from a commodity to a speciality market. Here, the systemic fungicides have opened up a new dimension which has yet to be fully explored.

CONCLUDING COMMENTS

So can we expect seed treatment to become a panacea for crop protection, as the title of this paper suggests or does the question mark reflect uncertainty? What do we mean by "panacea"? Webster's Dictionary defines it as "a remedy for all ills or difficulties" or "a universal remedy". In this broad, general sense seed treatment does not live up to this definition yet.

However, the level of protection of seeds from pathogens and insect pests achieved with the contemporary products and technology, clearly underlines the advantages and benefits of this approach. The stimulating effect of the ban of mercury-based products on the development of superior alternatives has been illustrated above. As the value of quality seeds is more appreciated by the farmer, and if environmental restrictions on the use of plant protection chemicals continue to increase, seed treatment will become more and more attractive to industry and the whole profession. Already the traditional fungicidal and insecticidal seed treatments offer opportunities for considerable improvement, such as products against stem and early season foliar diseases or better chemicals against soil-borne pests. Agriculture still awaits seed treatments to control seed-borne bacteria and viruses; to protect against nematodes, slugs and rodents; chemicals inducing systemic plant resistance; novel bird repellents; seed-applied volatile herbicides; safeners against non-selective herbicides such as glyphosate and sulfonylureas; plant growth regulators and micronutrients; symbiotic mycorrhizal fungi; and the exploitation of film coating technology to provide product combinations with slow release properties.

Finally, if the huge markets outside the industrial countries and the traditional crops can be developed, seed treatment will attract even more interest from industry. So, with some imagination seed treatment has the potential of becoming a panacea for crop protection. On the other hand, life has taught us that "remedies for all ills or difficulties" are rare. Therefore, it is wiser to have less demanding expectations. But even a partial remedy or one which overcomes a major difficulty would mean an optimistic outlook for seed treatment, embracing stimulating challenges and attractive potentials (Graham-Bryce, 1988). During this meeting we hope to hear about progress in many aspects of seed treatment which will uphold my optimistic outlook.

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Session 2

Cereal Seed Treatment Strategies

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STRATEGIES FOR CEREAL SEED TREATMENT

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ABSTRACT

Following the withdrawal of organo-mercury fungicides in 1992 cereal growers have a choice of seed treatments or can consider sowing seed untreated. The paper reports on cereal seed treatment practice in a number of countries and discusses seed treatment strategies appropriate to the UK.

INTRODUCTION

For more than 50 years seed-borne pathogens of cereals were effectively controlled in the United Kingdom by the extensive and routine use of organo-mercury fungicides. Because they were effective against a number of potentially damaging diseases, were relatively inexpensive and easily applied, organo-mercury treatments were rapidly and almost universally accepted by cereal growers. In 1977 95% of all UK cereal seed was treated with organo-mercury fungicides (Steed et al., 1979). It has been suggested (Yarham and Jones, 1992) that organo-mercury treatments were so successful that, for many years, the diseases which they had been introduced to control were rare and almost unknown to UK farmers. Nevertheless, largely because of their low cost, they continued to be used as routine treatments by the great majority of cereal growers.

Organo-mercury treatments were ineffective against loose smut (Ustilago nuda) since inoculum occurs within the embryos of infected seeds and it required the development of the systemic fungicide carboxin to facilitate effective routine chemical control. The introduction of seed treatment fungicides for the control of seedling foliar pathogens offered growers additional benefits and eventually led to competition with organo-mercury for a share of the UK cereal seed treatment market.

Richardson (1986) made comparisons of spring barley and winter wheat crops grown from untreated and organo-mercury treated seed. He concluded that seed treatment, to protect against seed-borne pathogens, was not necessary for certified seed used to produce a non-seed crop. However, the low cost of organo-mercury fungicides meant that, at that time, there was no economic incentive to sow untreated seed.

In response to concerns over the toxicity and persistence of mercury in the environment, EC Council Directive 79/117/EC (Anon., 1979) prohibited the use of mercury in agriculture, although a derogation permitted its use in the UK until March 1992. With the withdrawal of organo-mercury growers were faced with a range of significantly more expensive treatments, some of which had a different spectrum of activity compared with the mercury-based fungicides. This led growers and their advisers to seek detailed information on the risks posed by seed-borne cereal pathogens and question the need for continued routine treatment.

According to Brodal (1993) only a proportion of cereal seed is treated in Norway and Sweden and seed treatment decisions are based on the results of tests for seed-borne pathogens. In many countries organo-mercury was withdrawn some years before 1992 and it was considered useful to seek information on seed treatment practice in some of these countries.

METHODS

A questionnaire was sent to seed certification authorities in Canada, Denmark, Finland, France, Ireland, New Zealand, Norway and Sweden during 1993. Respondents were asked to provide detailed answers to a number of questions and were encouraged to confirm their information, where appropriate, with extension and trade colleagues. Separate forms were issued for barley and wheat. Among the questions asked were:-

a. What proportion of your national crop is grown from (a) certified, (b) farm-saved seed?

b. What proportion of (a) certified, (b) farm-saved seed is sown untreated?

c. Are there standards for seed-borne pathogens in your seeds regulations/certification schemes?

d. What proportion of seed is tested for seed-borne pathogens?

e. Are decisions on seed treatment made as a result of seed testing information?

f. What do you consider to be the most important seed-borne pathogens?

g. What are the most commonly applied seed treatments?

h. Are different treatments applied to different generations of certified seed?

In 1992 the Pesticide Usage Survey Group at The Scottish Agricultural Science Agency (SASA) was asked to collect detailed information on cereal seed treatment usage on autumn sown cereals from Scottish growers during an Arable Survey of Pesticide Usage and in 1993 6 major seed processing companies and 5 operators of mobile seed dressers in Scotland were asked to provide information on autumn cereal seed treatment usage.

RESULTS

Table 1 shows the proportion of certified and farm-saved seed sown in each of the countries that responded to the questionnaire and indicates the proportion of certified seed sown untreated. Information on the proportion of farm-saved seed sown untreated was usually not available.

Table 1 Proportion of cereal seed sown as certified and farm-saved seed and percentage of certified seed sown untreated

Country	Certified seed %	Farm-saved seed %	Percentage of certified seed sown untreated	
			Wheat	Barley
Canada	40	60	Nil	2
Denmark	90	10	10	10
Finland	35	65	30	30
France	50	50	nil	nil
Ireland	94	6	nil	nil
New Zealand	55	45	nil	nil
Norway	65	35	10	38
Sweden	55	45	5	5-35

Certified seed, or commercial seed of equivalent quality, accounted for a higher proportion of the barley and wheat area than farm-saved seed in most cases, but there was considerable variation between countries. In Denmark and Ireland more than 90% of the area of these crops was sown with certified seed whereas in Canada, Finland, France and Sweden half the cereal area was sown with farm-saved seed.

In all countries except Ireland a small percentage of farm-saved cereal seed was sown untreated. Generally, relatively little certified seed was sown untreated, but in Finland 30% of certified cereal seed was claimed to be sown untreated and in Norway and Sweden up to 40% of certified spring barley seed was sown untreated. There was a general tendency to sow a higher proportion of spring varieties untreated.

The most important seed-borne pathogens on barley were considered to be Ustilago nuda and Pyrenophora graminea (Table 2). There was general agreement that Fusarium seedling blight was of little importance on barley. Cochliobolus sativus was considered to be important on susceptible barley varieties. Bunt (Tilletia spp) and seedling diseases caused by Fusarium nivale and Septoria nodorum were considered important on wheat.

Few countries have specific standards for seed-borne pathogens in seeds regulations (Table 2). Several quoted the EC Council Directive (Anon., 1966) which requires that "Harmful organisms which reduce the usefulness of the seed shall be at the lowest possible level" but this

Table 2 Seed-borne pathogens considered important (Y) in seed production

Country	Pathogen: *Ustilago nuda*	*Fusarium* spp	*Drechslera* spp	*Septoria* nodorum	*Tilletia* spp	*Other* spp	Standards applied through certification or in seeds regulations
Canada (Barley only)	Y	-	Y	-	-	Y*	*U.nuda* (seed standard)
Denmark	Y	Y	Y	Y	Y	-	None
Finland	Y	-	Y	Y	Y	-	None
France	Y	Y	Y	Y	-	-	None
Ireland	Y	Y	Y	-	-	-	None
New Zealand	-	-	-	-	-	-	*U.nuda* (field standard)
Norway	Y	Y	Y	Y	-	Y♦	*U.nuda* (field standard) Voluntary standards for seed-borne pathogens of barley to facilitate seed treatment decisions, because of pesticide reduction policies
Sweden	Y	Y	Y	Y	Y	YØ	*U.nuda*, *Fusarium* spp *S. nodorum*, *Tilletia* spp., *Drechslera* spp *Cochliobolus sativus*

**Ustilago hordei*
Ustilago nigra
Barley stripe mosaic virus

♦*Rhynchosporium secalis*

Ø*Cochliobolus sativus*

vague requirement is open to wide interpretation and is difficult to enforce. Sweden has quite specific standards for cereal seed health in its certification scheme and these are tied to requirements for the treatment of seed that fails to meet the standards. Seed that has relatively low levels of seed-borne pathogens is often sown untreated. Norway has no officially enforced standards but has recently introduced a voluntary scheme in which all spring cereal seed is tested and fungicide treatment is required only if threshold levels for seed-borne pathogens are exceeded. Fungicide seed treatment is positively discouraged if disease thresholds are not reached.

Although cereal seed treatment usage was reported to be high in all countries there is no general requirement for seed treatment in national regulations or in certification schemes except in Sweden where seed must be treated if the threshold levels for seed-borne pathogens are exceeded. A number of countries have specific standards for loose smut and effective treatment is required if the threshold is exceeded, either in laboratory tests (Canada) or in control plots of multiplication grades (Norway; UK).

Table 3 Proportion of barley and wheat tested for seed-borne pathogens

Country	Percentage seed tested Wheat	 Barley	Seed treatment decisions made as a result of seed testing
Canada	-	<25	No
Denmark	Some farm-saved seed	Most winter barley for loose smut	Yes, particularly to control loose smut
Finland	50	60	Yes
France	0.5	Nil	No
Ireland	45	20	Yes
New Zealand	Nil	Nil	No
Norway	30	100	Yes (barley)
Sweden	80	80	Yes

There is considerable variation in the amount of non-statutory testing being done for seed-borne pathogens and the extent to which seed treatment decisions are made on the basis of advisory laboratory test results (Table 3). In France and New Zealand there is almost no advisory testing and treatments are applied on a routine basis irrespective of seed health. In Canada, Denmark, Ireland and the UK tests are occasionally made for loose smut infection in barley and seed treatment decisions are made on the basis of these results. In Finland, Norway and Sweden a high proportion of seed (30-100%) is tested for a range of seed-borne pathogens and treatment decisions are influenced by seed-borne inoculum. The highest proportion of untreated seed is sown in these countries.

Tables 4 and 5 list the active ingredients most often used on wheat and barley in the countries that responded to the questionnaire. Tables 6 and 7 give an indication of the relative proportions of fungicides applied to winter wheat and winter barley sown in Scotland in 1992 and 1993. The data are rough estimates, from relatively small samples and are included to show the range of fungicides used.

Table 4 Fungicide usage on wheat seed

Country	Active ingredients	Estimated percentage of treated seed
Denmark	bitertanol + fuberidazole	90
	guazatine	< 10
Finland	carboxin + imazalil	70
	guazatine + imazalil	15
	triadimenol + imazalil	5
France	oxyquinolate + anthraquinone	40
	oxyquinolate + anthraquinone + lindane + endosulfan	20
New Zealand	triadimenol + imazalil	93
	flutriafol + imazalil	5
Norway	guazatine	80
	guazatine + imazalil	20
Sweden	guazatine	90
	bitertanol + fuberidazole	10

There was little evidence that seed treatment fungicides were regularly applied below recommended rates, except in the UK and Ireland where triadimenol + fuberidazole was sometimes applied at reduced rates, especially on wheat.

Only in Ireland and the UK did respondents indicate that different active ingredients were applied to different generations during seed multiplication. In both cases a much higher proportion of systemic fungicides effective against U.nuda were applied to multiplication grades of seed where the aim was to produce final generation seed that met loose smut standards in seed regulations. Respondents were asked to indicate whether their country had a policy to reduce seed treatment usage. There are general moves to reduce pesticide usage in a number of countries, notably in Scandinavia, but only in Norway is there a specific policy to reduce cereal seed treatment usage.

Table 5 Fungicide usage on barley seed

Country	Active ingredients	Estimated percentage of treated seed
Canada	carboxin	70
Denmark	imazalil + carboxin (or thiabendazole or fuberidazole)	90
Finland	carboxin + imazalil	70
	guazatine + imazalil	5
	triadimenol + imazalil	10
France	oxyquinolate + anthraquinone + flutriafol + ethirimol	80
Ireland	tebuconazole + lindane	65
	triadimenol + fuberidazole	20
	guazatine	15
New Zealand	triadimenol + imazalil	88
	flutriafol + imazalil	8
	carboxin + thiram	4
Norway	guazatine + imazalil	45
	imazalil	25
	thiabendazole + imazalil	20
	carboxin + imazalil	5
	guazatine	5
Sweden	guazatine + imazalil	95
	fenfuram or carboxin	5

DISCUSSION

Until the withdrawal of organo-mercury seed treatments in 1992, the choice for UK cereal growers was relatively simple. An inexpensive single purpose organo-mercury seed treatment could be used as an insurance, or a systemic seed treatment could be applied to both control seed-borne pathogens and give protection against early infection by foliar pathogens. Seed for further multiplication was usually treated with a systemic fungicide effective against U.nuda. UK cereal growers now have the choice of a range of treatments, all significantly more expensive than organo-mercury and with different spectra of disease control. With increasing economic pressures on cereal growers and the need to look critically at inputs, some will consider using the least expensive treatments, some will apply reduced rates of treatment, especially on farm-saved seed and a number may consider sowing some of their cereal area with untreated seed. Advice and information on seed treatments and the pathogens they control may come from different sources and will inevitably reflect the interests of the adviser. Seed merchants are generally reluctant to sell certified seed untreated, partly because fungicide seed

Table 6 Fungicide usage on Scottish winter wheat sown in 1992 and 1993

Fungicide	Percentage of treated seed: Certified seed 1992[1]	Certified seed 1993[2]	Farm-saved seed 1992[1]	Farm-saved seed 1993[3]
untreated	< 1	< 1	< 1	< 1
guazatine	20	55	30	60
carboxin + thiabendazole	25	10	35	15
triadimenol + fuberidazole (full rate)	45	25	20	15
triadimenol + fuberidazole (reduced rate)	10	< 5	15	5
fenpiclonil	-	< 5	-	< 1

Table 7 Fungicide usage on Scottish winter barley seed sown in 1992 and 1993

Fungicide	Percentage of treated seed: Certified seed 1992[1]	Certified seed 1993[2]	Farm-saved seed 1992[1]	Farm-saved seed 1993[3]
untreated	nil	< 1	< 2	< 2
guazatine + imazalil	25	40	10	35
carboxin + thiabendazole + imazalil	30	15	15	15
triadimenol + fuberidazole (full rate)	10	20	10	5
triadimenol + fuberidazole (reduced rate)	< 5	< 1	5	5
ethirimol + flutriafol + thiabendazole (full rate)	25	25	25	20
ethirimol + flutriafol + thiabendazole (reduced rate)	5	nil	35	20

[1] Data collected by PUS, SASA
[2] Information from Scottish seed merchants
[3] Information from Scottish operaters of mobile seed-cleaning equipment

treatments generate an important element of added value and also because of concerns over crop performance.

Information from other countries suggests no uniform approach to cereal seed treatment usage. In New Zealand almost all cereal seed is routinely treated with relatively expensive broad spectrum systemic fungicides. The seed is not tested prior to treatment and seed-borne diseases are said to be of no importance in cereal production. With modern seed treatments this is a simple and effective means of controlling seed-borne pathogens, but there is a significant cost to the grower. On the other hand a relatively high proportion of untreated cereal seed is sown in Finland, Norway and Sweden. Seed is tested prior to treatment and treatment decisions depend on the incidence of seed-borne pathogens. In Norway and Sweden treatment is discouraged if seed-borne pathogens are present only at low levels.

In the UK, Denmark and Ireland a small but significant proportion of cereal seed is farm-saved and some of this is tested before treatment. Seed treatment decisions are based on seed testing results, for example a guazatine or fenpiclonil treatment may be favoured if wheat seed is heavily infected with F.nivale; carboxin or flutriafol may be used if U.nuda is present. In the UK and Denmark the seed may occasionally be sown untreated if only low levels of seed-borne pathogens are found to be present.

A similar approach could be extended to certified seed and UK growers could save £30-£80 for each tonne of seed sown untreated. If seed is effectively treated during multiplication the final generation should be relatively free from bunt, covered smut (Ustilago hordei), loose smut and barley leaf stripe - the diseases which are mainly seed-borne and which can "build-up" rapidly in successive generations of untreated seed. However, seed treatment cannot guarantee freedom from infection in the subsequent generation since U.nuda and P.graminea can infect developing seed from neighbouring diseased crops and T.caries and U.hordei can contaminate healthy seed from cleaning equipment. Seed would therefore have to be tested to ensure relative freedom from these pathogens. Pathogens which cause seedling blights, particularly F.nivale and S.nodorum, are not specifically seed-borne and do not multiply only in the absence of seed treatment. Their development on seed is encouraged by rainfall soon after flowering and disease incidence on harvested seed is probably not influenced by seed treatment in the previous generation. It would be necessary to test untreated seed to ensure that these pathogens were unlikely to affect germination and emergence. The cost of testing would reduce savings made through not using seed treatment but, with large lots of certified seed, testing costs would be low.

More significant factors would be the delay in processing winter cereal seed until a test result was available and the cost to the merchant of rejecting seed stocks found to be infected. Spring barley seed would offer the best opportunity to reduce seed treatment usage, or target fungicides for specific disease control, since a high proportion of UK seed is likely to meet seed-borne disease thresholds and there would be adequate time for testing. In Scandinavia it is mainly spring sown seed that is untreated.

In the short term, interest in sowing untreated seed is likely to be limited mainly to farm-saved seed. Pressure to sell certified seed untreated will come only if the relative costs of farm-saved and certified seed change, for example by applying royalties to farm-saved seed, or through environmental pressure to reduce pesticide usage.

There are risks in extending the area of untreated cereal seed. Seed-borne pathogens can multiply rapidly between years, loose smut and leaf stripe can infect neighbouring seed crops and bunt can contaminate clean seed during processing. To avoid the multiplication of seed-borne pathogens seed should never be sown untreated for 2 or more generations and untreated seed should always be tested before sowing. However, growers are free to ignore such guidance and may, by so doing, increase inoculum levels in cereal crops, thereby increasing the risks to other growers.

Growers now have a wider choice of cereal seed treatments than ever before and they have opportunities to choose seed treatments most suited to their needs or make savings by sowing untreated seed. Decisions on seed treatment should be made in the light of professional advice and with knowledge of the health status of the seed.

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CEREAL SEED TREATMENT - RISKS, COSTS AND BENEFITS.

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ABSTRACT

Fungicide seed treatments are routinely applied to over 90% of winter wheat and barley crops in the UK; primarily to control the seed borne diseases, bunt (*Tilletia caries*), loose smut (*Ustilago nuda*) and leaf stripe (*Pyrenophora graminea*), and seed and soil-borne fusarium seedling blight. A 15 site field experiment on winter wheat and barley quantified the risk from soil-borne seedling blight, and the benefits of seed treatment derived foliar disease and take-all control. Single year results: i) support previous studies in suggesting that where healthy seed is sown there is on average little or no yield benefit from seed treatment, and ii) conclude, tentatively, that the risk from soil-borne seedling blight is low and that the benefits of broad spectrum seed treatment against foliar pathogens and take-all are likely to be small in all but a few specific circumstances. Data are presented on the costs, risks and benefits of seed treatment, to assess the consequences of moving to a strategy of disease control where treatments are applied in response to risks quantified by seed testing.

INTRODUCTION

Concluding a major review of the need for routine cereal seed treatment, Richardson (1986) stated that: "[from the results of over 220 treated vs. untreated comparisons] there were no significant differences in overall mean yield associated with the absence of treatment for either wheat or barley". He estimated that nearly two thirds of UK cereal crops could be left untreated. In contrast Yarham and Jones (1992), reviewing the use of cereal seed treatment, concluded: "Any general advocacy of non-treatment of seed would be irresponsible in the extreme".

Risk / cost / benefit analysis for the use of cereal seed treatment is complicated by: i) the wide range of target pathogens (seed-borne, soil-borne and foliar), ii) fear of achieving short term savings from non-treatment, at the long term expense of a population increase in currently minor pathogens, iii) savings from non-treatment by an individual leading to communal losses via wind-borne spores (Yarham, 1993), iv) the risk of systemic conazole seed treatments increasing the probability of fungicide resistance developing in 'non-target' or 'marginal target' foliar diseases, v) the absence of data or techniques to quantify the risk from soil-borne pathogens, vi) the short period available in the autumn for seed health to be assessed and for appropriate treatment decisions to be implemented, and vii) the risk of phytotoxic effects from treatment (Skou, 1989).

It is this diversity of considerations that leads to the apparently contradictory statements in the first paragraph.

One area of uncertainty arises because the risk of seedling loss due to soil-borne *Fusarium* (principally *F. nivale*) has not been quantified. Hence, even when seed has been tested for pathogens and found to be within tolerances, the risk of soil-borne fusarium seedling blight has made it: "...advisable to treat where there is a risk of winter crops being sown late, or where seed may be sown in unusually cold or wet seedbeds that may delay seedling emergence" (Rennie & Cockerell, 1993). As seedbed conditions cannot be predicted at the time of the treatment decision, most cereal growers err on the side of caution. This is a contributory factor to 97% and 93% of winter wheat and barley crops in England and Wales being grown from treated seed (Polley and Slough, 1992a;1992b).

With cereal producers re-evaluating the use of seed treatments following the withdrawal of organomercury - and with immunological and nucleic acid techniques offering the prospect of rapid seed health assessment (Ball & Reeves, 1992) - consideration of the costs, risks and benefits of seed treatment seems timely. This paper presents data to address these issues and reports initial results from a multi-site experiment to quantify the risk of soil-borne fusarium seedling blight on winter wheat and barley.

COSTS AND RISKS OF SEED TREATMENT

Economic cost

The cost to the grower of cereal seed treatment ranges from approximately £35 to £80 tonne^{-1} at current prices, depending on the product used.

Fungicide resistance risk

The use of some systemic conazole materials as seed treatments exposes foliar pathogen populations to fungicide during the autumn, winter and early spring - a period when selection pressure for the development of fungicide resistance would not otherwise occur. It is now widely accepted that the period of exposure is an important determinant of the risk of pesticide resistance (Staub, 1991), although the increase in risk is difficult to quantify.

Phytotoxicity

In the absence of a compensating positive response from disease control, any negative effect of seed treatment on crop yield is an additional cost to be borne by the grower. Deleterious effects of treatments on crop establishment and yield, whilst noted from practical experience when severe, have seldom been quantified in the literature (Skou, 1989). As few field crops have the benefit of an untreated control for comparison, such effects as may occur are not widely appreciated.

Environmental

Whilst seed treatments are a relatively benign form of pesticide use, they nevertheless carry some environmental cost. It is now widely accepted that routine use of pesticides should be replaced by a strategy where applications are made in response to quantified risks.

BENEFITS OF TREATMENT

Growers should at least be able to expect a yield or quality gain from seed treatment, meaned across sites and seasons, that would compensate for the treatment costs and risks defined above.

Conversely, any scheme that encouraged the use of untreated seed in some controlled circumstances should ensure that the grower would not be exposed to even a small probability of a catastrophic loss, which the farm business might not survive.

Protection from bunt, loose smut, covered smut and leaf stripe

Without an effective seed treatment strategy, bunt (*Tilletia caries*), loose smut (*Ustilago nuda*), leaf stripe (*Pyrenophora graminea*) and covered smut (*Ustilago hordei*) have the combined potential to render UK cereal production uncompetitive. In recent years routine treatment, predominantly with cheap organomercurial materials, has kept these diseases in check; although problems of fungicide resistance (to carboxin and organomercury) have allowed a limited upsurgence of loose smut and leaf stripe in barley.

If the speed, logistics and economics of seed testing allowed it, all of these diseases (even those, such as leaf stripe, capable of contaminating seed from neighbouring crops) are completely vunerable to a strategy involving routine testing of seed, followed by treatment or sale for ware of batches found to be contaminated.

The only exception to the rule is bunt, which has occasionally been shown to persist as soil contamination (Yarham, 1993). Control of this soil-borne phase would continue to rely on vigilance on the part of wheat producers, and the use of triadimenol + fuberidazole treatment where soil contamination was suspected.

Protection from foliar diseases

Use of 'broad spectrum' seed treatments is often encouraged by claims of useful control of foliar diseases such as mildew (*Erysiphe graminis*), yellow rust (*Puccinia striiformis*) and in some cases *Septoria tritici*. This is a separate issue from the control of those foliar diseases which can have a significant seed borne phase, such as net blotch (*Pyrenophora teres*) and *Septoria nodorum*.

To assess the benefit of foliar disease control it is necessary to quantify the level and consistency of the control achieved, and the probability of this control either producing a yield benefit or replacing a foliar fungicide application. The data presented later in this paper help to quantify the former. A series of winter barley experiments in 1989 (ADAS unpublished) produced substantial mildew epidemics during the winter and early spring and provide some guide to the value of seed treatment derived foliar disease control (Table 1). In these experiments, the flutriafol + ethirimol + thiabendazole seed treatment generally provided good control of mildew during the winter and early spring.

Table 1. Effect of seed treatments and foliar sprays on yield of winter barley cv. Magie (mean of three sites where mildew affected 6-40% of leaf 2 or 3 during the autumn, winter or early spring in phenyl mercuric acetate treated plots).

	Grain yield (tonnes ha^{-1} at 85% dry matter)			
	Number of sprays in foliar fungicide programme			
Seed treatment	None	One	Two	Three
Phenyl mercuric acetate	5.11	6.12	6.63	6.92
Flutriafol + ethirimol + thiabendazole	5.11	6.33	6.77	6.94

There was no significant ($P<0.05$) yield benefit from the mildew active seed treatment compared to the organomercury product, or indication of mildew activity allowing a reduced spray programme.

Practical experience suggests that foliar disease control by seed treatment can be valuable where a yellow rust susceptible variety is being grown in a yellow rust prone area such as coastal Norfolk or Lincolnshire. In seasons with few frosts during the winter, crops grown from seed with no treatment active against yellow rust can require foliar sprays as early as February, wheras crops grown from triadimenol + fuberidazole treated seed seldom require further yellow rust control until late April.

Protection from seed and soil-borne fusarium seedling blight

Although soil-borne *Fusarium* can act as a source of seedling blight (Bateman, 1977), the importance of natural soil-borne inoculum has not previously been quantified in isolation from the seed-borne inoculum. Experiments where seed lots carrying different levels of seed-borne *Fusarium nivale* were grown untreated have shown that: i) the relationship between percentage seed infection and seedling loss is almost linear (W J Rennie, pers.comm.), and ii) more than a few percent seedling loss from seed lots carrying nil or low levels of disease is rare. Seed-borne seedling blight is clearly a significant risk, but one which can be quantified by seed testing. The data below were obtained from an experiment conducted at a wide range of locations, where the risk of soil-borne seedling blight might be expected to represent that experienced by winter cereals in England and Wales.

MATERIALS AND METHODS

Field experiments were conducted at 15 sites; nine sites on winter wheat cv. Riband and six on winter barley cv. Puffin. Sites were selected and managed to give a range of soil types, weather conditions, rotational positions, seedbed conditions and sowing dates representative of cereal growing in England and Wales (Table 2).

Certified seed was obtained centrally, randomly sub-divided and treated with the seed treatments listed in Table 3. Treatments were applied to the sub-samples either by a Rotostat (ICI) mobile seed treatment apparatus or by the manufacturer. After treatment the sub-samples were further divided and despatched to the sites. Additional coded product treatments were also included in the experiments at all sites. Data from these treatments were included in the analyses, but are not presented here.

Table 2. Site location, rotational position, soil type and drilling date

Site No.	Location	Rotation *	Soil texture	Drilling date
Winter wheat				
1.	ADAS Boxworth Cambs.	4th	Clay loam	10 October
2.	ADAS Bridgets, Hants.	1st	Silty clay loam	22 October
3.	Owstwick, N. Humberside	1st	Silty clay loam	10 October
4.	Fishtoft, Lincs.	1st	Silty clay loam	30 October
5.	Kneesall, Notts.	2nd	Clay loam	11 October
6.	Pancross, S. Glamorgan	1st	Silty loam	2 October
7.	Preston Deanery, Northants.	1st	Silt loam	7 October
8.	ADAS Arthur Rickwood, Cambs.	1st	Sandy peat	21 October
9.	ADAS Rosemaund, Hereford	1st	Silty clay loam	29 October
Winter barley				
10.	Attlebridge, Norfolk	3rd	Sandy loam	2 October
11.	ADAS Bridgets, Hants.	1st	Silty loam	27 September
12.	Pancross, S. Glamorgan	3rd	Silty clay	2 October
13.	Chipping Warden, Northants.	2nd	Sandy clay loam	2 October
14.	Nocton, Lincs.	4th	Sandy loam	27 September
15.	ADAS Rosemaund, Hereford	2nd	Silty clay loam	2 October

* - position of the experimental crop in the run of cereal crops since the last non-cereal 'break'.

Seed tests showed that both the wheat and barley samples were of high health status (Table 4). Occasional plants with loose smut were found at some barley sites. No bunt was detected at wheat sites.

Table 3. Seed treatments.

Treatment	Active ingredient/s	Dose (c.p. $tonne^{-1}$)
Winter wheat		
1. Untreated	-	-
2. 'Baytan'	Triadimenol + fuberidazole (Tr.+Fu)	2.0 litres
3. 'Panoctine'	Guazatine (G)	2.0 litres
4. 'Cerevax'	Carboxin+thiabendazole (C+Th)	2.5 litres
5. 'Panogen M'	Methoxyethyl mercuric acetate (MEMA)	1.0 litres
6. 'Beret'	Fenpiclonil (Fe)	4.0 litres
7. 'Ceresol'	Phenyl mercuric acetate (PMA)	1.0 litres
Winter barley		
1. Untreated	-	-
2. 'Cerevax extra'	Carboxin+thiabendazole+imazalil (C+Th+I)	2.0 litres
3. 'Ferrax IM'	Flutriafol+ethirimol+thiabendazole+imazalil (Fl+Et+Th+Im)	5.0 litres
4. 'Panoctine Plus'	Guazatine+imazalil (G+Im)	2.2 litres
5. 'Beret Extra'	Fenpiclonil+imazalil (Fe+Im)	4.0 litres
6. 'Ceresol'	Phenyl mercuric acetate (PMA)	1.1 litres
7. 'Panogen M'	Methoxyethyl mercuric acetate (MEMA)	1.1 litres

Table 4. Seed testing results

Cultivar	Germination (%)	*Fusarium nivale* (%)	*Drechslera graminea* (%)
Riband	98	1	-
Puffin	97	-	1

All the sites were sown by plot drill as a randomised block design with four replicates. Each replicate contained one plot of seed treated with each of the treatments listed in Table 2. Plots were a minimum of 24 m^2, and were typically 2m by 18m. All the experiments were oversprayed with foliar fungicide as appropriate to control foliar diseases. No foliar fungicides were applied earlier than growth stage 31 (Tottman, 1987). Plant establishment was measured as the number of plants along 10 randomly selected 0.5m drill row lengths within each plot, when the most advanced plants were at GS 13. These data were converted to number of seedlings m^{-2}. Foliar diseases were assessed on ten main tillers per plot at GS 31 (prior to any foliar fungicides being applied), using methods and keys described in the MAFF Manual of Plant Growth Stages and Disease Assessment Keys (Anon., 1976). Leaf numbers quoted in the results section are counted down the tiller from the youngest fully expanded leaf (leaf 1). Lodging was assessed, as percentage of plot area lodged, immediately prior to harvest. Experiments were harvested by plot combine and grain yields calculated as tonnes ha^{-1} at 85% dry matter. Statistical analysis of all data was by analysis of variance. Treatment means were separated by calculation of least significant difference (LSD) P=0.05.

RESULTS

Establishment

At the majority of sites none of the treatments significantly affected the number of seedlings established. Data from sites which produced significant treatment effects, and the cross-site analysis from all sites, are shown in Table 5. Vigour scores (data not presented here) showed that where seedling establishment was reduced by seed treatment the effect on crop ground cover and plant height tended to persist into the spring.

Table 5. Effect of treatment on seedling establishment

	Seedlings m^{-2} at GS 13				
Winter wheat	Site 2	Site 5	Site 8	Site 9	Cross-site
1. Untreated	274	210	387	288	293
2. Tr+Fu	273	158	383	260	279
3. G	296	204	353	232	287
4. C+Th	318	188	334	256	287
5. MEMA	283	199	402	250	286
6. Fe	314	204	352	252	285
7. PMA	313	175	372	253	278
SED 27df (cross-site 243df)	15.1	19.8	16.4	16.4	6.1
LSD	31.1	40.5	33.4	33.4	12.4

Winter barley	Site 10	Cross-site
1. Untreated	303	286
2. C+Th+Im	315	290
3. F1+Et+Th+Im	251	273
4. G+Im	268	284
5. Fe+Im	305	283
6. PMA	308	299
7. MEMA	298	300
SED 27df (cross-site 243df)	15.4	7.2
LSD $P< 0.05$	31.7	14.4

Foliar diseases

Foliar diseases were present at significant levels in untreated plots at winter wheat site 6 (12.5% *S. tritici* on leaf 2), site 1 (22.2% *S. tritici* on leaf 3) and site 5 (11.6% *S. tritici* on leaf 3); and at winter barley site 13 (21.6 % mildew on leaf 3), site 12 (1.6% mildew and 2.2% *Rhynchosporium secalis* on leaf 3), site 11 (1.2% mildew on leaf 2) and site 10 (3.7% mildew on leaf 4). Although in some cases there appeared to be marginal suppression of foliar disease, no significant ($P<0.05$) control was obtained from any of the treatments.

Lodging

Lodging or brackling (lodging of tillers where the 'break' occurs part way up the stem, usually at a node) occured at four sites, but significant treatment differences were found at only two sites - both of which had untreated plot area affected scores of less than 10%. Significant control was achieved at these sites by Baytan and Ferrax.

Grain yield

At the majority of sites grain yield was not affected by any of the treatments. Data from sites where significant ($P<0.05$) effects were recorded and data from a cross-site analysis are presented in Table 6.

Table 6. Effect of treatments on grain yield.

	Grain yield (t ha^{-1} at 85% dry matter)					
Winter wheat	Site 1	Site 2	Site 3	Site 5	Site 7	Cross-site
1. Untreated	6.98	8.40	6.03	4.62	8.03	7.31
2. Tr+Fu	6.88	8.56	6.53	4.39	8.13	7.32
3. G	6.98	8.56	6.22	4.46	8.35	7.37
4. C+Th	6.81	8.70	6.61	4.45	7.87	7.36
5. MEMA	6.63	8.47	6.25	4.52	8.21	7.33
6. Fe	7.12	8.55	6.42	4.57	8.36	7.45
7. PMA	6.84	8.64	6.10	4.44	8.32	7.29
SED 27df (x-site 243df)	0.129	0.129	0.232	0.120	0.160	NS
LSD	0.264	0.264	0.473	0.244	0.326	

Winter barley	Cross-site
1. Untreated	7.39
2. C+Th+Im	7.52
3. Fl+Et+Th+Im	7.48
4. G+Im	7.46
5. Fe+Im	7.49
6. PMA	7.49
7. MEMA	7.50
SED (cross-site 144df)	NS

Seed bed conditions and treatment responses

Mean establishment response and yield response data for all wheat sites were regressed individually for each treatment against two measures of seedbed conditions; soil temperature at drilling (mean of 10cm soil temperatures during the 10 days following drilling) and soil moisture (by cumulative rainfall during the 10 days before, and 10 days after, drilling). These data were derived from the nearest meteorological recording site to each experiment location. The spread of 10 day mean temperatures and cumulative rainfall between sites was 7.2^{o}C to 12.3^{o}C and 1mm to 103mm respectively. No significant ($P<0.05$) relationships to establishment or yield were observed. As no significant treatment yield effects were detected at the winter barley sites, and establishment effects were small, regression of responses against seed bed conditions was considered inappropriate.

Rotational position and treatment responses

There were no rotational position effects that implied a benefit from control of take-all; generally the 1st wheat sites were the more responsive. This is perhaps not surprising as most of the treatments tested do not have take-all activity, and responses to take-all control by triadimenol + fuberidazole treatment have previously been associated with very early sown 2nd to 4th wheat crops where severe disease developed (Hornby and Bateman, 1991).

DISCUSSION

Although overall there was no significant effect from any of the treatments on seedling establishment or yield, this result hides considerable site to site differences, which were not explained by foliar disease, lodging or take-all control. At some sites, positive yield responses were obtained from treatment and these were occasionally associated with improved establishment. At other sites deleterious effects of treatments on seedling establishment, combined with adverse seedbed conditions, reduced the plant population to a level where the crop was unable to compensate and yield was reduced.

Practical experience suggests that fusarium seedling blight is most damaging in cold, dry seedbeds, but regression analysis did not suggest that positive responses to treatment were associated with low seedbed temperature or moisture. Possibly the range of temperatures experienced was not sufficiently extreme to expose such an effect. The spread of soil moistures between sites was probably as wide as would be encountered in practice.

Clearly there are a wide range of variables that can interact to determine the response of cereals to seed treatment. Some of these factors may be more to do with the physiological effects of the treatment on the plant, than responses to disease control. The data gathered so far reinforce the findings of Richardson (1986), in suggesting that where healthy seed is intended for ware production, a consistent positive yield response to seed treatment is unlikely. The results, albeit from a single year's work, suggest that the risk from soil-borne fusarium seedling blight is low.

Seed-borne *Fusarium* remains a significant, but quantifiable, problem. In seasons when conditions during flowering are conducive to fusarium ear blight development, levels of *Fusarium* on the resulting grain may require extensive use of treatments - due to a shortage of grain below the treatment threshold - even if seed treatment was entirely determined by the results of seed health tests. This is illustrated by results from wheat seed testing at NIAB, quoted by Lovelidge (1993): in 1992/3 the proportion of samples failing to meet the advisory limit of <5% of seeds infected with *Fusarium nivale* was 77% (compared to 14% in the previous season).

The Scandinavian countries are already moving towards a strategy where cereal seed treatments are applied in response to results from seed health tests (Brodal, 1993). The data reviewed here suggest no scientific reason why such an approach should not be successful under UK conditions.

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SEED TESTING, SEED CERTIFICATION AND SEED TREATMENT IN THE CONTROL OF CEREAL SEED-BORNE DISEASE.

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ABSTRACT

Results are presented from a certification and advisory seed testing programme for the 1993 harvest illustrating, by comparison with results from previous seasons, how disease occurrence has varied. Percentage infections of loose smut (*Ustilago nuda*) in barley and *Fusarium nivale* in wheat have increased. Results from field examination of certification plots for the incidence of loose smut in the period 1990 to 1993 are presented and related to the usage of seed treatments. In addition the effect of various seed treatments on germination rates is presented.

INTRODUCTION

Seed health testing

Field and other environmental conditions during recent growing seasons in England and Wales appear to have been particularly favourable for the development of a number of plant pathogens. The National Institute of Agricultural Botany (NIAB) has tested a range of crops, either for seed certification purposes or as an advisory service to growers. Seed certification schemes are designed to ensure the adequate supply of seed meeting prescribed standards of quality in relation to germination, purity and seed health. Advisory testing is carried out for farmers and seed merchants for their own purposes. Summary results are presented from the seed testing programme for the 1993 harvest illustrating infection levels pooled across both certification (where appropriate) and advisory test categories. These results are presented in conjunction with those of previous seasons, where available, in order to demonstrate the seasonal variation in occurrence for a range of pathogens.

Seed certification and treatment

In addition to seed testing results, data from NIAB's Seed Production Department on the incidence of loose smut (*Ustilago nuda*) in the cereal certification growing-on plots are presented and the effects of a number of seed treatments on disease incidence are shown. The effect of seed treatments on germination is also given with this effect ascribed, at least in part, to the presence of *Fusarium* infection on the seed.

Loose smut is a potentially serious seed-borne disease which can affect most commonly grown cereal species and at present its incidence in the UK is currently lower than when the disease was at its peak. This reduction has been achieved by a combination of applying infection standards in seed certification schemes, the introduction of effective varietal resistance in wheat and the availability of seed treatments with extremely good activity against the *Ustilaginae*. A measure of this success is that in the last decade there has been no reported incidence of loose smut in seed certification plots for oats, rye or triticale. Loose smut is still common in seed of barley although certification failures are infrequent.

Loose smut has been readily controlled in oats by mercury seed treatments, because the spores are carried outside the seed coat. The low cost of mercury lead to very widespread usage until it was banned in 1992 and hence an extremely low incidence of this disease in oats. The first fully effective seed treatment for wheat and barley was carboxin, which was introduced in 1969. Until this time control methods were based on hot water treatment (effective but inconvenient and so not widely used) and control through seed certification. Annual reports of the NIAB (Anon,1968-1973) indicate that the incidence of loose smut in seed stocks fell significantly between 1969 and 1973. In 1969, 34% of wheat lots and 16% of barley lots failed the certification standard of 0.2% for the "Field Approved" category, whereas in 1973 the failure rates were around 4% and 2% respectively. Carboxin provided good, although not complete, protection against loose smut in both wheat and barley until the mid-1980's, when tolerant strains were first found in the winter barley cultivar Panda. This coincided with a peak in loose smut incidence in winter barley and 13% of seed stocks being multiplied for the 1984 harvest failed a seed certification standard. The equivalent figure for 1993 was 0.4%. This reduction in loose smut frequency can be attributed to the efficacy of triazole seed treatments, which largely replaced carboxin on seed for further multiplication.

Shortly after the introduction of carboxin there was a shift from very susceptible winter wheat varieties to those with greater resistance against the prevalent C4 race of loose smut. In 1969, susceptible varieties (NIAB rating of 3 or less) accounted for about 80% of certified seed. This situation had changed by 1973, when it had dropped to around 55%, mainly owing to the success of Maris Huntsman. Varietal resistance and seed treatment were both exploited in the certification scheme at the time; treatment was obligatory for all Basic and Certified seed of susceptible varieties of winter wheat. In barley there have been varieties with some resistance, although it has been morphological rather than physiological as in wheat (Wray and Pickett, 1985).

Since 1976 all cereal seed marketed in the United Kingdom must have been certified in the 'United Kingdom Seed Certification Scheme for Cereals'. This is a statutory scheme with procedures and seed standards applied through Seeds Regulations. The Ministry of Agriculture Fisheries and Food (MAFF) is the Certifying Authority for England and Wales, but much of the technical supervision is carried out by the NIAB. Seed is multiplied in a controlled way, with the number of multiplications being restricted by a so-called generation system (Anon,1985). Most of the seed bought by farmers is Certified Seed 2nd Generation, (C2). This may be certified at either of two standards; 'HVS' (higher voluntary standard) or 'Minimum'. The maximum level of loose smut infection allowed in certified seed is 0.2% for C2 HVS and 0.5% for C2 Minimum seed. The procedure for applying this standard is described below.

Germination and seed treatment

Loose smut and ergot (*Claviceps purpurea*) are the only seed-borne diseases of cereals for which the Cereal Seed Regulations (Anon,1985) specify standards in certified seed. However a number of other pathogens are of importance and if any of these are present at an economically significant level, purchasers may have a legitimate claim against the supplier. One such disease is *Fusarium nivale* which, amongst other effects, reduces germination and field emergence in wheat. Since one of the requirements of certified seed is that the minimum germination should be at least 85%, the presence of this disease can have an effect on certification.

In most years *F. nivale* has little effect on seed production, but when conditions favour its development in the time approaching harvest, the effects can be severe. A range of seed treatments is available which give adequate control of *F. nivale* in most circumstances, but seed can become too highly infected or rendered in an otherwise poor condition so that the seed should be discarded. In the last decade conditions have favoured severe *Fusarium* infections in English grown wheat three times; in 1982, 1987 and 1992. The incidence and severity of *Fusarium* can only be accurately measured by specifically testing for this pathogen but because of its known effects some correlation with germination can be expected although a number of other factors will have an affect.

METHOD

Seed health testing

Seed testing methods followed are as set out by the International Seed Testing Association (ISTA) unless otherwise stated (Anon., 1987). Data from 1993/4 seed testing year (1993 harvest) are incomplete at the time of writing and testing is still continuing. This arises from the delayed harvest in this season.

Ustilago nuda (loose smut) in barley

Seed samples received for testing originated from all areas of England with no apparent bias towards any region; however, the majority were from winter barley varieties. The total number of samples received in 1991/2 was 257; in 1992/3 the number was 240, and in1993 97 samples have been received so far. Almost all of these tests were advisory.

Pyrenophora graminea (leaf stripe) and *P. teres* (net blotch) in barley

The regional distribution of seed samples was broadly similar to that for loose smut tests. All tests were advisory, mostly on seed of winter barley varieties. In 1991/2, 287 samples were tested; in 1992/3 220 samples were tested and in 1993 78 tests have been carried out to date.

Tilletia caries (bunt) in wheat

Regional distribution of seed samples was biased to parts of central and southern England. All seed testing was advisory and was mostly on winter varieties of wheat. The number of samples received was 105 in 1991/2, 115 in 1992/3, and 49 in 1993.

Fusarium nivale (*Microdochium nivale*) in wheat

Seeds samples, the majority of which were from winter wheat varieties, came from all regions and were tested on an advisory basis only.

Septoria nodorum in wheat

The majority of samples received were from central and eastern England, and were tested on an advisory basis.

Seed certification and treatment

A representative sample of all seed stocks being grown for further multiplication in the certification scheme in England and Wales is grown-on in plots by NIAB. The suitability of seed stocks for further seed production is assessed by recording the level of loose smut and varietal impurities, as well as verifying the varietal identity of the sample. Thus it is the level of infection in the multiplication seed which is being measured, rather than routine testing of all C2 seed lots produced from it. Nevertheless seed producers have a legal obligation to ensure that all the seed which they market complies with the certification standards

The plots measure 1.2m by 8m and mean plant and ear populations are about 2000 and 6000 per plot respectively. Counts of infected ears in each plot are made, starting from the ear emergence growth stage (GS 51-55) and thereafter plots are recorded at regular intervals over the next three to four weeks. At each visit the infected ears are counted and removed from the plot. An ear population of the plot(s) is determined from ear counts in five, one-metre row sections, taken at random. The standards are not applied as a strict percentage but instead 'reject values' are used. These apply a formula, taking plot population into account, to ensure that the risk of rejecting a sample which just meets the standard is only 1%.

In the event that a seed stock has excessive infection, all seed crops sown with it are rejected at the category/level where the standard has not been met. However seed can be 'retrieved' from rejection in either of two ways:-

i) by treating each lot of seed produced with a seed treatment which the Certifying Authority has accepted as being sufficiently effective, or

ii) by having an embryo test caried out on a sample from each lot of seed produced, with a result which shows the seed to be within standard.

Germination and seed treatment

In some instances certified seed is sampled both before and after treatment and the data below summarise relevant results from germination tests carried out on winter wheat seed from the harvests of 1990, 1991 and 1992. The data presented come from C1 seed lots tested according to ISTA methods.

RESULTS

Seed health testing

Results from the 1991/2 and 1992/3 seed testing seasons are presented below for the diseases previously mentioned. Included is the certification standard(s) if applicable to a disease test, i.e. the level of a particular disease which, when exceeded, renders the seed lot unacceptable. Where these standards are available they have also been applied to any advisory testing carried out for the same pathogen. For those tests where no certification requirement exists, advisory standards have nevertheless been applied. These standards are also described but essentially they represent a level of infection above which advice on a suitable seed treatment should be sought. In other instances a nil standard has been applied, i.e. the presence of any infection is reported. This is done either because it is considered important that a seed sample is free of a particular pathogen or because insufficient data are available to devise a suitable advisory standard.

The results show that in general the incidence of seed borne cereal diseases has steadily increased over the previous four years although the data for 1993 harvest are as yet incomplete and should be interpreted with care. Only the results for *Septoria nodorum,* for which only one test on seed from the 1993 harvest has yet been done, show a decline. This general increase in incidence has been accompanied by an increase in the number of samples failing to meet "standards" for net blotch in barley, loose smut in wheat, for which only a small number of tests have been done, and for *Fusarium nivale* in wheat.

Seed certification and treatment

During the period 1990 to 1993 the number of seed lots with excessive infection by loose smut in the control plots has remained at a fairly low level, with a mean failure rate of around 0.5%. However 5.3% of the 5926 samples tested showed some infection. Around 32% of the samples were treated with a product known to give good control of loose smut and in these the incidence of infection was about 1%. In samples not treated with such products the incidence was 7%.

The following examples of seed pedigrees with loose smut infection data were taken from certification records for 1990 to 1993. They show how certification controls are applied and also how patterns of infection build-up can vary.

Results are expressed as percentage of infected ears per plot.

Example 1 Sown seed 1990

Cultivar	Camargue
Treatment:	Ethirimol + flutriafol + thiabendazole
Infection:	Nil

Progeny 1991

	Lot 1	Lot 2	Lot 3	Lots 4	Lots 5-9	Lot 10
Treatment:	None	None	Mercury	Mercury	Ethirimol + flutriafol + thiabendazole	Carboxin + imazalil+ thiabendazole
Infection:	0.42%	0.47%	0.82%	0.42%	NIL	0.06%

The results in example 1 demonstrate that there is always a risk of crops becoming infected with loose smut. Despite the use of a seed treatment, which on the evidence of the control plot was very effective, a serious infection was found in all the untreated 1991 progeny.

Example 2 Sown seed 1991

Cultivar:	Treatment:	Infection:
Bronze	None	0.06%

Progeny 1992

	Lot 1	Lot 2	Lot 3	Lots 4	Lots 5 & 6	Lot 7
Treatment:	None	None	None	None	Ethirimol + flutriafol + thiabendazole	Carboxin + imazalil+ thiabendazole
Infection:	0.38%	0.21%	0.16%	0.11%	NIL	NIL

In example 2 there was a range of infection level and if the samples were representative of the bulk it indicates a reinfection rates of between two-fold and six-fold in the same crop.

Germination and seed treatment

Table 1 clearly shows the value of seed treatments in effecting the recovery of seed samples with sub-minimal levels of germination. Treatment with fungicides has markedly improved the germinability of the seed by 15 percentage points in 1991 and by 25 percentage points in 1992. Levels of germination in 1991 were generally somewhat higher than those in 1992.

TABLE 1. Mean germination (in %) of winter wheat samples (below 85% germination) before and after treatment 1990 -1992.

Year	1990	1991	1992
Untreated	No examples	78.5 (4 samples)	69 (15 samples)
Treated	"	93.5 (")	94 (")

Figure 1. Loose smut infection in barley

Certification standards: basic=0.1% in 1000; certified=0.2% in 1000. (At the Higher Voluntary Standard)

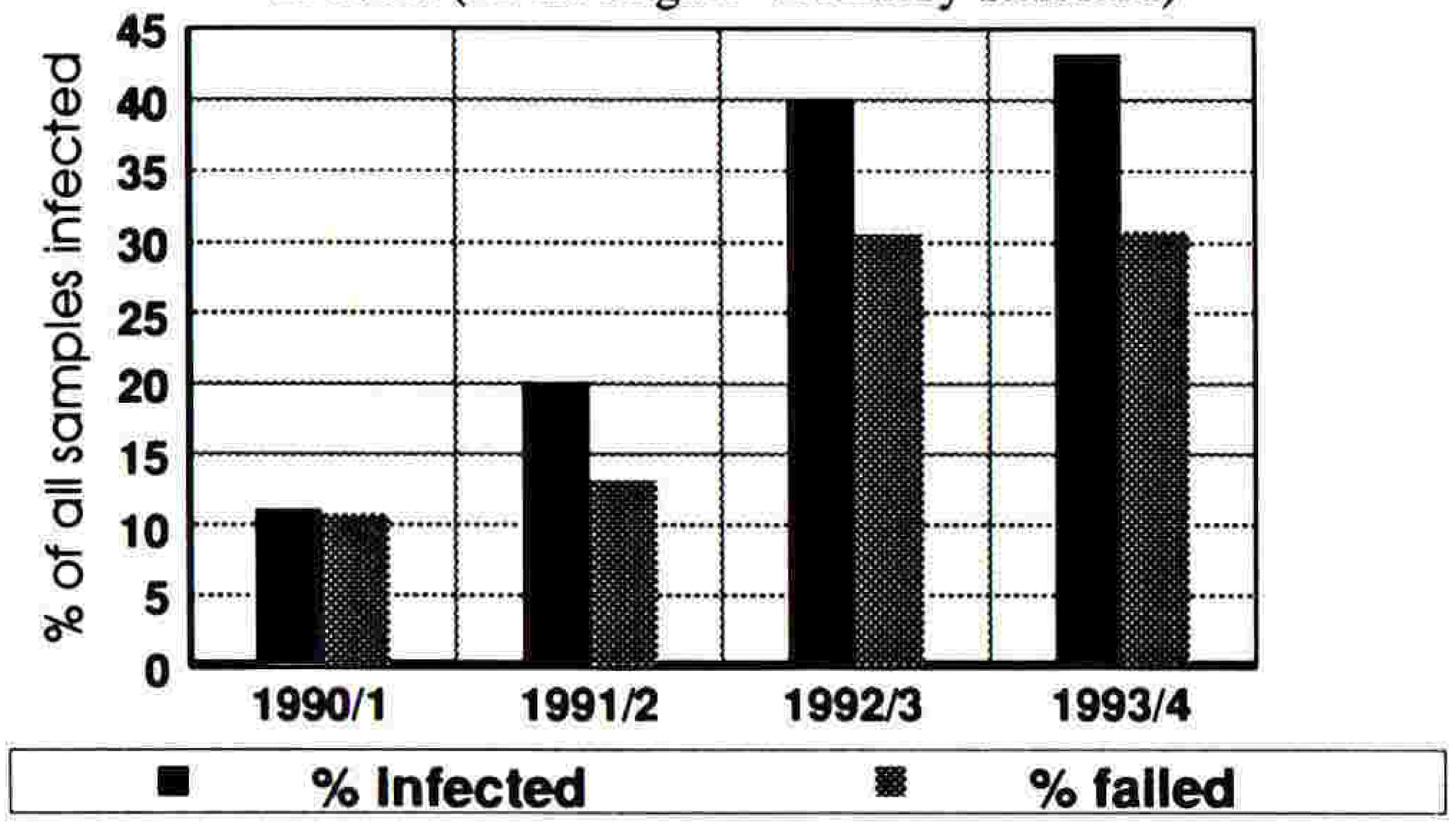


Figure 2. Leaf stripe and net blotch infection in barley.

No distinction was made between these 2 species in 1990/1 or 1991/2. A marketing standard of 2% infection with leaf stripe is currently applied to seed tests.

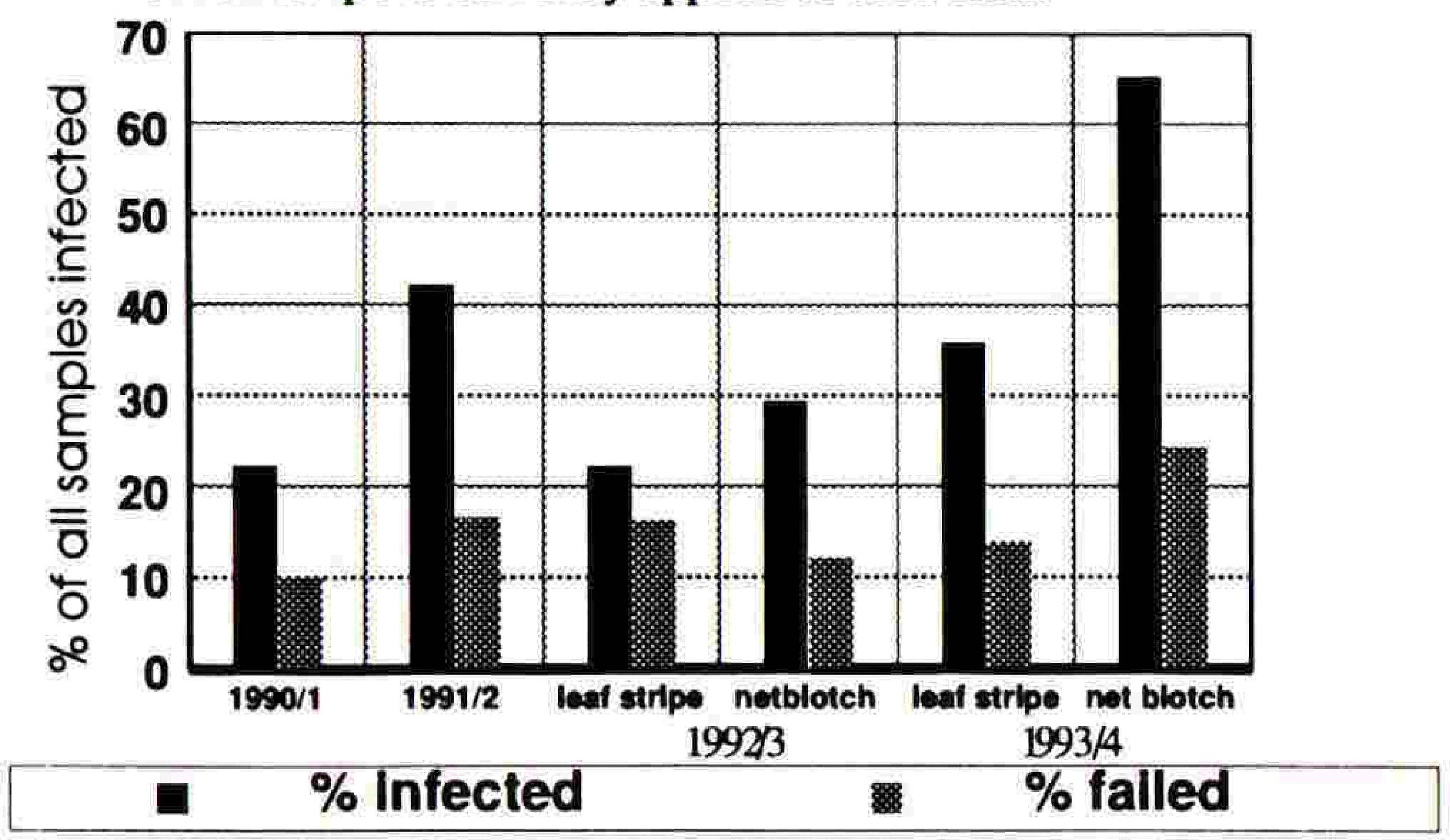


Figure 3. Bunt infection in wheat

No certification standards apply. Advisory limit: 20 spores/g of seed.

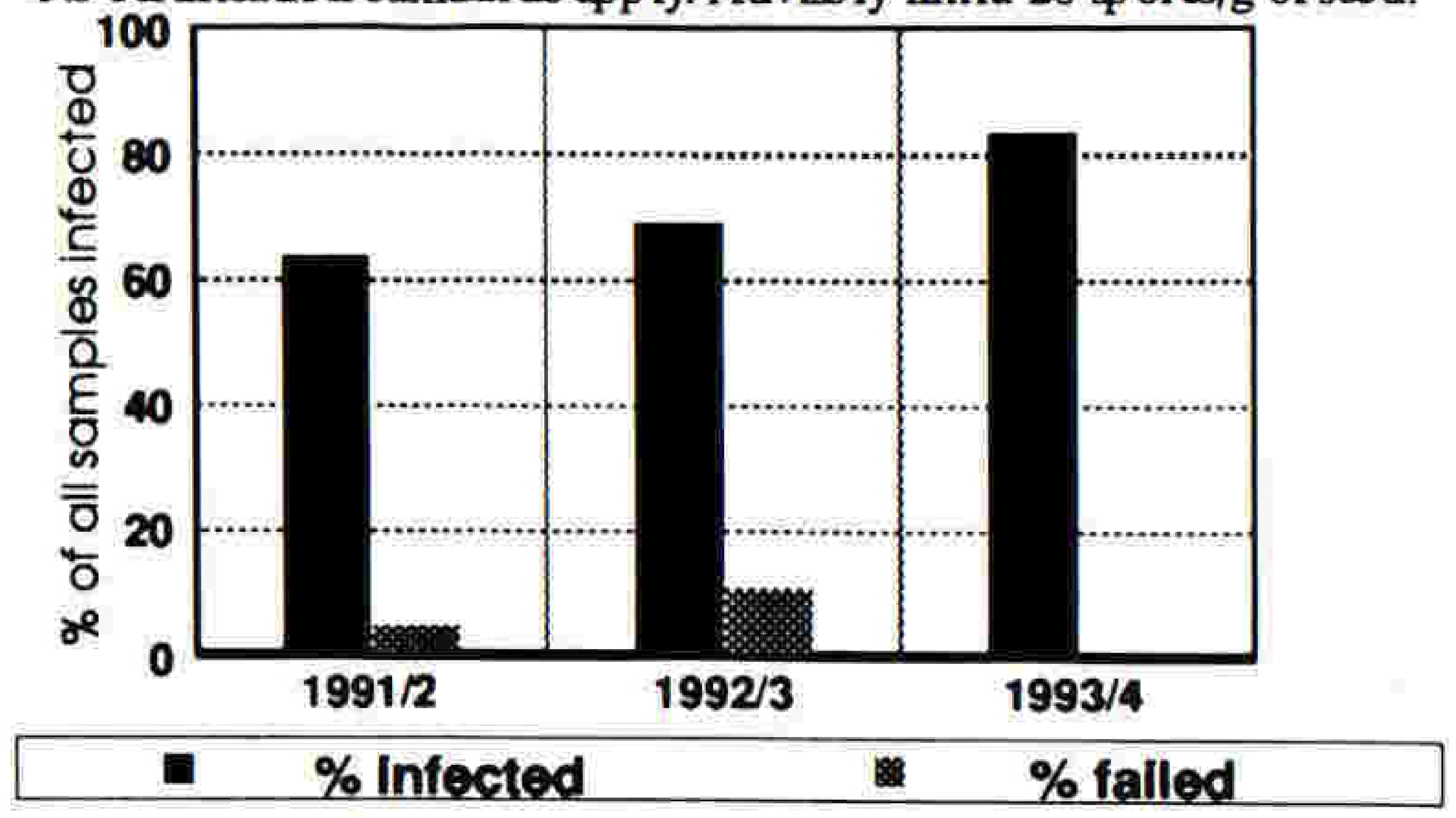


Figure 4. Fusarium nivale infection in wheat

No certification standard. Advisory limit 5%.

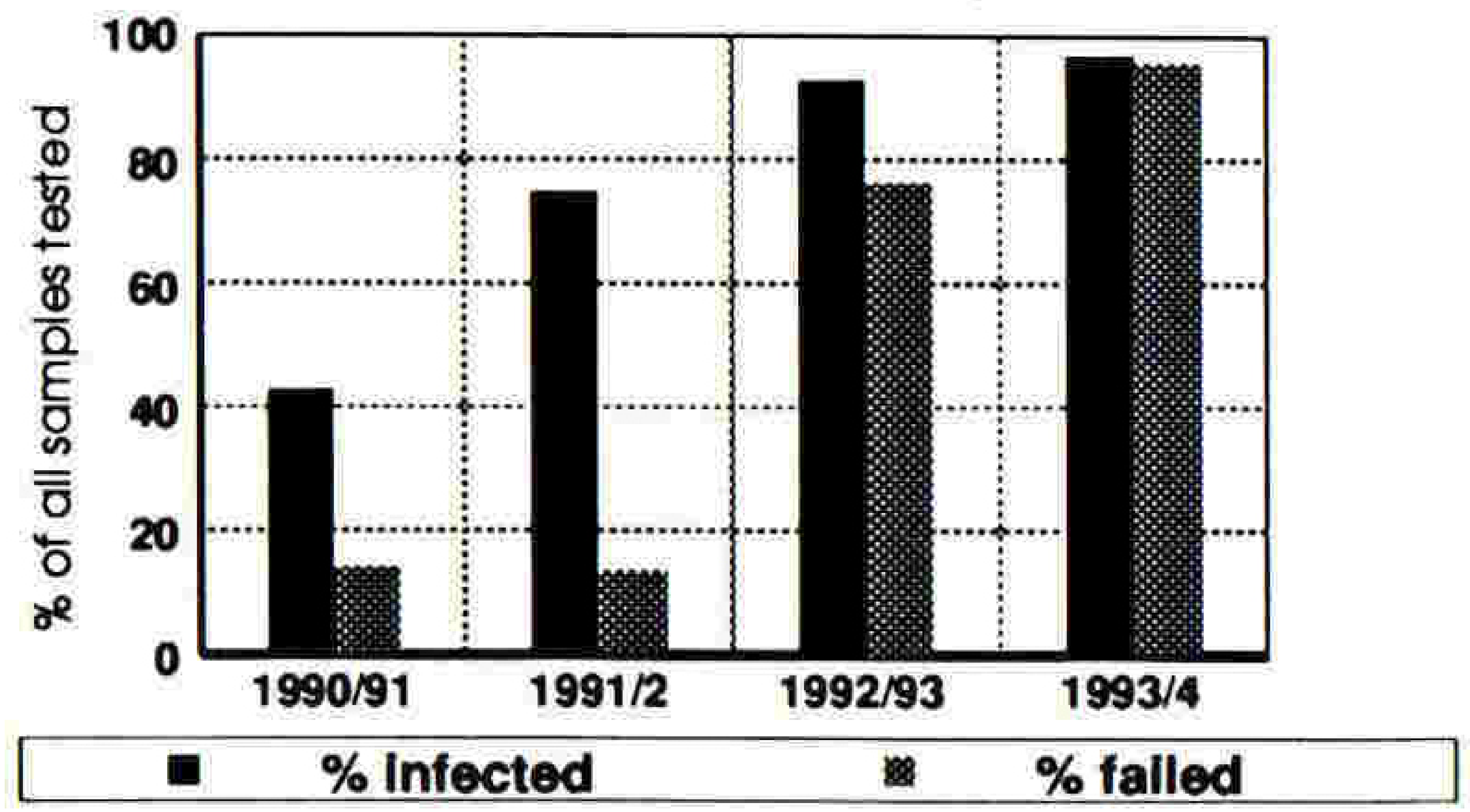
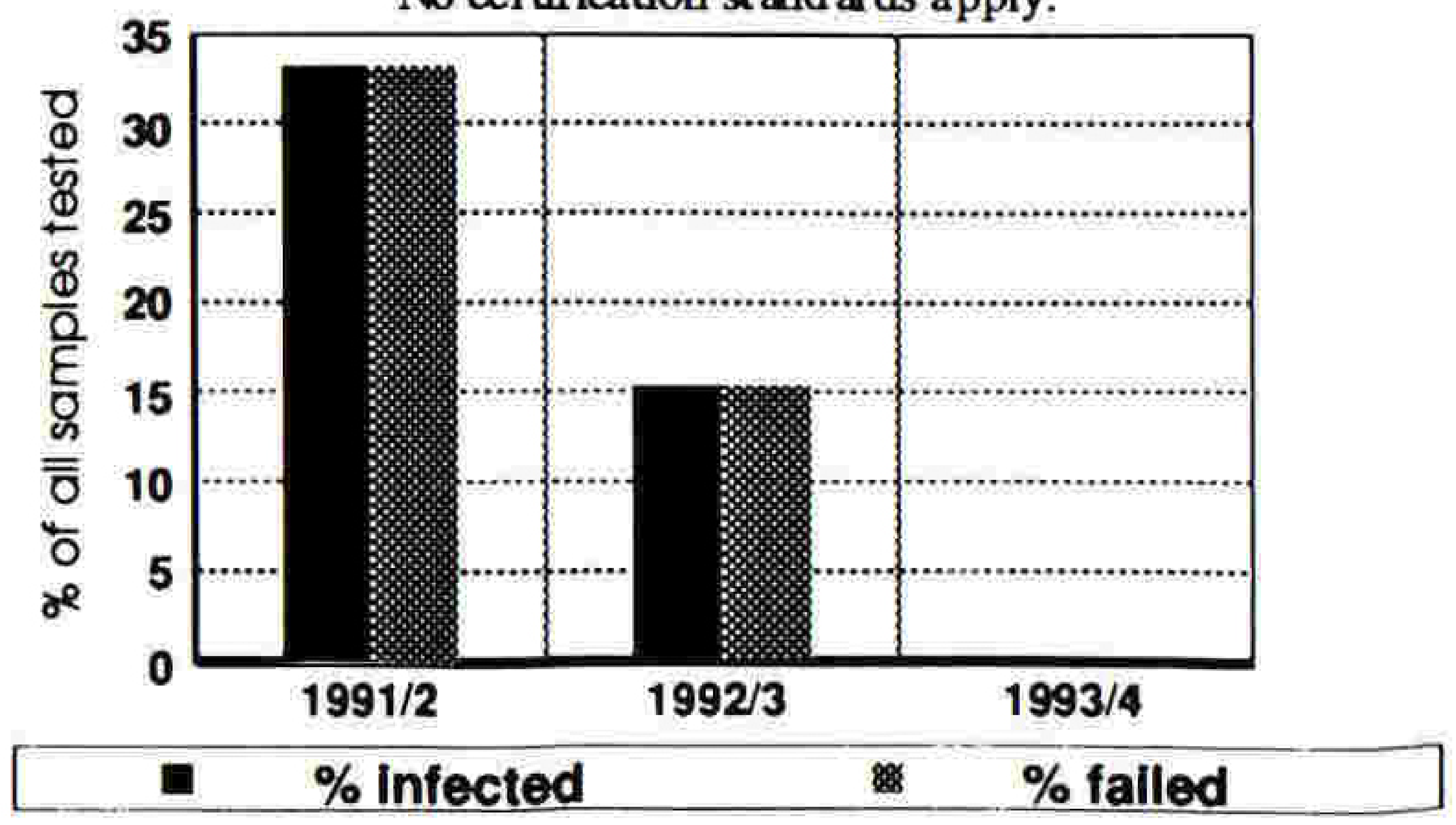


Figure 5. Septoria nodorum infection in wheat.

No certification standards apply.



DISCUSSION

Seed health testing

These data do not derive from a properly constituted survey and are therefore potentially subject to bias errors from a number of sources. For example, an advisory test may have been requested because the disease symptoms were seen in the crop which produced the seed. Motivation such as this could lead to an overestimation of the incidence of that particular disease if the estimate were based solely on the numbers and results of seed tests. Other errors occur where small numbers of tests are done and where a single positive finding, possibly confounded with the bias outlined above, can have a disproportionate effect.

Notwithstanding these caveats, a number of points emerge from this study. It is clear that seed is a major source of inoculum of a number of agriculturally important diseases and, particularly where it is also the primary vector of a disease, that it should not be overlooked in any disease control strategy. Seed certification schemes are one such strategy and previous studies have confirmed that certification schemes are of significant value in reducing seed borne disease.

For a number of diseases no certification standards exist. This often arises because insufficient epidemiological data are available to allow standards to be devised which minimise the risk of significant disease levels developing from seed. Clearly more research is required to redress this and should be related to the efficacy of seed treatments and the threshold of infection at which they are required. This information will also affect the design and improvement of certification schemes.

Seed certification and treatment

The two examples presented of the incidence of loose smut in certification show clearly the value of seed treatments in disease control. The difference between the levels of infection detected in the advisory seed health testing programme and the levels of infection in the certification plots also estimates the effectiveness of the combination of seed certification and seed treatment in the control of this disease. Samples for seed health testing were predominantly advisory, ie farm-saved seed, probably grown from untreated seed once or twice removed from C2. Here infection has consistently increased over the previous four years with between 40% and 45% of samples infected, about 30% of which failed at the Higher Voluntary Standard in 1992/3 and 1993/4. In certification plots seed has either been treated (32%) or grown from seed which has been embryo tested for the presence of the pathogen with a mean failure rate of 0.5% and only 7% infection rate even in untreated samples.

The comparison between infection levels in samples received for seed testing and those grown on in the certification procedures also shows that considerable reinfection of the seed has occurred after certification and during the farm-saving activity.

Germination and seed treatment

High levels of *Fusarium* are associated with cool wet weather and such conditions also lead to lower germination due to sprouting in the field prior to harvest.

Additionally, if grain has too high a moisture content, damage may be caused by over rapid drying. However these effects can be separated by comparing the germination results for treated and untreated seed. The use of a treatment will have a beneficial effect on infected seed but can be expected to make no difference or may further reduce germination where seed is damaged in some other way. Table 1 gave the effect of fungicidal seed treatments on levels of germination and it is clear that germination was improved indicating that fungal infection was implicated in the initial depression of germination. *Fusarium* spp. are known to have an effect on germination in wheat seed and it is probable that it is through the control of this pathogen that the seed treatment effect is mediated.

The data indicate some variation between years in the extent to which seed treatments were beneficial in achieving the minimum germination standard for certification. In 1990 weather conditions leading up to harvest were warm and dry and wheat germination levels were relatively high. In 1991 the South West experienced wet, humid weather whilst the rest of England and Wales stayed dry and in 1992 wet weather was general throughout the country. The incidence of adverse weather therefore parallels the number of instances where seed treatment has resulted in increased germination. Mean germination over this period shows a similar pattern (Table 2).

TABLE 2. Germination levels in winter wheat 1990 -1992

% of lots with germination 95% or more	1990	1991	1992
North	85	71	64
East	84	79	50
South West	81	30	36
% of lots with germination < 85%			
North	<0.1	0.2	0.8
East	0.2	<0.1	1.5
South West	0.2	3.8	1.6

Table 2 indicates a much lower proportion of seed lots from the South West achieving a germination of 95% or more in 1991 than in the North or East, whilst in all regions it was lower in 1992 than 1990. Similarly the number of lots with a low germination (<85%) was higher in the South West than elsewhere in 1991 and higher in 1992 generally than in 1990.

These germination data correlate closely with the incidence of *Fusarium nivale* (Figure 4). In 1992 more seed lots were infected with this pathogen than in previous years but more importantly the number of highly infected seed lots, ie. which failed to meet the advisory standard, rose from about 15% in 1991/2 to 75% in 1992/3. It is probable that this high level of infection is responsible to some extent for the poor germination in 1992. No regional data for *Fusarium* infections are available so it is possible only to speculate that the poor weather in the South West in 1991 was responsible for encouraging *Fusarium* development to the point where germination in this region was affected so markedly.

CONCLUSIONS

Seed can be an important vector of disease and the incidence of some seed borne diseases in the UK is currently at a high level, having increased over recent years. Seed health testing can be used to monitor the emergence of particular disease problems and to indicate the need for application of seed treatments. Control measures involving a combination of seed certification and seed treatment are effective in maintaining seed quality by reducing the proliferation and effects of seed borne diseases.

ACKNOWLEDGEMENTS

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CONTROL OF COMMON BUNT (*TILLETIA CARIES (DC) TULL.*) IN DENMARK

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ABSTRACT

Common bunt, which is normally a rare disease in Denmark, has occurred quite frequently in recent years. First in the mid 1970s and again from 1989. In both cases, unsatisfactory fungicide treatment has been a contributory cause. Trials with new seed treatments show that it is possible to obtain 98-100% control and, in order to stop the propagation of the disease, it has been decided only to give biological approval to products which have a very high degree of efficacy. In the trials, fungicide treatment with e.g. bitertanol/fuberidazole, fenpiclonil, fenpiclonil/imazalil and fenpiclonil/difenoconazole has given 99-100% control, and only these seed treatments have been approved for control of common bunt on winter wheat in Denmark. Only bitertanol/fuberidazole is presently registered and marketed in Denmark as a liquid formulation for control of common bunt. The older powder formulation carbendazim/maneb still holds an approval, but it is not used very often. In Denmark, farmers primarily use fungicide treated certified seed and disease control should be good. In 1993, soil infestation of common bunt was demonstrated in a few localities in Denmark. Soil infestation can make disease control more difficult, in particular if dry summers predominate.

INTRODUCTION

Common bunt (*Tilletia caries*) is normally a very rare disease in Denmark and has only been of minor importances since the use of fungicide treated seed became general. However, in the 1970s rather frequent occurrences of common bunt were observed after several years without attacks. The disease was controlled by means of efficient seed treatments, however, since 1989 there have again been more frequent reports on common bunt (Figure 1).

In Denmark, there is a long tradition of using certified seed, and it is estimated that most of the seed used is certified and fungicide treated. However, in the late 1960s the use of fungicide treated seed declined, and this led to the multiplication of common bunt (Figure 1). From 1976, prebasic, basic and certified seed of the 1st generation was again treated with a full dose of mercury-based products, whereas 2nd generation seed was treated with a full dose of other non-mercury products. In this way the rather frequent occurrences of common bunt in Denmark disappeared for some time (Jørgensen & Nielsen, 1990).

In the 1980s, mercury was gradually replaced by other products. In 1983/84, 22% of the seed grain was treated with mercury which is equivalent to the first three generations of seed grain (normally 20-25%). The use of mercury dropped over a 10-year period and stopped completely in 1989/90 (Table 1).

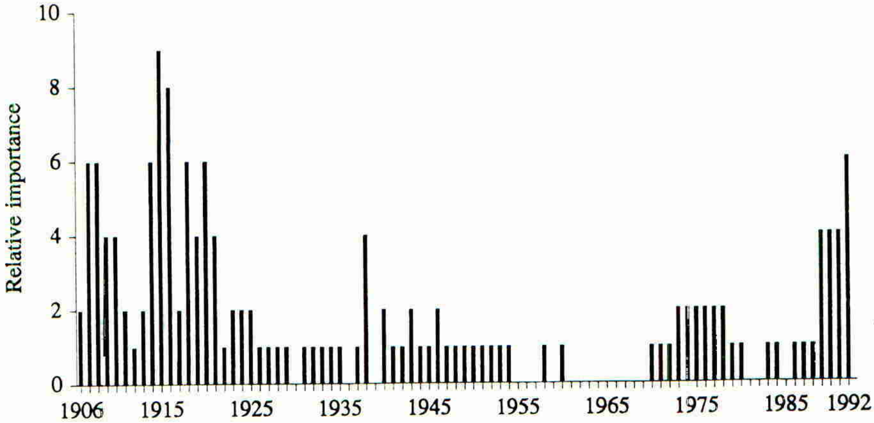

Figure 1. Attacks of common bunt in Denmark, estimated from disease surveys made by the Danish Institute of Plant and Soil Science (Stapel, Jørgensen & Hermansen, 1976 and Stapel & Nielsen, 1992).

Table 1. Use of Hg-seed treatment for cereals in Denmark 1982/83-1989/90. (Jørgensen & Nielsen, 1990).

Year	Cereal seed lots treated with Hg Per cent
1982/83	22.2
1983/84	21.8
1984/85	12.5
1985/86	13.7
1986/87	9.4
1987/88	1.7
1988/89	1.1
1989/90	0

The products, which since then have been used for fungicide treatment of wheat, are Na-N-dimethyldithiocarbamate/fuberidazole ('Neo-Voronit' which was on the market until 1991), carbendazim/maneb ('Derosal M bejdse'), guazatine ('Panoctine 30') and bitertanol/fuberidazole ('Sibutol LS 280' which came on the market in 1989, Table 2).

In 1989, after some years with sporadic occurrences, more common attacks of bunt were reported (Figure 1). Again, the propagation of common bunt was expected to be a consequence of unsatisfactory fungicide treatment. However, the role of soil borne inoculum which in the same period has been reported from the U.K. (Yarham & Jones, 1992) cannot be excluded.

In the light of this experience it was decided to intensify the demands on the efficacy of seed treatments and only approve the most effective products. In addition, it was impressed on the processors of seed grain that the quality of the fungicide treatment should be high.

The data below are from a number of the trials that have been established in order to examine the effect of new seed treatments on common bunt. The trials form part of the basis for the official approval of seed treatments (Nielsen & Jørgensen, 1986, 1989). In Denmark, the biological approval carried out at the Danish Institute of Plant and Soil Science is voluntary and is independent of the registration made by the National Agency of Environmental Protection. In practice, however, only seed treatments that have obtained a biological approval for the area in question are recommended and used.

MATERIALS AND METHODS

Trials to examine the effect of seed treatments were established as small plot trials with rows of 400 plants and with 4 replicates. In addition, yield trials with bigger plots (1.5 x 10 m) were established to examine the yield effect and possible phytotoxic effects of the seed treatments. In the trials, healthy seed, which prior to fungicide treatment had been inoculated with 0.25 g and 5.0 g bunt spores per kg, respectively, was used. Fungicide treatment was carried out in glass cylinders, which were rotated for 5 minutes after treatment. The standard dosages used in the official testing experiments are now 1/2, 3/4, 1/1 and 2/1 for observation trials and 1/2, 3/4 and 1/1 dose for yield trials.

Table 2. Seed treatment products and active ingredients.

Product	Dose/100 kg	Appr.	Active ingredients (a.i.)	g a.i. per l/kg
Beret FS 050	400 ml	(w)	fenpiclonil	50
Beret FS 060	400 ml	(w)	fenpiclonil/imazalil	50/10
Beret Combi	200 ml	(w)	fenpiclonil/difenoconazole	50/50
Derosal M bejdse	150 g	w	carbendazim/maneb	150/600
DLG Manebbejdse	200 g	sw	maneb	700
Fungazil C	200 ml		carboxin/imazalil	400/25
Neo-Voronit	250 ml		Na-N-dimethyldithiocarbamate/-fuberidazole	300/5
Panoctine 30	200 ml		guazatine	300
Sibutol LS 280	100 ml	w	bitertanol/fuberidazole	250/18
Vitavax 200 FF	250 ml		carboxin/thiram	200/200

w : Products with a biological approval against common bunt in winter and spring wheat in Denmark.
sw : Spring wheat only. (w) : Products which have an approval in wheat, but are not registered for use yet.

RESULTS

Table 3 shows the results of trials with the seed treatments that were used in the late 1980s. Only bitertanol/fuberidazole has given full control, whereas the other products have had weaker effects and show a rapidly decreasing effect when treated with half dose.

Table 3. Control of common bunt, 6 trials on winter wheat, 1987-90.

	Standard dose (1/1) g a.i./100 kg seed	Percentage control		
		Dose		
		1/2	1/1	2/1
Na-N-dimet.dt.carb./fuberidazole	75/1.3	68[a]	87[c]	97[d]
Guazatine	60	81[b]	88[c]	96[d]
Bitertanol/fuberidazole	50/3.6	100[e]	100[e]	100[e]
Percentage attacked plants in untreated control			42,0	

Values with the same letter do not differ significantly ($p \leq 0.05$)

Table 4 shows the results of trials carried out in recent years with two disease levels. Even at the low disease level, guazatine has a relatively weak effect compared to bitertanol/fuberidazole (which in this trial has been tested with 100 ml product).

Table 4. Control of common bunt, 3 trials on winter wheat, 1991-93 using different doses at two disease levels. Artificial inoculation with 0.25 and 5.0 g bunt spores per kg wheat.

	Standard dose (1/1) g a.i./ 100kg seed	Percentage control 0.25 g spores/kg wheat				Percentage control 5 g spores/kg wheat			
		Dose				Dose			
		1/2	3/4	1/1	2/1	1/2	3/4	1/1	2/1
Carb./maneb[1)]	22.5/90	100[d]	100[d]	100[d]	100[d]	96[c]	98[d]	98[d]	99[de]
Guazatine	60	80[a]	93[b]	97[c]	95[b]	89[a]	90[b]	95[c]	96[c]
Bitert./fub.	25/1.8	100[d]	100[d]	100[d]	100[d]	100[e]	100[e]	100[e]	100[e]
Percentage attacked plants in untreated control				6.6				22.5	

Values with the same letter at each dicease level do not differ significantly ($p \leq 0.05$)

[1)] Carb./maneb = Carbendazim/maneb, Bitert./fub. = bitertanol/fuberidazole

Common bunt can lead to severe yield losses and the close correlation between percentage diseased plants and yield loss is shown in Table 5.

A summary of the trials carried out in recent years with seed treatments on wheat is shown in Figure 2. The results of the individual products originate from different trials and the effects can therefore not be compared directly. However, the figures provides a good picture of the potential effects of the various seed treatments on common bunt, and it appears that there are several seed treatments which are very efficient.

Table 5. Control of common bunt, 7 trials on winter wheat, 1991-93.

	Rate g a.i./100 kg seed	Percentage control of common bunt	Yield t per ha
Guazatine	60	89[a]	6.48[b]
Bitertanol/fuberidazole	12.5/0.9	98[d]	6.57[ab]
Bitertanol/fuberidazole	18.8/1.4	99[e]	6.74[a]
Bitertanol/fuberidazole	25.0/1.8	99[e]	6.72[a]
Carboxin/thiram	30/30	95[b]	6.62[ab]
Carboxin/thiram	40/40	97[c]	6.67[ab]
Carboxin/thiram	50/50	98[d]	6.69[ab]
Untreated control		26.6% [1)]	5.13

Values with the same letter in each column do not differ significantly ($p \leq 0.05$)

[1)] Percentage attacked plants in untreated control.

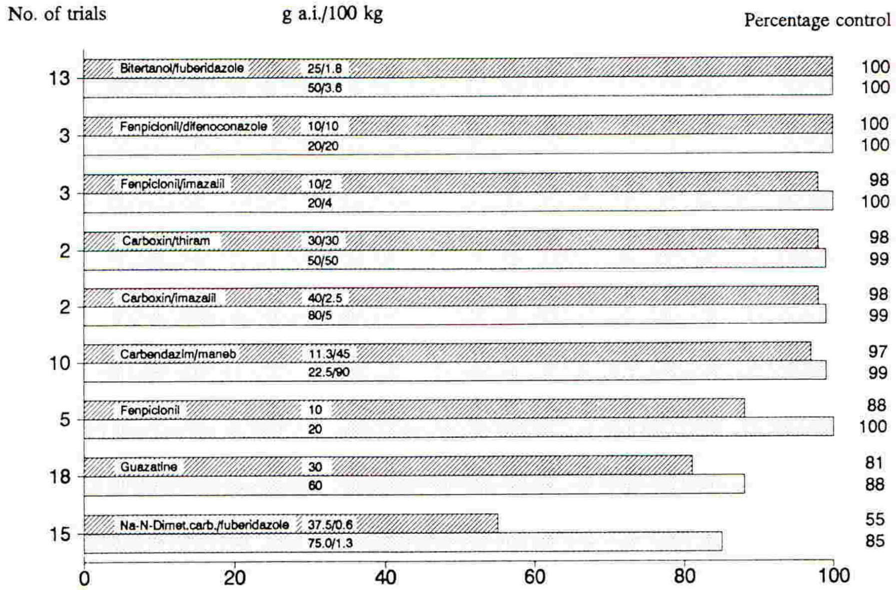

Figure 2. Efficacy of different products against common bunt in winter wheat in Denmark.

DISCUSSION

Trials with fungicide treatment against seed borne common bunt shows that it is possible to obtain almost 100% control. In all trials, bitertanol/fuberidazole has shown 99-100% control, even at low doses. The product was approved at a rate of 200 ml/hkg in 1987, which based on trials results was changed to 150 ml in 1990 and finally to 100 ml/hkg in 1991. The efficacy against Fusarium spp. and Septoria nodorum using this dose is considered satisfactory under Danish conditions. It was shown that the older seed treatment Na-N-dimethyldithiocarbamate/-

fuberidazole and guazatine had a lower efficacy as regards common bunt, which was also seen in Swedish trials (Olofsson & Johnson, 1985). Seed treatments with fenpiclonil, which proved to be effective against bunt, especially in combination with e.g. difenoconazole, are still under evaluation for registration in Denmark.

In order to stop the development of common bunt, it was decided in 1991 only to approve the most effective seed treatments for control of common bunt. The biological approvals are shown in Table 2 and among these products only bitertanol/fuberidazole (100 ml) is now on the market and can be used for control of common bunt in wheat. Guazatine now only holds an approval for control of Fusarium spp. and Septoria nodorum and is recommended for wheat only when the seed is free of common bunt.

In 1993, signs of soil infestation with common bunt were found in Denmark. The soil infestation was observed in an area where clean, untreated wheat had been sown in September 1992, following a crop with 10% bunt in summer 1992. Soil infestation has also been demonstrated in other Danish trials (Nielsen, 1993). Earlier it had been reported in Swedish trials that spores of T. caries could survive for 10 years in the soil (Johnson, 1990), but soil-borne spores are only regarded as having epidemiological significance in winter wheat regions with arid summers (Wiese, 1987). The recent dry years may have contributed to the development of common bunt due to the survival of soil borne inoculum as described in recent years in certain regions in the U.K. (Yarham & Jones, 1992). The possibility of soil infestation with common bunt further underlines the necessity to take a more stringent attitude towards controlling the disease.

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EVALUATION OF BROAD SPECTRUM SEED TREATMENTS FOR THE CONTROL OF CEREAL FOLIAR DISEASES IN SCOTLAND

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ABSTRACT

The use of broad spectrum cereal seed treatments for control of seed-borne diseases has increased over the past two seasons with the withdrawal of organomercury products. The advantage of these seed treatments is their activity against foliar diseases as well as seed-borne diseases. This paper reviews their efficacy at controlling foliar diseases and increasing yields in cereals grown under Scottish conditions.

INTRODUCTION

Cereal fungicide seed treatments, in particular the organomercury fungicides, have been used for over 50 years for the control of seed-borne diseases such as barley leaf stripe (*Pyrenophora graminea*), seedling blight (*Monographella nivalis* = *Fusarium nivale*) and wheat covered smut or bunt (*Tilletia tritici* = *Tilletia caries*). These early seed treatments had no activity against foliar diseases. The development of ethirimol in the late 1960s (Brooks, 1970) provided the first systemic seed treatment specifically for the control of a foliar disease, powdery mildew (*Erysiphe graminis*) in barley. In 1977, 93% of the cereal seed sown in Scotland received an organomercury seed treatment for control of seed-borne diseases (Steed *et al.*, 1979), most being applied to the spring barley crop which comprised 85% of the cereals grown at this time (Table 1). The use of ethirimol in combination with organomercury occurred on 43% of spring barley seed.

Subsequent to 1977 the area of winter barley and winter wheat grown in Scotland began to rise, with a corresponding reduction in the spring barley area (Table 1). The rise in winter barley acreage posed a potential threat to the spring barley crop, providing a 'green bridge' for carry over of powdery mildew (Yarham *et al.*, 1971). Likewise, spring barley posed a threat to early sown winter barley crops.

The development of several broad spectrum seed treatments in the 1970s and 80s, including fuberidazole + triadimenol (Baytan - Bayer UK Ltd) and ethirimol + flutriafol + thiabendazole (Ferrax - Zeneca) which could give control of both seed-borne and foliar diseases provided a single alternative to the organomercury/ethirimol two treatment option. Unlike ethirimol these new broad spectrum seed treatments were also effective against wheat mildew, yellow rust (*Puccinia striiformis*) and other foliar diseases. However, their use was limited in comparison to that of the cheap organomercury products until the withdrawal of organomercury from the UK market in 1992 (Table 1). Growers must now make a choice between a broad spectrum seed treatment or one of the new alternatives to mercury specifically for seed-borne disease control.

Table 1. Summary of fungicide seed treatment used on cereals in Scotland.

Crop	Active ingredient	% Crops Treated/Year 1974	1977	1982	1988	1990	1992
Spring barley	organomercury	92	95		79	82	48
	ethirimol	-	43		0.5	0.5	-
	fuberidazole+ triadimenol	-	-		8	5	11
	ethirimol + flutriafol + thiabendazole	-	-		8	7	22
(% of total	cereal crop)	78	85	78	61	57	55)
Winter barley	organomercury	-	-		86	69	39
	fuberidazole + triadimenol	-	-		20	7	17
	ethirimol + flutriafol + thiabendazole	-	-		15	18	25
(% of total	cereal crop	0	+	8	13	14	13)
Winter wheat	organomercury	43	89		86	69	39
	fuberidazole + triadimenol	-	-		15	23	48
(% of total	cereal crop	7	4	8	19	23	26)
Spring oats	organomercury	90	83		79	69	66
	fuberidazole + triadimenol	-	-		0	1	0
	ethirimol + flutriafol + thiabendazole	-	-		1	0	2
(% of total	cereal crop	16	11	6	7	6	5)

Chapman *et al.*, 1977; Steed *et al.*, 1979; Snowden *et al.*, 1991a, 1991b; Bowen *et al.*, 1993.

This paper reviews work carried out by the Scottish Agricultural College (SAC) over the past eleven years to determine the effectiveness of systemic broad spectrum seed treatments for control of foliar diseases in the major cereal crops grown in Scotland. Unless stated, in *the trials* presented comparing broad spectrum seed treatments with organomercury seed treatment foliar fungicide oversprays have also been applied; but for any one trial the overspray(s) has been the same fungicide applied at the same timing.

SPRING BARLEY

The main disease of spring barley in Scotland is powdery mildew but Rhynchosporium (*Rhynchosporium secalis*) can occur in wet seasons. Net blotch (*Pyrenophora teres*) and brown rust (*Puccinia hordei*) are of less importance. Trials carried out in north-east Scotland during the 1970s showed the use of a broad spectrum seed treatment of fuberidazole + triadimenol gave good foliar disease control and significant yield increases in spring barley (Wale & Shipton, 1981). These results preceded the development of insensitivity by *E. graminis* to 'triazole' fungicides. Prior to this time the use of ethirimol had not been generally recommended in Scotland. For example in the south of Scotland Channon & Boyd (1973) found no yield advantage from the use of ethirimol, except where mildew infections occurred early or were known to occur in local areas when its use was advised (Channon & Clark, 1980).

When the effect of broad spectrum seed treatments alone (without subsequent foliar sprays) was tested, the yield responses when disease pressure was high, as when fuberidazole + triadimenol was evaluated, generally covered the cost of the seed treatment (Table 2). In years when mildew levels were low, when ethirimol + flutriafol + thiabendazole was evaluated, the cost of the seed treatment was not covered and resulted in an overall loss of £14.21/ha. These trials were done on the cultivar Golden Promise which was fully susceptible to powdery mildew (Anon., 1987). Most modern varieties show better resistance to powdery mildew (Anon., 1992). Mildew susceptibility must be considered when seed treatment decisions are taken.

Table 2. Effect of broad spectrum seed treatments on yield of spring barley, margin over cost and mildew infection compared to an organomercury control, 1982-92; cv. Golden Promise.

Seed treatment	Yield (t/ha) at 15% MC)		Margin/cost (£/ha)	mildew - mean % LAI GS 45-65	
organomercury	4.85	4.97		25.4	tr
fuberidazole+ triadimenol	5.02	-	2.93	23.3	-
ethirimol+ flutriafol+ thiabendazole	-	4.98	-14.21	-	tr
no. of trials	3	10			

Margin/cost calculated as (yield broad spectrum - yield organomercury x £94) - (cost of broad spectrum - cost mercury). Based on prices at time of publishing. No fungicide oversprays.

In trials where broad spectrum seed treatments with subsequent foliar sprays were compared to one or two foliar sprays, they resulted in relatively good control of mildew but were not always cost effective. In one series of trials (Table 3, Series A), mildew control from a fuberidazole + triadimenol seed treatment with an over-spray was equivalent to a two spray programme. The yields, however, were no greater than a single well timed spray.

In a second series of trials, an ethirimol + flutriafol + thiabendazole seed treatment with a single 'early' overspray gave a lower yield and was less cost effective than a two spray programme 'early' and 'late' (Table 3, Series B).

Table 3. Effect of broad spectrum seed treatment plus foliar spray(s) at different timings on yield of spring barley, fungicide cost and mildew infection, cv. Golden Promise.

SERIES A (3 trials) 1981-82

Seed treatment	Spray timing early	mid	late	Yield (t/ha) at 15% MC	Cost of fungicide (£/ha)	mildew % LAI GS 71-80
organomercury	x			5.52	23.60	38.8
organomercury		x		5.67	23.60	23.8
organomercury	x		x	5.88	37.41	11.8
fuberidazole+ triadimenol			x	5.60	36.65	10.5

SERIES B (1987-89)

Seed treatment	Spray timing early	late	No. trials	Yield (t/ha) at 15% MC G.P.	Golf	mildew - % LAI at GS 65-81 G.P.	Golf
organomercury *			3	4.01	4.83	46.1	30.8
organomercury	x	x	3	5.03	5.66	7.9	4.5
fuberidazole+ triadimenol	x		2	5.00	5.35	36.8	22.0
ethirimol+ flutriafol+ thiabendazole	x		3	4.77	5.22	23.6	11.7

* - organomercury seed treatment with no foliar fungicide

One of the main reasons for use of a seed treatment with action against foliar diseases in Scotland is 'peace of mind'. Their use in spring barley gives growers the chance to delay the timing of the foliar spray without affecting yield. In practice, the delay may only be a few days, but in an area where mixed arable farms are common and silage making is an important feature of the farm calender, one week delay in spraying spring barley crops can give the grower breathing space.

Where a suceptible variety such as Blenheim is grown, on farms where mildew is a problem or where spring barley is grown in close proximity to winter barley an early foliar spray may have to be followed up by a second spray. At full dose, two foliar sprays are usually more expensive than a seed treatment plus one spray. The use of broad spectrum seed treatments in these situations is more favourable.

Rhynchosporium is an important disease of spring barley in wet seasons, when grown in damp coastal areas and in areas known to show high levels of infection, especially where a suceptible variety such as Prisma, Blenheim or Derkado is grown.

The use of fuberidazole + triadimenol gave only a small yield benefit in eight field trials where Rhynchosporium infections was absent or at low levels (Table 4). The yield response just covered the cost of treatment. In four trials where Rhynchosporium levels were higher, the average yield response was 0.78 t/ha, making this a very profitable treatment. However, unlike mildew, Rhynchosporium is more sporadic in occurence and there is less justification for routine treatment.

Table 4. Effect of broad spectrum seed treatment on yield of spring barley, margin over cost and control of Rhynchosporium compared to an organomercury control, cv. Maris Mink 1978-83.

Seed treatment	Yield (t/ha) at 15% MC Rhynchosporium infection: nil - slight	 Mod-sev
organomercury	5.43	2.88
fuberidazole+ triadimenol	5.58	3.67
Margin/cost (£/ha)	1.05	61.21
no. of trials	8	4

Yield equivalent to cost of fuberidazole + triadimenol = 0.14 t/ha.
No fungicide oversprays.

WINTER BARLEY

On average, treatment with fuberidazole + triadimenol gave no yield advantage over an organomercury control in 17 trials carried out between 1982 and 1990, resulting in an overall economic loss to the grower (Table 5). Ethirimol + flutriafol + thiabendazole consistently gave slightly higher yields than fuberidazole + triadimenol. Where the later was used, brairding was consistently delayed for 3 to 5 days compared to that of the organomercury control. In some trials the seed treatment reduced autumn mildew or early spring Rhynchosporium infection but in others there was no effect. In all trials levels of both powdery mildew and Rhynchosporium at the end of the season, after foliar sprays had been applied, were similar irrespective of whether a broad spectrum seed treatment had been used or not. The value of a broad spectrum seed treatment was much greater the earlier trials were sown (Wale, 1987).

Table 5. Effect of broad spectrum seed treatment on yield of winter barley, margin over cost and disease control compared to an organomercury control, 1982-1990.

Seed treatment	No. trials	Yield (t/ha) at 15% MC	Margin/cost (£/ha)	Disease assessments % LAI at GS 45-71 mildew	Rhyncho	
organomercury	19	6.80		8.8	3.5	[11]
fuberidazole + triadimenol	17 (3)	6.73	-19.63	7.7	6.0	[9]
ethirimol + flutriafol + thiabendazole	13 (0)	7.11	13.99	5.1	6.0	[7]

() no. trials where yield increase significant at p=0.05.
[] no. trials where diseases assessments carried out

WINTER WHEAT

The area of winter wheat grown in Scotland has gradually increased from 30,000 ha (6.6% of the cereal crop) in 1974 to 120,000 ha (26.4% of the cereal crop) in 1992 (Table 1), making it the second most important cereal crop in Scotland. Until 1988 much of the crop was still treated with organomercury seed treatment for control of seed-borne diseases but this rapidly decreased until 1992 when only 39% of seed was organomercury treated. There was a corresponding increase in broad spectrum seed treatments, culminating in almost half the seed sown in 1992 being treated.

The most important foliar diseases of winter wheat are powdery mildew, *Septoria tritici* and yellow rust. In a series of trials carried out by SAC between 1984 and 1992 in east and north-east Scotland, the use of a broad spectrum seed treatment consistently increased the yield of winter wheat compared to the organomercury treated control (Table 6). One in five of the trials gave a significant yield increase. Increases in yields were accompanied by a corresponding (but not significant) decrease in foliar disease infections: *Septoria tritici* was the main disease. In general, the cost of the seed treatment was covered by yield benefits.

Of the trials where the use of a fuberidazole + triadimenol seed treatment gave significant yield benefit over the organomercury control, the increase in yields could not be associated with large reductions in disease levels (Table 7). Economic benefits were large and seed treatment use was cost effective.

Table 6. Effect of broad spectrum seed treatment on foliar diseases control and yield of winter wheat compared to an organomercury control, 1984-92, various cultivars.

Seed treatment	Yield (t/ha) at 15% MC	Disease assessments-% LAI at GS 31-83		
		Powdery mildew	Septoria tritici	Yellow rust
organomercury*	6.60	3.2	11.2	13.1
organomercury	8.34	1.7	6.1	2.1
fuberidazole+ triadimenol	8.71	1.4	4.4	0.6
Margin/cost (£/ha)	21.64			
total no. trials	20	14	15	10
no. where increased	12 (4)	4 (0)	4 (0)	0 (0)
no. where decrease	7 (0)	7 (0)	8 (0)	7 (1)

() no. trials where increase or decrease significant at p = 0.05
* organomercury seed treatment with no foliar fungicides.
Yield equivalent of cost of fuberidazole + triadimenol = 0.14 t/ha.

Table 7. Relationship between yield increase and disease reduction in seed treated winter wheat compared to organomercury control where yield response was significant

Seed treatment	Yield (t/ha) at 15% MC	Disease assessments-% LAI at GS 59-83		
		Powdery mildew	Septoria tritici	Yellow rust
organomercury*	5.42	2.7	4.4	9.4
organomercury	7.52	0.8	3.0	2.0
fuberidazole + triadimenol	8.62	0.8	1.4	1.1
Margin/cost (£/ha)	93.18			

* organomercury seed treatment with no foliar fungicides applied

Broad spectrum seed treatments gave reductions in foliar disease levels at the time of the first foliar fungicide spray (GS 31) compared to the organomercury control (Table 8), which were maintained through to later growth stages. Subsequent foliar fungicide oversprays gave equal control of disease in both the mercury and fuberidazole + triadimenol seed treatments: there were no interactions. Foliar sprays, at GS 31, 39 and 59, usually give large yield responses, much larger than that of the broad spectrum seed treatment (Sutherland *et al.*, 1993).

Sowing dates of winter wheat in Scotland vary from September through to November. The later the crop is sown, the colder the seed-bed and hence the more prone the crop is to delayed emergence, slower growth and increased risk from seedling blight. Field observations have shown the use of a fuberidazole + triadimenol seed treatment can delay emergence from a few days up to a few weeks depending on sowing date. There was a trend towards earlier sown crops giving a positive yield benefit from the use of a broad spectrum seed treatment (Table 9) but there was no corresponding reduction in disease levels.

Table 8. Persistance of seed treatment for control of foliar diseases on winter wheat, compared to an organomercury control.

	Disease Assessments - % LAI					
	GS 31-32 (before fungicide oversprays)			GS 59-83 (after fungicide oversprays)		
Seed treatment	Pm	St	Yr	Pm	St	Yr
organomercury*	0.9	2.9	0.2	1.9	13.6	9.1
organomercury	0.9	3.8	0.3	1.2	4.6	1.3
fuberidazole+ triadimenol	0.4	2.6	0.1	1.3	3.5	0.6

total no. trials = 10   no. of trials where decrease sig. = 0

Pm = powdery mildew; St = Septoria tritici; Yr = Yellow rust
*organomercury seed treatment with no foliar fungicides applied

CONCLUSIONS

Although early seed treatment trials on spring barley showed good disease control and yield responses, more recent work has shown their use solely for the control of foliar diseases is not cost effective. However, in situations of high disease pressure (susceptible cultivar, locality, proximity to winter barley) or where the grower, because of other on-farm commitments, wants to delay the time of spraying, broad spectrum seed treatments are advisable. Similar advice can be given for winter barley.

The use of fuberidazole + triadimenol seed treatment in winter wheat for the control of foliar disease is not essential. Only where a threat of early infection of yellow rust exists (early sowing, susceptible variety) is this seed treatment easily justified since where late attacks occur, warnings of outbreaks south of the border allow growers in Scotland to tailor their GS 31 sprays accordingly. On average *fuberidazole* + triadimenol gave a cost-effective yield response. This may be due in part to foliar disease control but it may also be related to other factors such as reduction in autumn take-all and stem base disease and improved rooting which occur sometimes. These other factors are most important in early sown crops and, because fuberidazole + triadimenol can cause delays in emergence in later sowings, this seed treatment is most strongly recommended for use in early sowing. The trial results broadly support this contention.

Table 9. Effect of sowing date on yield of winter wheat, foliar disease control and margin over cost for a broad spectrum seed treatment compared to an organomercury control.

Yield (t/ha) at 15% MC

Sowing date	Seed treatment organo-mercury*	organo-mercury	fuberid+ triad	Margin/ cost (£/ha)	No. trials
30 Sept - 10 Oct	6.27	7.23	7.68	29.48	7 (3)
11 Oct - 20 Oct	7.55	9.10	9.14	-10.70	8 (0)
21 Oct - 31 Oct	7.76	8.76	8.88	- 2.86	2 (0)
1 Nov - 6 Nov	6.09	9.13	10.25	95.14	2 (1)

* organomercury seed treatment with no foliar fungicide applied
( ) - no. where yield increase significant

Disease assessments - % LAI at GS 59-83

	Seed treatment organomercury*			organomercury			fuberidazole + triadimenol		
	Pm	St	Yr	Pm	St	Yr	Pm	St	Yr
30 Sept- 10 Oct	4.9	7.8	4.4	1.4	2.4	0.2	1.0	1.3	0.1
11 Oct - 20 Oct	2.1	14.9	3.0	2.0	5.7	0.4	1.7	4.7	0.1
21 Oct - 31 Oct	1.0	4.1	3.0	0.0	0.4	0.0	0.0	0.5	0.0
1 Nov - 6 Nov	1.0	0.5	15.7	0.6	0.2	3.7	0.8	0.04	1.9

* organomercury seed treatment with no foliar fungicide applied
Pm = powdery mildew St = Septoria tritici Yr = Yellow rust

With the withdrawal of organo-mercury products and the introduction of more expensive non-mercury alternatives, the price differences between these and broad spectrum seed treatments are narrower making the use of broad spectrum seed treatments with the added bonus of foliar disease control more inviting to growers.

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THE USE OF GUAZATINE-BASED PRODUCTS FOR THE CONTROL OF SEED-BORNE DISEASES OF CEREALS

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ABSTRACT

Guazatine, used as a treatment for wheat seed has had a significant impact in the UK since the withdrawal of organomercury. The seed-borne diseases - *Fusarium nivale, Tilletia caries*, and *Leptosphaeria nodorum* have been shown to be well controlled by the fungicide.

In barley, guazatine plus imazalil has been shown to give improved control of *Pyrenophora graminea*, *Cochliobolus sativus* and a useful effect against *Ustilago nuda.*

INTRODUCTION

Fungicidal properties of the salts of guazatine were first reported by Catling et al.(1968). The triacetate was later developed as a cereal seed treatment by Murphy Chemical in the UK and by Kenogard in Sweden.

The first reports of activity against *Leptosphaeria nodorum, Monographella nivalis (Fusarium nivale), Tilletia caries, Pyrenophora graminea, P.avenae* and *Ustilago avenae* were confirmed by Jackson et al. (1973).

In an attempt to provide the same level of control as organomercury against *P.graminea*, on barley, Bartlett and Ballard (1975) were successful when a mixture of guazatine (0.6g/kg seed) and imazalil (0.04g/kg seed) was used.

Guazatine alone, and in mixture with imazalil , has been used in a number of European countries since 1973. It has been jointly developed in the UK by Rhône-Poulenc as 'Panoctine' (wheat) or 'Panoctine Plus' (barley) and by DowElanco Ltd as 'Rappor' or 'Rappor Plus'.

MATERIALS AND METHODS

The products tested are listed below:

Product name	active ingredient	dose rate → product/tonne seed
Panoctine	guazatine	2L
Panoctine Plus	guazatine + imazalil	2.2L
Baytan	tradimenol + fuberidazole	2.0L
Cerevax	carboxin + thiabendazole	2.5L
Cerevax Extra	carboxin + thiabendazole + imazalil	2.0L
Ferrax	flutriafol + thiabendazole + ethirimol	5.0L
Panogen	organo-mercury	1L

Seed was treated in the laboratory using a Hege seed treater no. II. In the case of *Fusarium* on wheat and *P.graminea* and *U. nuda* on barley, naturally contaminated seed was used, but with *T. caries* on wheat seed was infected prior to treatment with 2g spores/kg seed.

Plot sizes in the case of Scottish Agricultural College (SAC) were 2 x 5m, all other sites being 2m x 12m replicated 3 or 4 times, drilling was achieved using a Hege small plot drill.

Results are expressed as plant population /m² or percent disease incidence. An analysis of variance (LSD or SED) was carried out on all means.

RESULTS

1) <u>*Fusarium nivale* - winter wheat.</u>

The results of 3 independent trials carried out in 1992 using infected seed stocks of winter wheat are shown in Table 1.

TABLE 1. *Fusarium nivale* - effect on seedling emergence of winter wheat

Plant population/m^2

Treatment	Site % seed infection	Bratton, Wilts 60	Lavant, Sussex 60	Rosemaund, Herefs 48
Untreated		73.3	112.4	141.7
Guazatine		200.0	211.6	229.0
Triadimenol +		201.3	-	230.9
fuberidazole		166.2	-	199.1
Carboxin thiabendazole				
	LSD	31.6	12.4	28.0
	CV (%)	7.2	3.4	9.1

2) *Tilletia caries* - winter wheat

Trials carried out by SAC in 1990 and 1992, using high grade, artificially infected seed gave excellent bunt control with guazatine.

TABLE 2. Control of *Tilletia caries* - SAC results 1990 and 1992

Winter wheat C1 seed, artificially infected - 2g spores/kg seed

% bunted heads

Treatment	Year	1990	1992
Untreated		85.1	32.2
Guazatine		3.1	0.0
Organomercury		7.4	-
Triadimenol +		0.6	0.7
fuberidazole		-	6.7
Carboxin +			
thiabendazole			
	SED +/-	12.9	4.03

3) *Pyrenophora graminea* - Barley

Results from trials carried out at SAC during 1990-92 show good control of *P.graminea* with guazatine /imazalil (see Table 3.).

TABLE 3. Control of *Pyrenophora graminea*

SAC trials - spring barley 1990-1992 (infected seed)

Treatment	Year	1990	1991	1992
		% leaf stripe		
Untreated		5.54	19.4	21.3
Guazatine & imazalil		0.00	0.00	0.00
Organomercury		1.32	-	-
Flutriafol + thiabendazole + ethirimol		0.00	0.00	0.00
Triadimenol + fuberidazole		-	0.1	0.9
	SED +/-	1.99	2.51	4.46

4) <u>*Ustilago nuda* - Barley</u>

Although there is currently no label claim for the control of loose smut, trials data (Table 4) confirm that activity is equivalent to that given by other products.

TABLE 4. Control of *Ustilago nuda*

SAC trials 1991 and 1993 - Winter barley

Treatment	1991 no. smut/m. drill	1993 % smut
Untreated	9.21	8.38
Guazatine + imazalil	0.04	0.00
Triadimenol + fuberidazole	0.00	-
Carboxin + thiabendazole +	-	0.00
imazalil	-	0.00
Flutriafol + thiabendazole +		
ethirimol		
SED +/-	0.44	1.168

DISCUSSION

Crop Tolerance

Jackson et al. (1973) quote the proven crop safety of guazatine in both laboratory and field emergence studies in wheat , barley and oats, as equivalent to that for organo-mercury. Bartlett and Ballard (1975), further showed the safety of a guazatine/imazalil mix in barley.

In 17 winter wheat trials carried out by Rhône-Poulenc, the crop vigour in guazatine plots showed a 10% increase over the untreated control. Noon and Jackson (1992) also commented on the safety of guazatine in winter wheat. In the 20 winter barley RP sites, results were equivalent to both untreated and organomercury with guazatine/imazalil. Emergence was equivalent to, or greater than untreated control, in both spring-sown wheat and barley and winter and spring oats. Although no recommendation presently exists, tolerance was also found to be good on durum wheat, rye, triticale and naked oats.

Winter wheat disease control

1) *Fusarium nivale*. A major strength of guazatine lies in the control of *Fusarium nivale* seedling blight particularly as the fungicide provides a suitable replacement for strains of the fungus shown to be resistant to the benzimidazoles. Guazatine controls both surface and deep-seated infections of *Fusarium*, as a result of its penetrant properties.

F.nivale is increasing in importance, and is now probably the major seed-borne disease of wheat. According to Reeves and Simpkins (1993), 76% of seed samples submitted in 1992 to the Official Seed Testing Station for England and Wales were above the 5% advisory limit for the disease.

Jackson et al. (1973) showed guazatine to give a similar level of control to mercury in spring wheat and barley, whilst Roberti et al. (1992) found that this fungicide gave good control of *F culmorum* in winter wheat in Italy.

Seed treatment trials conducted by ADAS in 1986 (Jones, 1993) used seed stocks of wheat heavily infected with *F.nivale* . Guazatine was found to be the most effective treatment, significantly increasing plant emergence compared with untreated seed and organo-mercury. Referring to a 1986 survey (Locke et al, 1987) showing high levels of resistance of the fungus to benomyl, the author noted that guazatine was the only non-benzimidazole fungicide available for *F.nivale* control, and suggest this material to be the most suitable treatment for seed stocks with high levels of the disease.

In a trial carried out by the SAC in 1992 using winter wheat with 50% *F.nivale* infection, guazatine gave a statistically significant increase in plant emergence over other standard fungicides. Noon and Jackson (1992). showed that, although not statistically different from other standards, guazatine gave the highest plant counts and yield increases where *F nivale* was controlled.

2) *Tilletia caries* Jackson et al.(1973) confirmed original reports that guazatine was effective against this disease, but showed a slightly lower control compared to organomercury, results confirmed in later trials by Noon and Jackson (1992). Skorda (1981) showed activity of guazatine/imazalil against hexachlorobenzene insensitive strains of *T.foetida* in Greece, whilst researchers in Canada also found levels of bunt ,caused by the same fungus, to be significantly reduced by guazatine (Atkinson, 1974).

Trials conducted by ADAS in the UK during 1990-92 (Jones D.R. - Pers. comm.), indicate good control of *T.caries* with guazatine. Treatments were applied to artificially infected graded seed, or to naturally infected uncleaned, ungraded seed. With the graded seed, guazatine was found to give similar control to mercury and other standard fungicides over the three seasons of the trial; however, where ungraded seed was used, inferior control was experienced with most products. These latter poor results may possibly be explained by reduced seed surface loading due to the presence of higher numbers of small grains.

Control of bunt has been found to be in excess of 90% in situations where normal grade seed is involved. Recent work has shown guazatine to give similar control to current standards. Evidence on bunt control collected from 60 sites across Europe (not reported here), demonstrate the superiority of guazatine over organomercury, and its consistent achievement of high levels of control.

Barley disease control

1) *Pyrenophora graminea* Jackson et al.(1973) reported that guazatine alone was not sufficiently active against leaf stripe, and Bartlett and Ballard (1975) showed superior control compared to organomercury when imazalil was added to guazatine. During the 1980's instances occurred of *P.graminea* resistance to organomercury seed treatments. Jones et al.(1989) showed that guazatine + imazalil was effective against both organomercury-sensitive and resistant strains of the fungus. Noon and Jackson (1992) showed that in 3 trials with winter barley carried out in 1991, guazatine/imazalil gave excellent control of leaf stripe, equivalent to that given by mercury. In a further 2 spring barley trials the mixture eliminated the disease, giving superior control compared to mercury, which at one site completely failed to arrest the leaf stripe.

2) *Ustilago nuda* Although control of *nuda* is not currently claimed on the label text for the product , recent results indicate that control may be obtained, although in view of the systemic nature of the disease the mechanism of control by the mixture is not understood.

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