Fungicide Insensitivity in Pulse Crops

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Fungicides have become an essential tool for growing high yielding, top-quality pulse crops in Saskatchewan. However, with increased fungicide use year after year, resistance (insensitivity) within some of the main pulse crop diseases has begun to emerge. Awareness of potential insensitivity issues, in-depth understanding of fungicide groups, proper fungicide use and rotation, and integrated disease management strategies are required in order to delay further development of fungicide insensitivity.

What is Fungicide Insensitivity?

Fungicide insensitivity (resistance) refers to the reduced sensitivity of a pathogen (fungus) to a specific fungicide. This insensitivity is a heritable trait that is passed on to new generations from the few original pathogens that are naturally insensitive within the fungal population (Figure 1).

Pathologists often use the term insensitivity to refer to the resistance of a pathogen to a fungicide. The term resistance is typically reserved to describe the resistance of a host plant to a particular pathogen. In short, insensitivity refers to a pathogen, whereas resistance refers to a plant.

Fungicide Insensitivity in Saskatchewan

Fungicide insensitivity has been reported for Ascochyta blight in chickpeas in Saskatchewan, as well as in North Dakota and Montana. The first report of Group 11 (QoI, strobilurin) insensitive *Ascochyta rabiei* was in 2003 as part of a baseline study that tested 106 isolates, of which 88 were from Saskatchewan (Gossen and Anderson 2004). One of the Saskatchewan isolates showed cross resistance to both azoxystrobin and pyraclostrobin. A few years later, BASF confirmed Group 11 insensitive *A. rabiei* in several chickpea fields in southwest Saskatchewan from samples collected in 2006. By this time, it was apparent that a large shift in sensitivity of the *A. rabiei* population had occurred. In a recent survey of commercial chickpea fields in southern Saskatchewan in 2019, *A. rabiei* was detected in 33 fields. Group 11 insensitive *A. rabiei* was present in all 33 (100%) of these fields. Only 8 (24%) of the 33 fields additionally contained Group 11 sensitive (susceptible) *A. rabiei* (Hubbard 2019).

Ascochyta rabiei isolates have also been tested for sensitivity to chlorothalonil (Group M5) and mancozeb (Group M3), along with pyraclostrobin (Group 11), in a lab setting (Chang et al. 2007). A total of 66 isolates were collected from chickpea fields in southern Alberta in 2003 and 2004. The overall results found 35% of the isolates to be insensitive to chlorothalonil, 53% insensitive to mancozeb, and 24% insensitive to pyraclostrobin.

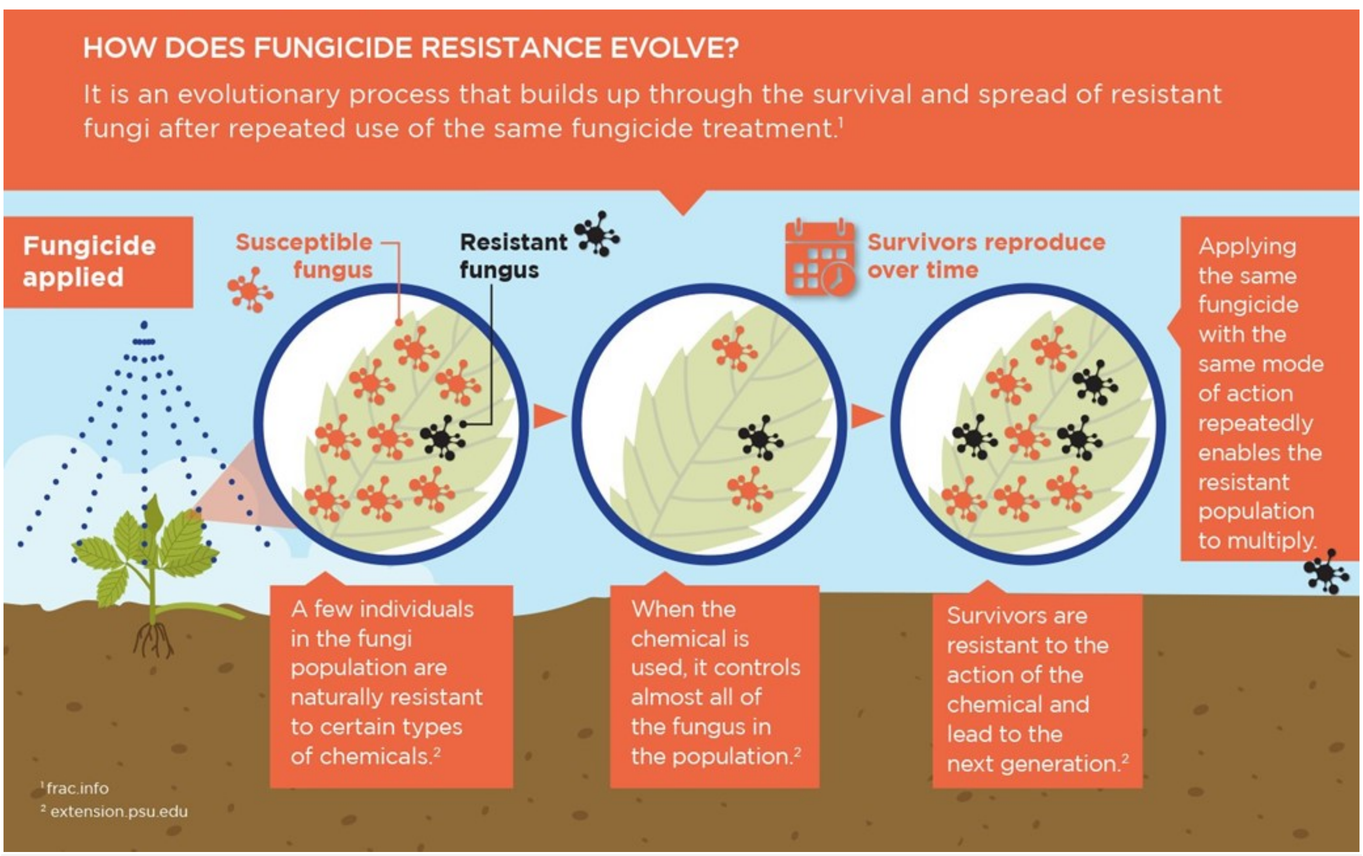

Figure 1. How Fungicide Insensitivity Evolves
Source: CropLife International

Some isolates were also found to be insensitive to multiple fungicides: four isolates (6%) were insensitive to all three fungicides, seven isolates (11%) were insensitive to chlorothalonil and mancozeb, three isolates (approximately 5%) were insensitive to chlorothalonil and pyraclostrobin, and seven isolates (11%) were insensitive to mancozeb and pyraclostrobin. This study suggests insensitivity to the Group M fungicides could exist in a lab, depending on the methods used, although this issue has not been reported in the field.

In 2019, BASF collected Anthracnose isolates from targeted (not random), heavily diseased lentil fields in Saskatchewan. Samples came back showing insensitivity to Group 11. The mutation found (G143A) confers cross resistance to all Group 11 chemistries. Survey work is being done in 2020 by a larger industry task force to gain a better understanding of the extent and severity of Group 11 Anthracnose insensitivity.

Researchers in Alberta have studied the sensitivity of *Mycosphaerella pinodes* in field peas to pyraclostrobin (Bowness et al. 2016). In order to develop a baseline sensitivity, they tested 70 unique *M. pinodes* isolates (40 from Agriculture and Agri-Food Canada in Saskatoon and 30 from the United States Department of Agriculture in Washington). The isolates were all collected prior to 2003, before Group 11 fungicides were registered for use in these areas and so had never been exposed to this fungicide group previously. All 70 isolates were sensitive (susceptible) to pyraclostrobin, thus establishing a true baseline of sensitivity that can be used to monitor future changes in the Mycosphaerella population. The researchers then tested 324 *M. pinodes* isolates collected from pea fields in Alberta, Saskatchewan, North Dakota, and Washington State in 2010 and 2011. In total, 19 isolates (6%) were insensitive to pyraclostrobin: nine from central Alberta, five from northern Alberta, and five from central and southern Saskatchewan. These results should serve as a warning for industry and growers to ensure the proper use of Group 11, incorporate other disease management strategies, and to continuously monitor the effectiveness of fungicide chemistries.

Fungicide Insensitivity Risk

The risk of developing fungicide insensitivity depends on three main factors: pathogen risk, fungicide risk, and agronomic factors.

1. **Pathogen Risk**
   Using scientific evidence, experience and reported insensitivity over the past 50 years, the Fungicide Resistance Action Committee (FRAC) has created a classification system for pathogens affecting the major world crop markets. The following factors, based on the biological properties of the pathogen, increase the risk of the pathogen developing insensitivity to a fungicide:
    - Polycyclic (short, multiple disease cycles per season increases the chance of repeated fungicide applications, putting more selection pressure on the pathogen and accelerating genetic changes within the pathogen population)
    - High spore production (higher chance of an insensitive mutant in the population)
    - Spores are dispersed by wind, allowing them to spread to other plants, crops, and regions
    - All crop growth stages can be infected (requires repeated fungicide applications)
    - Presence of a sexual stage in the life cycle (lower risk if asexual stage only)
    - Insensitive pathogen is as competitive as susceptible population (no fitness penalty observed)
    - Pathogen overwinters
    - Insensitivity within the pathogen population has evolved in the past after only a few years of fungicide use

Table 1 categorizes the insensitivity risk of pathogens causing disease in pulse crops in Western Canada.

Table 1. Pathogen Risk for Pulse Crops in Western Canada
Source: Fungicide Resistance Action Committee

Pathogen	Pathogen Insensitivity Risk	Crop	Disease	Characteristics Contributing to Insensitivity Risk				Fungicide Use (Pressure) per Season	Comments
				Polycyclic	Sexual Stage	Windblown Spores	Infects Multiple Crop Growth Stages		
Alternaria alternata	High	Pea, lentil, chickpea, faba bean	Alternaria blight/Brown leaf spot	Yes	Not in W. Canada	Yes	Yes	0 (currently not targeted for fungicide application)	Typically a weak, secondary pathogen that colonizes already damaged tissue. Possibly more pathogenic in faba bean compared to other pulse crops
Botrytis cinerea	High	Lentil, chickpea, faba bean, dry bean, soybean	Grey mould; seedling blight (from planting infected seed); Chocolate spot in faba bean	Yes	Not in W. Canada	Yes	Yes	1-2x	Sexual stage has not been observed on chickpea stubble in nature but can be produced in a lab, and has not been reported on lentil at all
Botrytis fabae	High	Faba bean, lentil (occasionally)	Chocolate spot	Yes	No	Yes	Yes	1-2x	More prevalent in faba bean than *B. cinerea.* Produces asexual conidia only
Ascochyta rabiei	Medium	Chickpea	Ascochyta blight	Yes	Yes	Yes	Yes	Very high (up to 5-6x)	Spreads by airborne ascospores (sexual) and rainsplashed conidia (asexual). Heavy fungicide pressure has contributed to *A. rabiei* insensitivity in the field

Table 1 (continued). Pathogen Risk for Pulse Crops in Western Canada

Pathogen	Pathogen Insensitivity Risk	Crop	Disease	Characteristics Contributing to Insensitivity Risk				Fungicide Use (Pressure) per Season	Comments
				Polycyclic	Sexual Stage	Windblown Spores	Infects Multiple Crop Growth Stages		
Ascochyta pisi	Medium	Pea	Ascochyta blight	Yes	Not in W. Canada	No	Yes	1-2x	Asexual conidia are spread by rainsplash
Ascochyta lentis	Medium	Lentil	Ascochyta blight	Yes	Not in W. Canada	No	Yes	1-2x	*A. lentis* is highly host specific to lentil. Asexual conidia are spread by rainsplash, including windblown mist. Favoured by cool, moist conditions
Ascochyta fabae	Medium	Faba bean	Ascochyta blight	Yes	Not in W. Canada	No	Yes	1-2x	Not commonly sprayed for at this time
Cercospora sojina	Medium	Soybean	Frogeye leaf spot	Yes	No	No	Likely	0-1x	Not commonly sprayed for at this time
*Colletotrichum lentis/ C. truncatum**	Medium	Lentil, faba bean, dry bean, pea (minor)	Anthracnose	Yes	Not in W. Canada	Spores are not windblown, but asexual conidia on windblown debris and harvest dust can spread disease	Yes	1-2x	Insensitive populations of *C. lentis* have been identified in lentil in SK. In pea, Anthracnose does not advance past the small, non-spreading lesions on leaves and stems, except for microsclerotia that can form on tendrils. *C. lentis* infects lentil. *C. truncatum* infects faba bean and pea. *C. pisi infects* pea only. *C. lindemuthianum* infects dry bean
Erysiphe spp.	Medium	Pea, lentil (minor), faba bean, soybean, dry bean	Powdery mildew	Yes	Yes	Yes	Yes	0-1x	All W. Canadian pea varieties must be immune to powdery mildew in order to be released. Unless old varieties are being grown, disease pressure and fungicide use should be non-existent
Mycosphaerella pinodes	Medium	Pea	Mycosphaerella leaf spot/blight	Yes	Yes	Yes	Yes	1-2x	Insensitive populations have been identified in lab but not the field in W. Canada
Peronospora spp.	Medium	Pea, lentil, chickpea, faba bean, soybean	Downy mildew	Yes	Yes	Yes (via asexual conidia)	Yes	0-1x	*P. viciae* infects pea, faba bean, and lentil. *P. lentis* infects lentil only. *P. ciceris* infects chickpea only. *P. manshurica* infects soybean
Septoria glycines	Medium	Soybean	Brown spot	Yes	No	No	Yes	0-1x	Spores are spread via rain splash. Not commonly sprayed for at this time
Stemphylium spp.	Medium	Lentil	Stemphylium blight	Yes	Not known if formed in nature	Yes	Yes	No fungicides registered	Since Stemphylium blight shows up late, fungicides used for Botrytis or Sclerotinia likely have some activity on the pathogen. Some resistance has been incorporated into varieties bred by the Crop Development Centre
Aphanomyces euteiches	Low	Pea, lentil, dry bean (variety dependent)	Aphanomyces root rot	No	Yes	Yes (via winblown soil)	Yes	1x (seed treatment)	Sexual oospores can be spread through the movement of soil particles by wind and water. Large volumes of spores can be produced and multiple infections can occur during the season
Fusarium spp.	Low	All pulse crops	Fusarium root rot	No	No	Yes	Yes	1x (seed treatment)	
Phytophthora sojae	Low	Soybean	Phytophthora root rot	No	Yes	Yes (via winblown soil)	No	1x (seed treatment)	Sexual oospores can be spread through the movement of soil particles by wind and water
Pythium spp.	Low	All pulse crops	Pythium seed rot and seedling blight	No	Yes	No	No	1x (seed treatment)	Sexual oospores can be spread through the movement of soil particles by wind and water
Rhizoctonia spp.	Low	All pulse crops	Rhizoctonia seed, seedling, and root rot	No	Yes	Yes	No	1x (seed treatment)	*R. solani* infects pulse crops, as well as canola. Sexual stage does not play a major role in disease development and spread (it may not even be present)
Sclerotinia sclerotiorum	Low	All pulse crops	White mould	No	Yes	Yes	Yes	1-2x	
Uromyces spp.	Low	Pea, lentil, faba bean, dry bean	Rust	Yes	Yes	Yes	Yes	Not usually targeted in W. Canada	*U. viciae-fabae* infects pea, lentil, and faba bean. *U. appendiculatus* infects dry bean

**Note: C. truncatum* that infects lentils was renamed *C. lentis* in 2014. *C. truncatum* still exists so it is important to use *C. lentis* when referring to Anthracnose in lentil

Botrytis cinerea, which causes grey mould, is considered to be one of the most risky pathogens in the world. It is categorized as high risk because it is polycyclic, it releases billions of windblown spores that infect numerous host plants at different growth stages, it can be found everywhere in the world, and it has become insensitive to multiple modes of action within one to two years after their introduction into the marketplace.

Ascochyta rabiei, causing Ascochyta blight in chickpeas, is the most known example of a pathogen showing fungicide insensitivity in Saskatchewan. It has wide genetic diversity, exhibits sexual reproduction, produces high amounts of wind-borne sexual ascospores, and has a polycyclic life cycle. Repeated fungicide applications (as many as 5-6 during a rainy year) are required for blight management each growing season. Within just 2-3 years, the Group 11 fungicides largely lost their effectiveness on Ascochyta blight in chickpeas in the province. However, *A. rabiei* is classified as medium risk for pathogen insensitivity, not high risk as might be expected. This is because globally, there are not that many reports of Ascochyta insensitivity overall. That being said, a medium risk is still cause for concern, and when a medium risk pathogen like Ascochyta is paired with a high risk fungicide group, such as Group 11, the pathogen-fungicide combination would be considered high risk.

2. **Fungicide Risk**

Fungicides are classified as low, medium, or high risk for the development of insensitivity. How a fungicide is categorized is based on its chemical group, mode of action, the insensitivity type of the pathogen, and the properties of the fungicide itself.

Chemical Group

Based on decades of insensitivity monitoring, the potential for a pathogen to become insensitive to a given fungicide can be fairly accurately predicted by the chemical group to which the fungicide belongs. For example, if a new Group 11 active ingredient is developed, based on the high insensitivity risk of this group, the new active will also be considered a high risk for insensitivity.

When a pathogen becomes insensitive to one fungicide and as a result, also becomes insensitive to another fungicide within the same fungicide group, it is called cross resistant. Active ingredients within the same group all act on the same target site, so when a target site mutation occurs, the pathogen is generally considered to be cross resistant across the entire fungicide group. For Group 11, cross resistance occurs between every active ingredient within the group. For example, a pathogen that is insensitive to pyraclostrobin will also be insensitive to azoxystrobin, picoxystrobin, and trifloxystrobin even if the pathogen has never been exposed to the latter active ingredients. Cross resistance is also shown between all active ingredients of Group 7 (SDHIs) and is generally accepted to occur across Group 3 (DMIs) as well.

When a pathogen becomes insensitive to more than one group of fungicides (i.e. more than one target site), it is said to have multiple resistance. Several distinct mutations are required by the pathogen in order for multiple resistance to occur.

Mode of Action

Compared to herbicide and insecticide resistance, which can be due to either target site mutations or metabolic resistance, fungicide insensitivity is usually the result of an altered target site in the pathogen. Fungicides that act on a single target site, such as Group 11, have a higher risk of selecting for insensitivity because the pathogen only has to acquire one mutation to render the fungicide ineffective. In comparison, fungicides that act on multiple sites (Group M) have a low insensitivity risk because the pathogen would have to make multiple mutations in order to confer resistance, which is highly unlikely to occur in nature.

Pathogen Insensitivity Type

Fungicide insensitivity can be quantitative or qualitative. Quantitative insensitivity is controlled by multiple genes and allows the pathogen to become less sensitive to the fungicide, but using higher rates or more applications can still control the disease. Qualitative insensitivity is controlled by a single dominant gene, resulting in the pathogen being completely insensitive to the fungicide and control is no longer achievable. Group 11 and Group 7 insensitivity is typically qualitative.

Fungicide Properties and Persistence

Generally, systemic fungicides have had more insensitivity issues than contact fungicides. However, this is not always the case. Group 11 fungicides can greatly differ in their systemic abilities. For example, azoxystrobin is highly systemic while trifloxystobin is nearly non-systemic. Yet, all Group 11 actives have had insensitivity issues with various pathogens. The greatest risk for insensitivity is with fungicides that act on a single target site, and many of these products also happen to have systemic properties. Table 2 on page 5 summarizes the insensitivity risk for foliar fungicides used in pulse crops in Western Canada.

3. **Agronomic Factors**

Of the three components contributing to fungicide insensitivity risk, the agronomic factors, which also include environmental factors, are arguably the most important. Agronomic factors will determine the disease severity in the local geographic area. Without the disease pressure, the use of fungicides would not be necessary and fungicide insensitivity risk would be non-existent.

The most significant agronomic risk factor is the weather. To cause disease, three components are required: the pathogen, the host crop, and the environment. The environment is the primary driving factor causing disease in pulse crops in Saskatchewan since most pathogens are already well-established in pulse-growing areas and pulses are a consistent part of crop rotations on many farms. While the environment may be the most important factor influencing disease, it is also the one that is the least controllable. This is where using best agronomic practices as part of an integrated disease management strategy becomes critical to mitigate the effects of weather on disease development (Table 3, page 6).

Strategies for Fungicide Use

Fungicides should be applied according to a well thought-out plan, taking into account the fungicide group as well as the role the fungicides play in protection of the plant (preventative vs. curative). Preventative fungicides are best used to protect green plant tissue during the early stages of disease development. Curative fungicides can stop fungal infections that have already begun to grow inside of the plant tissue, but typically only those that occurred 24-72 hours before the application, depending on the fungicide used. Curative fungicides cannot erase a lesion or repair any cellular damage that the pathogen has already caused, and like all fungicides, they too should be applied proactively, with prevention in mind. (continued on page 6).

Table 2. Insensitivity Risk of Foliar Fungicides used in Pulse Crops in Western Canada

Group & Active Ingredients	Comments
High Risk	
Group 11 QoI (Strobilurins) azoxystrobin picoxystrobin pyraclostrobin trifloxystrobin	• Insensitivity confirmed in Ascochyta in chickpea, Anthracnose in lentil, and Mycosphaerella in field pea in Western Canada • Target site mutations and additional mechanisms convey insensitivity • Cross resistance shown between all members of Group 11
Group 1 MBC (Benzimidazoles) thiophanate-methyl	• No insensitivity identified in pulse crops in Western Canada to date • Insensitivity common in many fungal species due to target site mutations • Cross resistance shown between all members of Group 1
Medium to High Risk	
Group 7 SDHI benzovindiflupyr boscalid fluopyram fluxapyroxad isofetamid penthiopyrad pydiflumetofen	• No insensitivity identified in pulse crops in Western Canada to date • Insensitivity in other pathogens is due to target site mutations • Cross resistance shown between all members of Group 7
Medium Risk	
Group 3 DMI (Triazoles) flutriafol metconazole propiconazole prothioconazole tebuconazole	• No insensitivity identified in pulse crops in Western Canada to date • Insensitivity in other pathogens is due to target site mutations and additional mechanisms • Generally accepted that cross resistance occurs between Group 3 fungicides active against the same pathogen
Low Risk	
Group M1 & M2 (Inorganics) copper (M1) sulphur (M2)	• Generally considered a low risk group • Multi-site contact activity
Group M3 (Dithiocarbamates) mancozeb	• Insensitivity reported from lab studies in Ascochyta in chickpea, but no field insensitivity has been reported in Western Canada • Generally considered a low risk group • Multi-site contact activity
Group M5 (Chloronitriles) chlorothalonil	• Insensitivity reported from lab studies in Ascochyta in chickpea, but no field insensitivity has been reported in Western Canada • Generally considered a low risk group • Multi-site contact activity
Group 29 fluazinam	• Considered low risk
Unknown Risk	
Group B2 (Microbials) *Bacillus amyloliquefaciens* *Bacillus subtilis*	• Insensitivity not known but is very unlikely • Biologicals with multiple modes of action
Not Classified (NC) Biofungicide *Coniothyrium minitans*	• Insensitivity not known but is very unlikely • Diverse group consisting of mineral oils, organic oils, inorganic salts, and material of biological origin with unknown target sites

Source: FRAC

Table 3. Agronomic factors affecting the development of fungicide insensitivity and the best management practices that can be used to lessen disease risk

Agronomic Factor	Influence on Fungicide Insensitivity	Best Management Practice to Lessen Disease Risk
Cultivar Selection	Resistant cultivars exhibit increased tolerance to certain diseases which lessens the pressure put on fungicides for disease control	Choose resistant cultivars where possible
Seed Quality	Seed-borne pathogens and cracked seed coats can promote the development of seed and seedling diseases. Seed sources contaminated with infested seed, sclerotia, or other overwintering pathogen structures contribute to the introduction of pathogens into new areas and overall disease inoculum	Invest in clean, high-quality seed, with low disease, high germination, and high vigour. If using farm-saved seed, send samples for disease, germination, and vigour testing after harvest so adequate time is available to source new seed if needed
Crop Rotation	Impacts the amount of disease inoculum in individual fields. Tighter crop rotations can increase disease pressure and reliance on fungicides for disease control	Multiple years between susceptible crops help reduce the amount of inoculum in the soil and stubble as spores can only live so long. Diverse rotations help break the disease cycle of many pathogens but not those that infect various crops (ex. Sclerotinia)
Field Selection	Windblown spores can spread from infested residue into adjacent fields the following year, increasing disease pressure on the crop	For hard to manage diseases such as Ascochyta in chickpea, choose a field at least 500 metres away from chickpea stubble and wait at least two years before planting chickpeas directly beside a chickpea stubble field
Fertilization and Seeding Rates	Lush canopies create a more humid environment for disease to develop in, increasing the reliance on fungicides. Higher seeding rates also promote thicker canopies with higher humidity	Increase scouting efforts in lush crops to identify early disease development before populations get out of control. Even in drier years, disease can still develop in the humid microclimate of dense crops
Irrigation	Increases relative humidity within the crop canopy, promoting disease development and increasing the potential for fungicide use	Increase scouting efforts to identify early disease development before populations get out of control
Monocropping	Disease, especially polycyclic diseases, can spread quickly through a monocrop field, increasing the pressure put on fungicides for disease control	Intercropping increases plant diversity by providing a non-host crop to interfere with pathogen infection. Research and grower experience has been showing positive results for disease reduction in flax-chickpea intercrops
Tillage	In some cases, burying residue may reduce inoculum for pathogens that overwinter on crop residue by speeding up decomposition and putting the fruiting bodies that release spores underneath the soil, making it more difficult to infect above-ground plant parts	For some pathogens, such as Anthracnose in lentil, research has shown that buried residue actually increases disease transmission from infested residue to healthy plants compared to residue left on the soil surface. Research has also found that factors such as environment, crop rotation, seed quality, and cultivar selection can have a larger impact on disease risk than tillage regime. The negative impacts of tillage (soil degradation, soil erosion, soil moisture evaporation) may outweigh any potential decrease in disease inoculum
Equipment Sanitation	Increased equipment sanitation can minimize the movement of the pathogen to other fields to reduce build-up of disease inoculum	For pathogens that are spread via soil, remove large clumps of soil from machinery before moving from field to field
Fungicide Use	The number of fungicide applications per year as well as the number of applications that target the same pathogen year after year play a large role in selecting for fungicide insensitivity	Use fungicides only when disease risk warrants application. Fungicides should be used as part of an integrated plan, not the sole solution for disease management. Select fungicides strategically, rotate fungicide groups, and apply multiple modes of action where possible. Use recommended rates, water volume, and appropriate nozzles. Biofungicides can be used in conjunction with traditional fungicides to help reduce selection pressure from specific fungicide groups on pathogen populations

(continued from page 4)

An important concept to understand is the minimum effective dose or critical dose rate. The minimum effective dose is the rate of active ingredient required to effectively control the target pathogen. If the fungicide is a single mode of action product, all of the control (and selection pressure) is attributed to that one mode of action. However, when working with two modes of action that act on the same disease, it is important that each individual mode of action is at a dose rate that could effectively control the pathogen on its own. If the pathogen is insensitive to one mode of action, the other component is solely responsible for the control of the pathogen. Reduced rates can contribute to a shift in the sensitivity of pathogen populations, allowing them to become less sensitive to the active ingredient because of their ability to not be shut down by a critical dose rate.

The fungicide group of most concern when it comes to pathogen insensitivity is Group 11. The insensitivity that has already been reported in common pathogens in lentils and chickpeas has come about from the repeated use of Group 11 applications within the same season, year after year, as well as the general lack of other disease management options. As such, more restrictions on the use of Group 11 and better planning around the timing of these products was needed, but simply switching to another single group, such as Group 7 or Group 3, to use repeatedly would not be sustainable either.

In an effort to curb the use of Group 11s as a solo application, manufacturers began to formulate products with multiple modes of action. The risk of Group 11 insensitivity developing is greatest when fungicides with a single Group 11 active ingredient are used. However, even applying a fungicide with multiple modes of action can eliminate Group 11 sensitive parts of the pathogen population. So while using products with multiple modes of action is a useful strategy from a preventative standpoint, it is not foolproof as fungicide insensitivity will still eventually develop.

Additional care must be taken when choosing a fungicide to use on a known Group 11 insensitive population. If a dual mode of action product containing a Group 11 is used on a Group 11 insensitive pathogen, it is the same as applying a single mode of action product on that pathogen because the Group 11 component will not be effective. In turn, this increases the selection pressure of the non-Group 11 active ingredient on the pathogen population, potentially selecting for multiple resistance. Also, each active ingredient in the multiple mode of action product must exhibit individual control of the target pathogen in order for the product to be truly effective for insensitivity management. For example, fluxapyroxad is included in dual mode of action products registered for Anthracnose in lentils. However, research conducted by North Dakota State University found that fluxapyroxad alone had no activity on Anthracnose in lentils (Wunsch 2013). As a result, any Anthracnose control from these products will come solely from the other active ingredient in the mixture, which again increases selection pressure on the other mode of action. If insensitivity to this other active ingredient already exists in the pathogen population, then Anthracnose control from these products will be very minimal. Therefore, it is important to fully understand the components of any fungicide and to recognize that the vast majority of fungicides used on pulse crops contain Group 3, Group 7, and/or Group 11 chemistries (Table 4).

A number of challenges exist with the current use of fungicides in pulse crops. Fungicide use has been increasing overall and three main fungicide groups (3, 7, and 11) are extensively used. These three modes of action are at medium to high risk of developing pathogen insensitivity. As well, there are very limited non-Group 3, 7, or 11 options for pulse crops. Therefore, proper fungicide stewardship is critical in order to extend the longevity of the main fungicides in the market, even for those classed as medium risk. Based on recommendations from FRAC and key fungicide manufacturers, specific advice for using Group 11, Group 7, and Group 3 fungicides are summarized in Table 5.

Biological Fungicides (Biofungicides)

Biofungicides offer a different, low-risk mode of action that can be used as a complement to traditional fungicides as part of an integrated fungicide program. In addition, certain biofungicides can be used in the off-season to help reduce disease inoculum before and/or after the growing season. Some biofungicides can be applied in the fall, acting on pathogens that could have developed insensitivity to the fungicides used that growing season. Incorporating biofungicides into a fungicide plan may help preserve the longevity of the higher risk fungicide groups and can offer an alternative to pathogen insensitivity that could already be occurring in the field. Table 6 summarizes the biofungicides registered for pulse crops in Western Canada.

Table 4. Chemical Grouping and Insensitivity Risk of Foliar Fungicides for Pulse Crops

Product Name	Active Ingredient	Fungicide Chemical Group									
		1	3	7	11	29	BM2	M1	M2	M3	M5
Insensitivity (Resistance) Risk		High	Medium	Medium - High	High	Low	Low	Low	Low	Low	Low
Acapela™	picoxystrobin				■						
Allegro® 500 F	fluazinam					■					
Bravo® ZN/ZNC, Echo® 720/90DF	chlorothalonil										■
Cercobin™	thiophanate-methyl	■									
Copper 53 W, Copper Spray, Coppercide WP/XLR, Kocide® 2000, Parasol® WG, Cueva®	copper sulphate, copper oxychloride, copper hydroxide, copper octanoate							■			
Cotegra®	prothioconazole + boscalid		■	■							
Delaro® 325 SC	prothioconazole + trifloxystrobin		■		■						
Dithane™ Rainshield™, Manzate® 200 WP/DF/Pro-Stick™, Penncozeb® 75DF Raincoat/80WP	mancozeb									■	
Double Nickel LC/55™	*Bacillus amyloliquefaciens* strain D747						■				
Dyax™	fluxapyroxad + pyraclostrobin			■	■						
Elatus®	benzovindiflupyr + azoxystrobin			■	■						

Table 4 (continued). Chemical Grouping and Insensitivity Risk of Foliar Fungicides for Pulse Crops

Product Name	Active Ingredient	Fungicide Chemical Group									
		1	3	7	11	29	BM2	M1	M2	M3	M5
Resistance (Insensitivity) Risk		High	Medium	Medium - High	High	Low	Low	Low	Low	Low	Low
Folicur® 250 EW	tebuconazole		■								
Fullback® 125 SC	flutriafol		■								
Headline® EC, MPOWER® Spade	pyraclostrobin				■						
Kenja® 400 SC Fungicide	isofetamid			■							
Kumulus® DF, Cosavet® DF Edge	sulphur								■		
Lance® WDG	boscalid			■							
Lance® AG	boscalid + pyraclostrobin			■	■						
Miravis® Neo	propiconazole + pydiflumetofen + azoxystrobin		■	■	■						
Priaxor®	fluxapyroxad + pyraclostrobin			■	■						
Proline® 480 SC	prothioconazole		■								
Propulse™	prothioconazole + fluopyram		■	■							
Quadris®, Azoshy 250 SC	azoxystrobin				■						
Quash®	metconazole		■								
Quilt®, Blanket AP®, Topnotch™, Sharda Fungtion SC	azoxystrobin + propiconazole		■		■						
Serenade® OPTI	*Bacillus subtillis* strain QST 713						■				
Tilt® 250 EC, Bumper® 432 EC, Pivot® 418 EC, Propel®, Nufarm Propiconazole, Propi Super 25 EC, Fitness®	propiconazole		■								
Trivapro®	propiconazole + benzovindiflupyr + azoxystrobin		■	■	■						

Source: Sabine Banniza and Sherrilyn Phelps

Table 5. Recommendations for Commonly Used Fungicide Groups

Fungicide Group	Protective Role in Plant	Pulse Industry Recommendations for Fungicide Group Use
Group 11 QoI (strobilurins) **High risk**	Preventative - Group 11s are very effective at preventing spore germination and should therefore be used at the early stages of disease development	• Preferably use only one application of Group 11-containing product per season, or a maximum of two applications if repeat spraying is necessary. This includes any Group 11s used during herbicide timing • Mixtures are preferred. Tank-mix partner should also exhibit effective control of target pathogen if used alone and should have a different mode of action • Do not use solo applications of Group 11s • Apply at effective rates (do not cut rates)
Group 7 SDHI **Medium to High risk**	Preventative and limited curative - like Group 11s, Group 7s, prevent spore germination and should be used at early stages of disease development	• Applications per season should be limited, whether applied solo or as a mixture • Tank-mix partner should also exhibit effective control of target pathogen if used alone and should have a different mode of action • Apply at effective rates (do not cut rates)
Group 3 DMI (triazoles) **Medium risk**	Preventative and curative	• Repeated solo applications should not be used on the same crop in one season against high risk pathogens • Reduced rates can accelerate the shift to less sensitive pathogen • populations. Half-rates endanger the entire Group 3 class. Use recommended rates • When used in mixtures, recommended effective rates of each active ingredient must be maintained

Source: FRAC

Table 6. Biofungicides Registered for Pulse Crops

Product Name	Active Ingredient	Crops Registered	Diseases Controlled	Comments
Contans®	*Coniothyrium minitans*	Pre-plant application - in soils where lentil or dry bean will be planted Post-harvest application - any crop can be planted the following spring	Sclerotinia white mould	Apply and incorporate in soil prior to planting, at least 3 months before typical onset of Sclerotinia Post-harvest applications on fields with a history of white mould Annual maintenance applications are recommended
Double Nickel LC/Double Nickel 55™	*Bacillus amyloliquefaciens* strain D747	Soybean	Sclerotinia white mould	Apply from early flowering until pod set
Serenade® OPTI	*Bacillus subtilis* strain QST713	Pea, lentil, chickpea, soybean, dry bean	Sclerotinia white mould and Botrytis grey mould in all crops. Septoria brown spot and Cercospora frogeye leaf spot in soybean	Application can begin soon after emergence and when conditions are conducive for disease development Preventative biofungicide for the suppression of plant diseases
Serenade® SOIL	*Bacillus subtilis* strain QST713	Pea, lentil, chickpea, dry bean	Root rot caused by Fusarium, Pythium, and Rhizoctonia species	For ground application at planting (broadcast, band, in-furrow, irrigation) Preventative biofungicide for the suppression of plant diseases

Source: Saskatchewan Guide to Crop Protection

Key Points for Fungicide Insensitivity

- Fungicide insensitivity is already occurring in Saskatchewan pulse crops. Insensitive populations of Ascochyta blight in chickpeas, Anthracnose in lentils, and Mycosphaerella in peas have been documented, and it is possible that other issues exist which have not yet been reported.
- Many of the pathogens that are routinely sprayed for each year in pulse crops are at a medium-to-high risk of becoming insensitive based on their biological characteristics.
- The three most common fungicide mode of actions used in pulse crops belong to Groups 3, 7, and 11, and are considered medium-to-high risk for insensitivity development. Fungicide insensitivity already occurs in Group 11 in multiple pathogen populations. Although Group 7 insensitivity has not yet been reported in Western Canada, it is at a higher risk of insensitivity because single gene mutations have led to insensitivity in pathogens in other parts of the world.
- Using medium-to-high risk fungicide groups on medium-to-high risk pathogens creates a higher overall risk for insensitivity to develop. Employ all available management practices such as Integrated Pest Management (IPM) to mediate agronomic risk factors in order to reduce the insensitivity risk of a particular fungicide-pathogen combination.
- IPM involves controlling the controllables. Incorporate longer crop rotations, select fields carefully, use disease resistant cultivars, pay attention to seed quality, and fertilize adequately.
- Make smart fungicide applications. Scout diligently, and carefully evaluate the need for a fungicide on a field by field basis. Use multiple modes of action when possible and rotate modes of action when making multiple fungicide applications. Preferably only use Group 11 products one time per season (this includes herbicide timing), or no more than two times per season if repeated applications are needed, and do not apply Group 11s alone. Use recommended rates in order to apply an effective dose and follow water volume recommendations. Choose correct nozzles and droplet sizes for the best application possible.
- Evaluate fungicide performance. If control is unsatisfactory, contact the appropriate agricultural representative.
- Consider incorporating biofungicides, which offer an alternative mode of action, into the overall disease management plan.

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