Succinate Dehydrogenase Inhibitor (SDHI) Working Group

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Protocol of the discussions and use recommendations of the SDHI Working Group of the Fungicide Resistance Action Committee (FRAC)

Participants

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1. Monitoring Results 2015 (FRAC members)

1.1 Cereal diseases

Wheat – Septoria leaf blotch (*Mycosphaerella graminicola*)
(Bayer CropScience, Syngenta, BASF, Du Pont, Isagro/ FMC)

Disease pressure was moderate in most of the European countries in 2015. Field performance of SDHI fungicides against Septoria was good.

Extensive monitoring programs were carried out since 2003. Most isolates tested in routine monitoring programs were sensitive, within the baseline. Since 2012, few isolates with reduced sensitivity were detected in DE, FR, IR and UK (SDH subunit C: T79N, W80S, N86S, SDH subunit B: N225T, T268I). The resistance factors were low and field performance was not affected.

In 2015, for the first time single isolates with moderate resistance factors and bearing the mutation H152R (SDH subunit C) were detected at trial sites in IR and UK. The impact of this finding is under further investigation.

Wheat – Brown rust (*Puccinia recondita*)
(BASF, Bayer CropScience, Syngenta)

Extensive monitoring programs were carried out since 2005. All isolates tested were sensitive, within the baseline.

Wheat – Yellow rust (*Puccinia striiformis*)
(BASF, SYN)

In 2015, samples from DE were tested and showed full sensitivity, within the baseline.

Wheat – Snow mold (*Microdochium* spp.)
(Syngenta)

Monitoring programs carried out in 2014 showed full sensitivity of isolates from different European countries.

Wheat – Powdery mildew (*Blumeria graminis*)
(BASF)

Monitoring programs carried out in 2015 showed full sensitivity of isolates from different European countries.

Barley – Net blotch (*Pyrenophora teres*)
(Bayer CropScience, Syngenta, Du Pont, BASF)

Disease pressure in 2015 was low to moderate in Europe. Field performance of SDHI fungicides against net blotch was good.

Extensive monitoring programs were carried out since 2003. Until 2011, all tested isolates were sensitive, within the baseline. In 2012, the sensitivity of 2 isolates from North-Germany was outside of the baseline range. A target site mutation was identified in the SDH-B subunit at position 277 (B-H277Y). In 2013 and 2014, more isolates were detected with reduced sensitivity, carrying different mutations (link to mutations table) in FR, IT, DE and UK. The predominant mutation was C-G79R. The resistance factors were low for B-H277Y, D-D124E,

D-D145G and moderate for C-G79R, C-H134R, C-S135R, C-N75S, C-R64K, D-H134R, C-K49E.

In 2015, the situation was similar to 2014. The frequency of mutations was low in UK, IR, PL, Southern FR, Southern DE and DK. Moderate frequencies were observed in Northern FR and Northern DE. No mutations were detected in HU, IT, HR, LT, LV, SK, ES, BG, RO, UA, CZ, FI, SE and RU. The mutation D-G138V was detected for the first time and found to be associated to very low resistance factors.

However, field performance reductions were not reported. These findings emphasize the importance of adhering to FRAC guidelines.

Barley – Scald (*Rhynchosporium secalis*)
(Bayer CropScience, Syngenta, BASF, DuPont)

Extensive monitoring programs were carried out since 2003. All isolates tested were sensitive, within the baseline.

Barley - Ramularia leaf spot (*Ramularia collo-cygni*)
(BASF, Syngenta)

In 2014, single isolates with slightly decreased sensitivity were detected from FR and DE. Retesting of 2014 isolates showed full sensitivity. Isolates sampled in 2014 from CZ were sensitive, within the baseline.

In 2015, extensive monitoring in Germany showed particularly in trial-sites for the first time occurrence of strains with strongly decreased dose-response in bioassays, carrying the mutation C-H142R or C-H149R. Another mutation, C-N83S, which was found to be associated with low resistance factors, was monitored in DE, IE and SI in single isolates. No mutations were detected in AT and HR. The relevance of these findings for the agricultural practice is currently under further investigation.

Barley – Rust (*Puccinia hordei*)
(Bayer CropScience)

Monitoring programs were carried out since 2006. All isolates tested were sensitive, within the baseline.

No monitoring was carried out in 2015.

1.2. Grape diseases

Grape grey mold (*Botrytis cinerea*)
(Bayer CropScience, BASF)

Extensive monitoring programs were carried out since 2003.

Few isolates with resistance to SDHIs were detected in FR and DE in 2012 with an increasing frequency in DE in 2013. No new mutations have been identified and the percentage of less sensitive isolates remained stable since 2013.

In 2015, resistant isolates were detected in DE, FR, IT, PT and CL at low frequency.

Grape powdery mildew (*Erysiphe necator*)
(BASF, Bayer CropScience)

Extensive monitoring programs were carried out since 2003. All isolates tested were sensitive, within the baseline (AT, FR, DE, HU, PT, ES, CH). Single strains carrying a mutation (SDH subunit C-G169D) with moderate resistance factors were detected in single fields in IT (retrospective investigations from 2014 samples, no detection in 2015), SL and GR (both from 2015 samples), resp.

Field performance reductions were not reported. These findings emphasize the importance of adhering to FRAC guidelines.

1.3 Pomefruit and stonefruit diseases

Apple scab (*Venturia inaequalis*)
(Syngenta, DuPont, BASF, BCS)

Extensive monitoring programs were carried out since 2005.

Preliminary data from 2015 show full sensitivity in BG, BE, CH, DE, ES, FR, GR, HU, HR, IR, IT, LT, LV, NL, RO, PT, PL, UK and SR.

Product performance was not affected.

Single isolates from trial sites with slightly reduced sensitivity were found in BG, IT and ES.

For resistant isolates originating from trial sites in IT, the mutation B-Y137C was detected.

Apple powdery mildew (*Podosphaera leucotricha*)
(BASF, Syngenta)

All isolates tested in 2014 were sensitive, within the baseline (FR, ES, A, HU, DE, RO, BG).

All isolates tested in 2015 coming from BE, CH, DE, ES, FR, IT, LV, NL, PT and PL were sensitive, within the baseline.

Stonefruit - Brown rot (*Monilinia* spp.)
(BASF)

Sensitivity of samples from ES, FR, IT, DE and PL was analysed and showed full sensitivity in 2014.

In 2015, samples originating from BE, FR and HU were all sensitive, within the baseline.

1.4. Cucurbit diseases

Cucurbit powdery mildew (*Sphaerotheca fuliginea*, syn. *Podosphaera xanthii, Erysiphe cichoracearum, Golovinomyces cichoracearum*)
(Syngenta, BASF, BCS)

Extensive monitoring programs were carried out since 2005.

Monitoring studies in 2014 were carried out in FR, IT, GR, DE, CH, CN and ES. Full sensitivity was observed except for ES, IT and CN, where single resistant isolates were detected.

In 2015, full sensitivity was observed in BE, BG, ES and NL. Resistant isolates were detected in DE, CZ, IT, PL, GR and FR.

1.5 Other crops

Strawberries – Grey mold (*Botrytis cinerea*)
(Bayer CropScience, DuPont, BASF)

Extensive monitoring programs were carried out since 2003.

In 2015, monitoring was carried out in DE, BE, HU, IT, FR, DE, DK, PL, SE, NL (raspberry) and UK. Some resistant isolates were detected in DE, PL, BE and UK.

When used according to manufacturers' recommendations, field performance of SDHI containing products is good.

Grey mold (*Botrytis cinerea*) on other vegetable crops (tomato, lettuce, zucchini, cucumber)
(Du Pont)

Monitoring data were reported from 2013 (FR, IT, PT, GR).

Resistant isolates were found in IT, GR and PT. No cases of reduced field performance were reported.

No monitoring was carried out in 2015.

Vegetables – *Alternaria* spp. (cabbage, broccoli, carrot)
(Syngenta)

Resistance was detected in 2014 at low frequency in *A. brassicae* and *A. brassicicola* isolated from cabbage in DE and *A. alternata* sampled from broccoli in ES.

In 2015, a single isolate with resistance was detected in *A.alternata* from broccoli in ES.

Peas, beans – White mold (*Sclerotinia sclerotiorum*)
(Bayer CropScience)

Samples from NL and BE were all sensitive, within the baseline.

Oilseed rape – White mold (*Sclerotinia sclerotiorum*)
(BASF, Bayer CropScience, Syngenta)

Extensive monitoring programs were carried out since 2006.

In 2014 and 2015, single resistant isolates were detected in FR. No resistant isolates were detected in 2014 in CZ, DE, UK and PL.

In 2015, no resistance was detected in NL, BE, FR, PL, CZ, UA and DE. Monitoring is ongoing.

Field performance was not affected.

Oilseed rape - Blackleg (*Leptosphaeria maculans, L.biglobosa)*
(BASF, DuPont, Bayer CropScience)

All isolates tested were sensitive, within the baseline (FR, DE, PL, UK and HU).

2015 Monitoring is still ongoing.

Potato – Early blight, Alternaria leaf spot (*Alternaria solani, A.alternata*)
(Syngenta, BASF)

Monitoring studies are carried out since 2009.

In 2015, no SDHI resistance was detected in *A.solani* in AT, FR, GR, HU, IT, SK and ES. Isolates with reduced sensitivity were detected in Europe in BE, DE, NL and DK.

In *A.alternata*, isolates with reduced sensitivity were detected in AT, BE, DE, HU, IT, SK and NL. Full sensitivity was found in FI, FR, GR, LV and ES.

The practical relevance of these mutations and the role of *A.alternata* in the disease complex are still under discussion by the research community.

Tomato – Early blight, Alternaria leaf spot (*Alternaria solani, A.alternata*)
(Syngenta)

In 2015, no SDHI resistance was detected in *A.solani* in PL, BG and ES. In *A. alternata*, a single isolate from IT showed reduced sensitivity. No SDHI resistance was reported from ES and BG.

Soybean – Asian soybean rust (*Phakopsora pachyrhizi*)
(Syngenta, Bayer CropScience, BASF, DuPont)

Monitoring programs were carried out since 2010 in BR.

In 2015, all samples remain sensitive, within the baseline.

Soybean – Target spot (*Corynespora cassiicola*)
(BASF)

All samples analysed from BR showed full sensitivity.

Potato – Silver scurf (*Helminthosporium solani*)
(Syngenta)

In 2014, single resistant isolates were detected in BE and NL. No resistant isolates were detected in UK, FR and DE.

Potato – Stem canker/ Black scurf *(Rhizoctonia solani*)
(Syngenta)

All samples analysed from UK, NL, FR and DE in 2014 showed full sensitivity.

Banana – Black sigatoka (*Mycosphaerella fijiiensis*)
(Syngenta, Bayer CropScience, BASF)

In vitro monitoring studies have revealed first isolates with reduced sensitivity in EC and CR. No information on target site mutations is available at this point in time. Field performance was not affected.

More details are published by the Banana FRAC working group.

2. Detection of Resistance (other monitoring data sources, non-FRAC)

A complete overview on resistant plant pathogenic organisms, including published cases of SDHI resistance, can be viewed in the publications area of the FRAC website. See the List of Resistant Plant Pathogenic Organisms - February 2013. There is also a more recent List of Species Resistant to SDHIs April 2015.

3. Use Recommendations

3.1 General SDHI Guidelines (all crops)

- Strategies and General Guidelines for the 2015 season

    - Strategies for the management of SDHI fungicide resistance, in all crops, are based on the statements listed below. These statements serve as a fundamental guide for the development of local resistance management programs.
    - Resistance management strategies have been designed in order to be proactive and to prevent or delay the development of resistance to SDHI fungicides.
    - A fundamental principle that must be adhered to when applying resistance management strategies for SDHI fungicides is that:

      The SDHI fungicides (benodanil, benzovindiflupyr, bixafen, boscalid, carboxin, fenfuram, fluopyram, flutolanil, fluxapyroxad, furametpyr, isopyrazam, mepronil, oxycarboxin, penflufen, penthiopyrad, sedaxane, thifluzamide) are in the same cross-resistance group.

    - Fungicide programs must deliver effective disease management. Apply SDHI fungicide based products at effective rates and intervals according to manufacturers' recommendations.

    - Effective disease management is a critical component to delay the build-up of resistant pathogen populations.
    - The number of applications of SDHI fungicide based products within a total disease management program must be limited.
    - When mixtures are used for SDHI fungicide resistance management, applied as tank mix or as a co-formulated mixture, the mixture partner:
        - should provide satisfactory disease control when used alone on the target disease
        - must have a different mode of action
    - Mixtures of two or more SDHI fungicides can be applied to provide good biological efficacy; however, they do not provide an anti-resistance strategy and must be treated as a solo SDHI for resistance management. Each application of such a mixture when used in a spray program counts as one SDHI application.
    - SDHI fungicides should be used preventively or at the early stages of disease development.
    - Please refer to the "FRAC Recommendations for Mixtures – January 2010" (Located on the publications page of the FRAC website) for more information on fungicide mixtures for resistance management.

3.2 SDHI Guidelines – Grapes

- Apply SDHI fungicides according to manufacturers' recommendations.
- When mixtures are used for SDHI fungicide resistance management, applied as tank mix or as a co-formulated mixture, the mixture partner:
    - should provide satisfactory disease control when used alone on the target disease
    - must have a different mode of action
- Apply a max. of 3 SDHI-containing fungicides per year over all diseases, solo or in mixture with effective mixture partners from different cross-resistance groups but not more than 50% of the total number of applications.

- A maximum of 4 SDHI fungicide applications may be used where 12 or more fungicide applications are made per crop.
- If used solo, apply SDHI fungicides in strict alternation with fungicides from a different cross-resistance group.
- If used in mixture, apply SDHI fungicides in a maximum of 2 consecutive applications.
- Apply SDHI fungicides preventively.
- For SDHI fungicide applications specifically targeted against grey mold, *Botrytis cinerea*, refer to the table below.

Grey mold (*Botrytis cinerea*) spray table:

Total number of *Botrytis cinerea* spray applications per crop	1	2	3	4	5	6	>6
Maximum recommended Solo SDHI fungicide sprays **(apply in strict alternation)**	1	1	1	2	2	2	3
Max. recommended SDHI fungicide sprays in mixture **(apply a max. of 2 consecutive applications)**	1	1	2	2	2	3	3

3.3 SDHI Guidelines – Pomefruit

- Apply SDHI fungicides according to manufacturers' recommendations.
- When mixtures are used for SDHI fungicide resistance management, applied as tank mix or as a co-formulated mixture, the mixture partner:
  - should provide satisfactory disease control when used alone on the target disease
  - must have a different mode of action
- Apply SDHI fungicides using not more than 2 consecutive applications.
- Apply SDHI fungicides preventively.

The following spray table shall be used as a guideline irrespective of the targeted disease in pomefruits.

Total number of spray applications per crop	1	2	3	4	5	6	7	8	9	10	11	12	>12
Maximum recommended Solo SDHI fungicide sprays	1	1	1	1	2	2	2	2	2	3	3	3	3
Max. recommended SDHI fungicide sprays in mixture	1	1	2	2	2	3	3	3	3	3	3	4	4

3.4 SDHI Guidelines – Stone fruits

- Apply SDHI fungicides according to manufacturers' recommendations.
- When mixtures are used for SDHI fungicide resistance management, applied as tank mix or as a co-formulated mixture, the mixture partner:
  - should provide satisfactory disease control when used alone on the target disease
  - must have a different mode of action
- Apply a max. of 3 SDHI-containing fungicides per year over all diseases, solo or in mixture with effective mixture partners.
- If used solo, apply SDHI fungicides in strict alternation with fungicides from a different cross-resistance group.
- If used in mixture, apply SDHI fungicides in a maximum of 2 consecutive applications.
- Apply SDHI fungicides preventively.

3.5 SDHI Guidelines – Other multi-spray crops (e.g. vegetables, including small berries and strawberries)

- When mixtures are used for SDHI fungicide resistance management, applied as tank mix or as a co-formulated mixture, the mixture partner:
  - should provide satisfactory disease control when used alone on the target disease
  - must have a different mode of action

The following spray table shall be used as a guideline irrespective of the targeted disease in the crops specified above.

Total number of spray applications per crop	1	2	3	4	5	6	7	8	9	10	11	12	>12
Maximum recommended Solo SDHI fungicide sprays **(apply in strict alternation)**	1	1	1	1	2	2	2	3	3	3	3	4	*
Max. recommended SDHI fungicide sprays in mixture **(apply a max. of 2 consecutive applications)**	1	1	1	2	2	3	3	3	3	3	4	4	*

* When more than 12 fungicide applications are made, observe the following guidelines:

- When using a SDHI fungicide as a solo product, the number of applications should be no more than 1/3 (33%) of the total number of fungicide applications per season.
- For programs in which tank mixes or pre-mixes of SDHI are utilized, the number of SDHI containing applications should be no more than 1/2 (50%) of the total number of fungicide application per season.
- In programs where SDHIs are made with both solo products and mixtures, the number of SDHI containing applications should be no more than 1/2 (50%) of the total no. of fungicide applied per season.
- If used solo, apply SDHI fungicides in strict alternation with fungicides from a different cross-resistance group.

- If used in mixture, apply SDHI fungicides in a maximum of 2 consecutive applications.

3.6 SDHI Guidelines - Banana

Guidelines for the use of SDHI fungicides in banana are published by the Banana FRAC working group (next meeting scheduled for 2016).

3.7 SDHI Guidelines – Cereals

3.7.1. Foliar applications

- Apply SDHI fungicides always in mixtures
- The mixture partner:
  - should provide satisfactory disease control when used alone on the target disease
  - must have a different mode of action
- Apply a maximum of 2 SDHI fungicide containing sprays per cereal crop.

Apply the SDHI fungicide preventively or as early as possible in the disease cycle. Do not rely only on the curative potential of SDHI fungicides. Strongly reduced rate programs including multiple applications must not be used. Refer to manufacturers' recommendations for rates.

3.7.2. Seed treatment applications

SDHIs are and will be used as seed treatment products.
It is FRAC's objective to protect this fungicide group and integrate all uses into technical recommendations. These minutes contain a recommendation on seed treatments, including those which have efficacy on foliar pathogens.
These recommendations will be reviewed regularly and supported by monitoring. When an SDHI fungicide is used as a seed treatment on cereals, there should be no implications regarding SDHI FRAC guidelines on the use of foliar SDHI fungicides on the same crop as long as the SDHI seed treatment is directed by rate and efficacy against seed and soil borne diseases or 'low risk' foliar pathogens as defined in the "FRAC Pathogen Risk List" (found on the publications page of the FRAC website (www.frac.info) .

SDHIs used as a seed treatment in cereals providing foliar efficacy against pathogens with moderate/ high resistance risk count against the total number of SDHI applications.

3.8 Soybeans

- Apply SDHI fungicides always in mixtures

- The mixture partner:
  - should provide satisfactory disease control when used alone on the target disease
  - must have a different mode of action
- Apply a maximum of 2 SDHI fungicide containing sprays per soybean crop.

Apply the SDHI fungicide preventively or as early as possible in the disease cycle. Do not rely only on the curative potential of SDHI fungicides. Strongly reduced rate programs including multiple applications must not be used. Refer to manufacturers' recommendations for rates.

Good agricultural practices must be considered to reduce disease pressure and resistance risk, e.g. avoiding multiple cropping.

3.9 All other crops

- Refer to the general guideline for the use of SDHI fungicides.

Oilseed rape

Extensive monitoring programs have been carried out. Reduced sensitivity has been detected in *S.sclerotiorum*.

Further monitoring programs will continue and clarify the necessity for a specific crop guideline.

The general guidelines for the use of SDHIs are currently considered to be sufficient because current data shows sporadic detection, no consistent increase and spread of resistant mutations. In addition, the life cycle of the pathogen, its distribution and rotation with non-host crops confirm that *Sclerotinia* in OSR justify the classification as a low risk pathogen.

3.10 Seed treatment for other crops

There are no guidelines for additional crops because currently the relevant pathogens are not considered as high risk pathogens. Monitoring programs will continue to be carried out and serve as basis for regular reviews of the need for specific guidelines.