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PHENOTYPING & ENVIROTYPING SOLUTIONS FOR AGROECOLOGY

PHENET Webinar: biotic interaction in agroecosystems
Plant Health: Validated sensors and methodology applicable for biotic stresses in wheat

Philippe Vermeulen (CRA-W), Valérie Cadot (GEVES), Juan Herrera (AGROSCOPE)

29 November 2024,

Online

Objectives of this webinar

What question does this presentation address?

How to improve the crop resilience to biotic stress ?

How did we address this?

By building phenotyping tools using different optical sensors and developing models for plant disease detection with real time prediction

In particular, by the study of 5 approaches to assess wheat diseases in laboratory and in field

- ➢ *Handheld fluorometer in field (AGROSCOPE)*
- ➢ *RGB images in field (GEVES, AGROSCOPE, CRA-W)*
- ➢ *Multispectral Visible NIR imaging in laboratory and in field (GEVES)*
- ➢ *Hyperspectral NIR imaging in laboratory and in field (CRA-W)*
- ➢ *NIR Spectrometer and sorting system in laboratory (CRA-W)*

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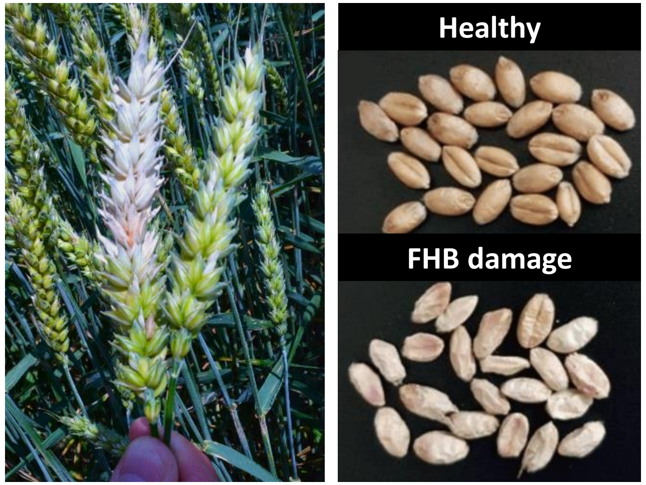
Study case: Plant Health: Fusarium Head Blight (FHB) in wheat
What is it? And why this choice?

Wheat is the major grain cereal crop cultivated in Europe

One of the major fungal diseases affecting wheat is Fusarium Head Blight (FHB)

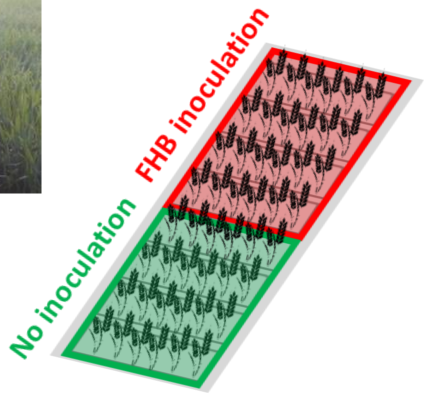
- ❑ Infects the ears at the flowering stage
- ❑ Damages the kernels
  → yield and quality decrease
- ❑ Can produce mycotoxins
  → risk for human and animal health

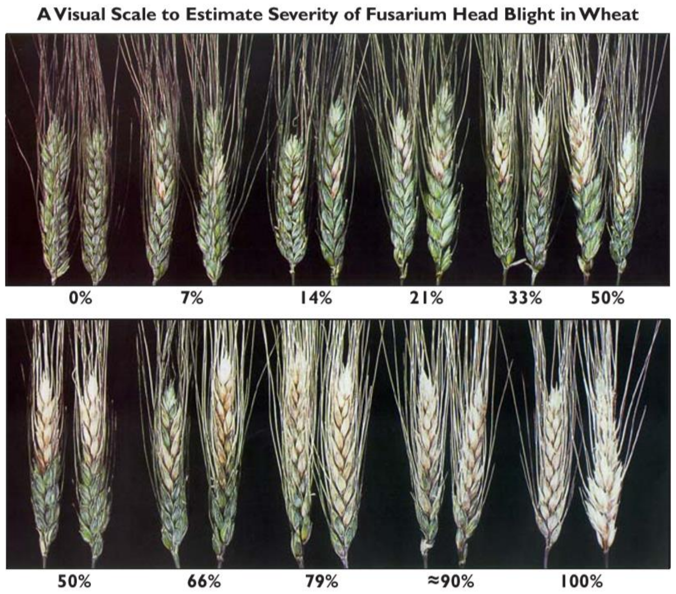


Source: Birr T. et al. (2020)

➔ Fungicide treatment is only preventive and not fully effective …
➔ Disease-tolerant varieties are needed
➔ Symptoms observable at the canopy level

Study case: Plant Health: Fusarium Head Blight (FHB) in wheat
Experimentation and classical method





Source: Stack R.W. & McMullen M. (2011)

Varietal trial

Fusarium Head Blight (FHB) inoculation

Visual observation according to a reference scale
- at ear level (number of spikelets infected by ear)
- at plot level (number of ears infected by plot)

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1st approach: Fluorescence measurement: acquisition

- +/- 10000 fluorescence measurements in the field by Agroscope

Based on the chlorophyl fluorescence
Green and at maturity ears
Contact sensing ☹
Low cost ☺
Time consuming ☹
Point to point measurement ☹
Not early detection, need high infection ☹

FluoroPen

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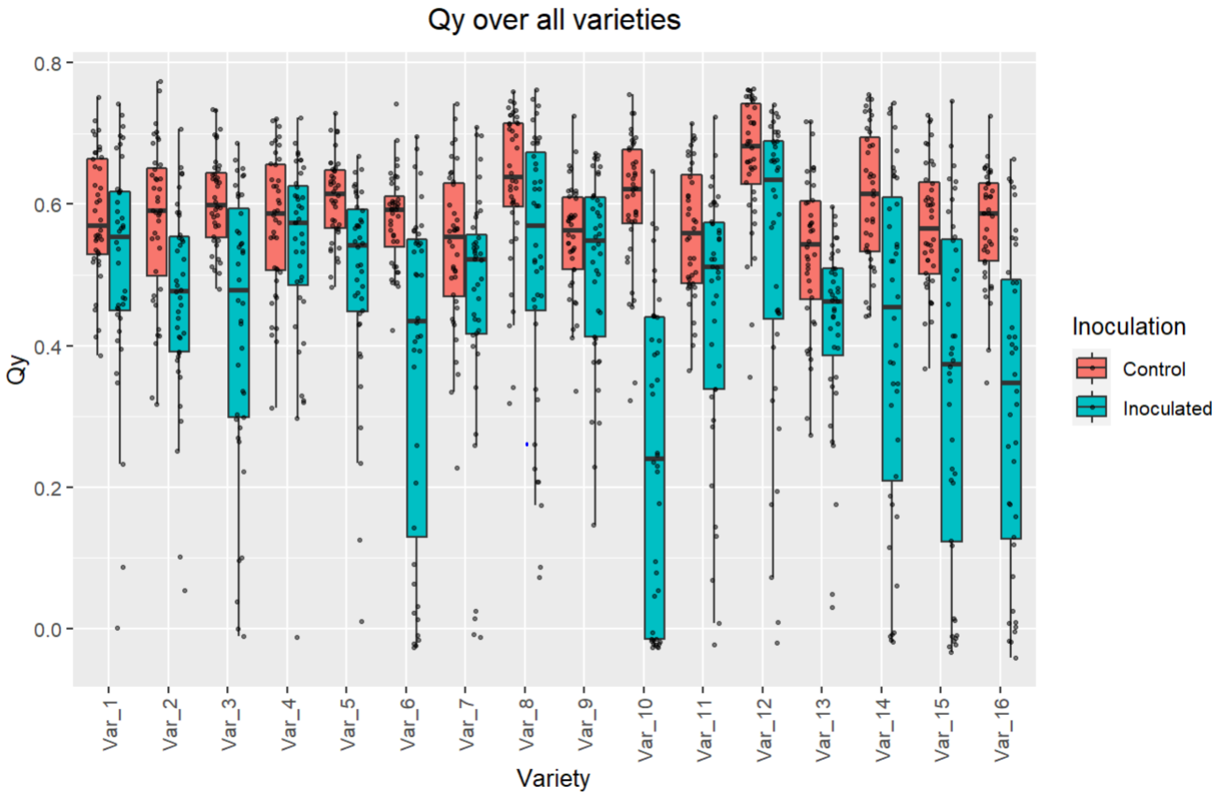
1st approach: Fluorescence measurement: results

➢ *Quantum yield (Qy) results for measurements on ears in the field*
showing a very large variability in relation to strong infections



S. Treier (2025). Digital optical lean phenotyping methods in the context of wheat variety testing. Thesis in Agroscope

1st approach: Fluorescence measurement: next steps

- Assess its potential application under natural infections in a variety testing network to improve the comparability among campaigns, sites and operators

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Agroscope

2nd approach: RGB imaging: acquisition

- +/- 3000 RGB images acquired
  by Agroscope, CRA-W, GEVES

Based on the color (green/white)
Green ears
Proximal sensing ☺
Low cost ☺
Random and quick acquisition ☺
Image on full ears acquired with an angle of 45°/90° ☺
Early detection when one spikelet is infected ☺

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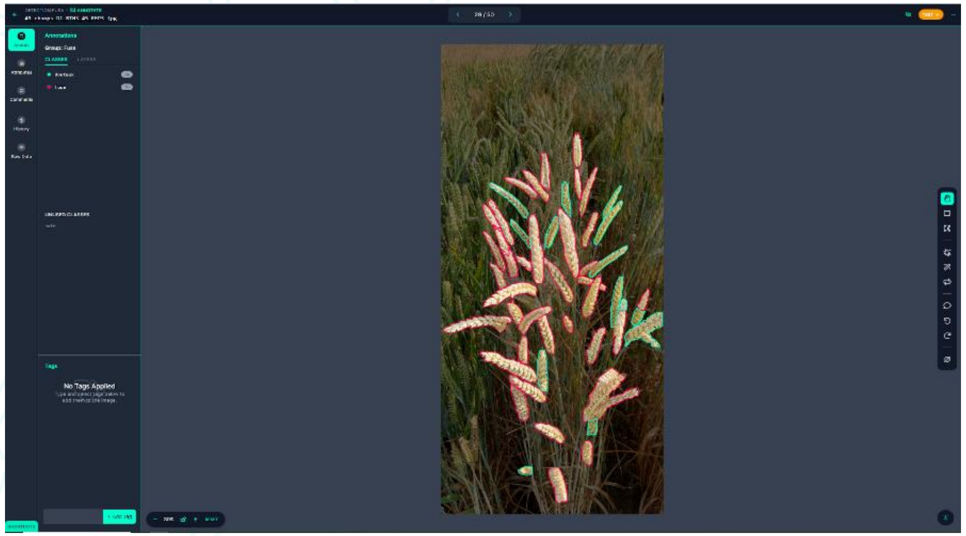
2nd approach: RGB imaging: Annotation models

- Plateforme used: Roboflow
- Exemple of annotations with 2 classes: healthy / Fusarium
- 3 methods: manual, semi-automatic model (« SAM ») and development of an automatic model
- Nb images annotated by GEVES: ≈ 800 images=239 from CRA-W + 561 from GEVES



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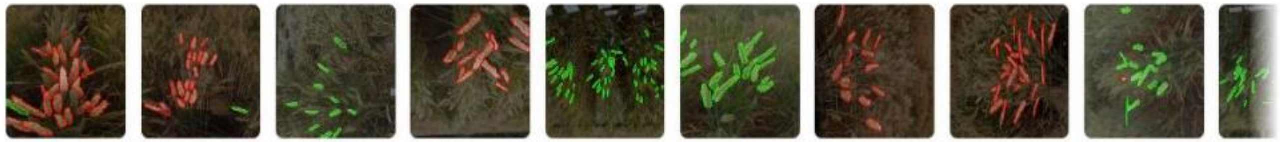
2nd approach: RGB imaging: method of prediction

- 1 model selected upon 17 models of Deep learning

1113 Total Images — View All Images →



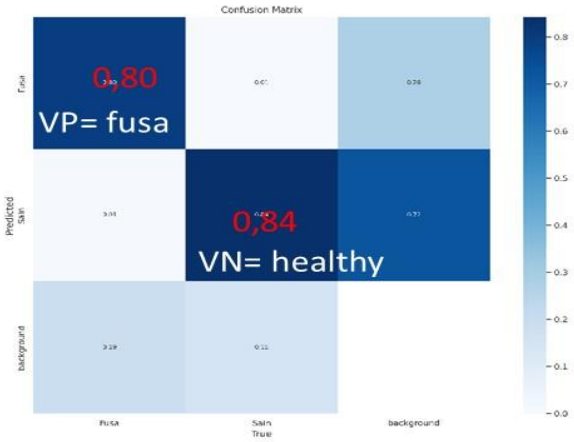
Dataset Split

TRAIN SET 84%	VALID SET 12%	TEST SET 5%
930 Images	130 Images	53 Images

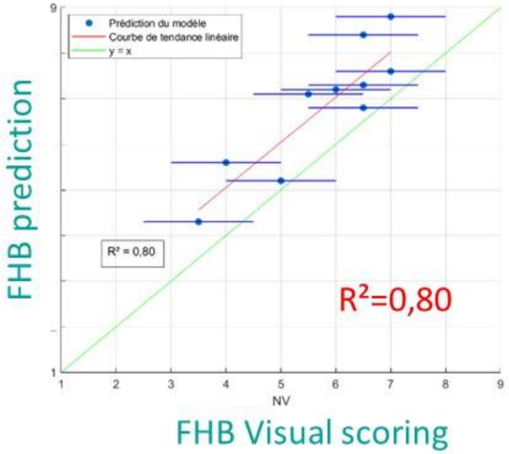
Segmentation

Class	Precision	Rappel	mAP50	mAP50-95):
all	0.794	0.728	0.806	0.474
Fusa	0.823	0.72	0.808	0.481
Sain	0.766	0.736	0.804	0.468

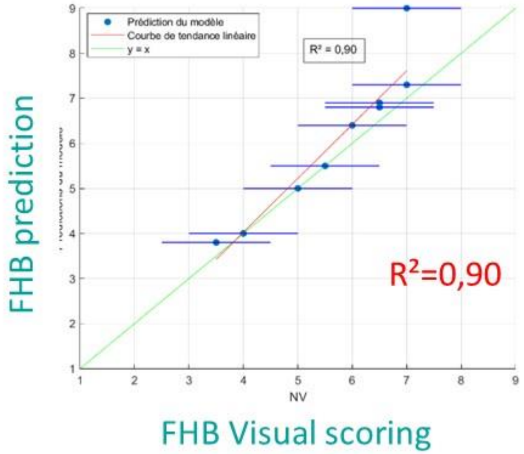
Confusion matrix



Without detection of spikes



With detection of spikes
(model coming from Global Wheat Challenge 2021)



High correlation between FHB predictions & visual scorings in field

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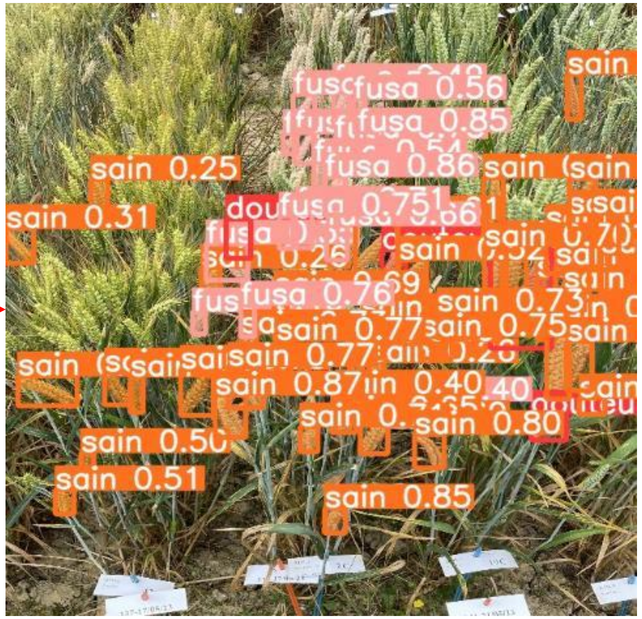
2nd approach: RGB imaging: method of prediction

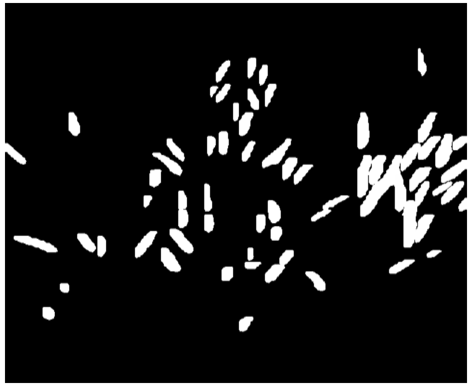
RGB image in perspective

prediction

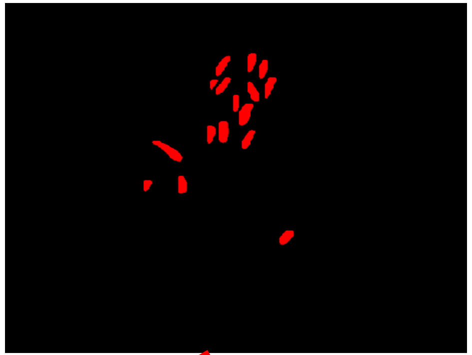
FHB prediction by Deep learning (Yolo V8)



All Mask



Fusa mask

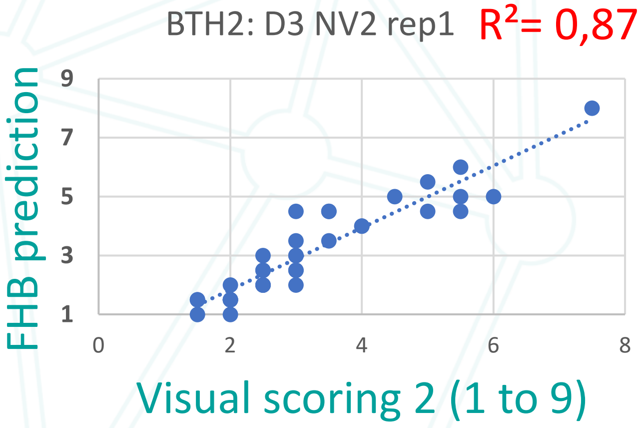


% FHB area=Fusa mask/all mask ; Ex:9.03 %

2nd approach: RGB imaging: comparisons of DL performance between sensors

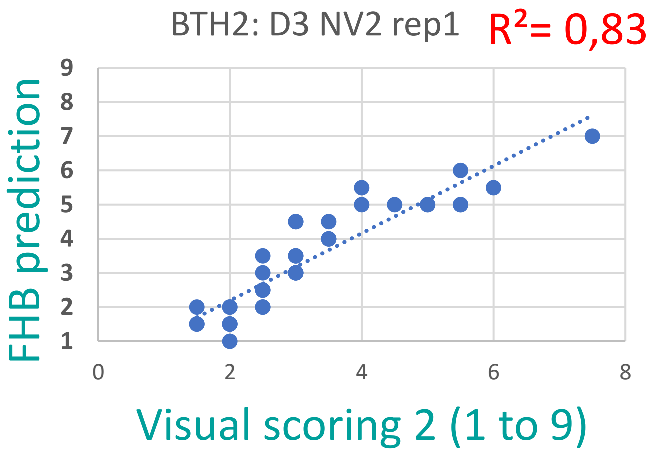
Camera Sony

Groupe	R²	REP1	REP2	REP3	MOY
BTH1	D1NV1	0,62	0,60	0,46	0,56
	D2NV2	0,27	0,69	0,76	0,58
BTH2	D3NV2	0,87	0,77	0,74	0,79
BDH	D3NV2	0,58	0,60	0,66	0,61



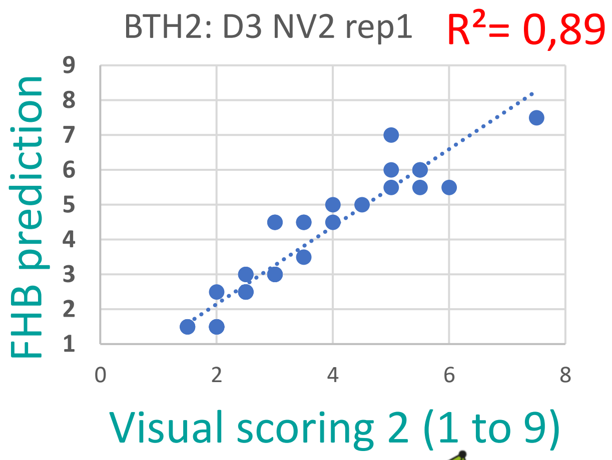
Smartphone Samsung A 54

Groupe	R²	REP1	REP2	REP3	MOY
BTH1	D1NV1	0,61	0,37	0,37	0,45
	D2NV2	0,46	0,66	0,41	0,51
BTH2	D3NV2	0,83	0,73	0,74	0,77
BDH	D3NV2	0,81	0,55	0,68	0,68



Smartphone Google Pixel 8

Groupe	Groupe	R²	REP1	REP2	REP3	MOY
BTH1	BTH1	D1NV1	0,85	0,55	0,35	0,58
		D2NV2	0,38	0,69	0,44	0,50
BTH2	BTH2	D3NV2	0,89	0,88	0,81	0,86
BDH	BDH	D3NV2	0,59	0,82	0,91	0,77



The same Deep Learning model adapted to different low cost RGB sensors

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2nd approach: RGB imaging: user interface
to collect the % FHB area/image

Analysis for 1 several image

Détection d'objets YOLOv8 et Visualisation des Masques

Analyse d'une seule image   Analyse de plusieurs images

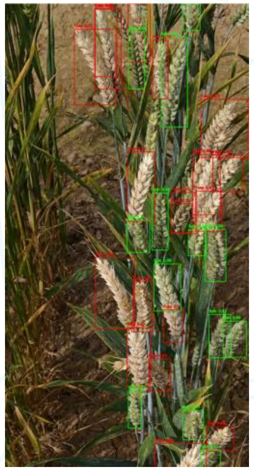
Analyse d'une seule image

Choisissez une image...

Drag and drop file here
Limit 200MB per file • JPG, JPEG, PNG
Browse files

crop_49-Sony-D2-BTH1-2-REP2.JPG 0.7MB   X

% FHB area
ex : 64,8%



Analysis for several images

Analyse d'une seule image   Analyse de plusieurs images

Analyse de plusieurs images

Choisissez des images...

Drag and drop files here
Limit 200MB per file • JPG, JPEG, PNG
Browse files

crop_49-Sony-D2-BTH1-41-REP3.JPG 0.8MB ✕
crop_49-Sony-D2-BTH1-40-REP3.JPG 1.0MB ✕
crop_49-Sony-D2-BTH1-39-REP3.JPG 0.7MB ✕

Showing page 1 of 14

	Image	Pourcentage de Fusa
0	crop_49-Sony-D2-BTH1-1-REP3.JPG	64.8226
1	crop_49-Sony-D2-BTH1-2-REP3.JPG	86.5061
2	crop_49-Sony-D2-BTH1-3-REP3.JPG	80.0881
3	crop_49-Sony-D2-BTH1-4-REP3.JPG	16.9305
4	crop_49-Sony-D2-BTH1-5-REP3.JPG	14.4327
5	crop_49-Sony-D2-BTH1-6-REP3.JPG	88.2476
6	crop_49-Sony-D2-BTH1-7-REP3.JPG	86.6072
7	crop_49-Sony-D2-BTH1-8-REP3.JPG	78.1664
8	crop_49-Sony-D2-BTH1-9-REP3.JPG	77.9965
9	crop_49-Sony-D2-BTH1-10-REP3.JPG	98.9945

Télécharger les résultats en Excel

% FHB area loaded on Excel

Image	Pourcentage de Fusa
crop_49-Sony-D2-BTH1-1-REP3.JPG	64,82
crop_49-Sony-D2-BTH1-2-REP3.JPG	86,51
crop_49-Sony-D2-BTH1-3-REP3.JPG	80,09
crop_49-Sony-D2-BTH1-4-REP3.JPG	16,93
crop_49-Sony-D2-BTH1-5-REP3.JPG	14,43
crop_49-Sony-D2-BTH1-6-REP3.JPG	88,25
crop_49-Sony-D2-BTH1-7-REP3.JPG	86,61
crop_49-Sony-D2-BTH1-8-REP3.JPG	78,17
crop_49-Sony-D2-BTH1-9-REP3.JPG	78,00
crop_49-Sony-D2-BTH1-10-REP3.JPG	98,99

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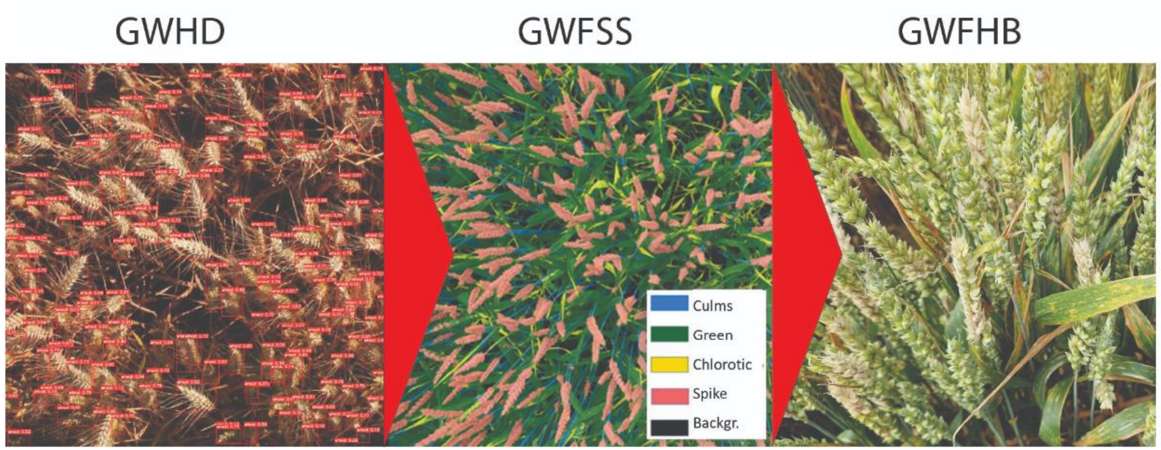
2nd approach: RGB imaging: results

- Contribution to the GWFHB: Global Wheat Fusarium Head Blight



Head Detection | Full Semantic Segmentation | Fusarium Head Blight

Global Wheat Datasets

https://www.global-wheat.com/gwfss.html

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2nd approach: RGB imaging: next steps

- Guidelines document for images
  (semi-automatic) annotating to assess biotic stress
- Use of the annotated images
  for model development by GEVES
- Use of this model to extend the portfolio of agronomics traits
  on existing phenotyping device such as:
  - the Mobile-based Rapid Phenotyping (MoRPH) application developed by WUR
  - the Literal stick developed by Hiphen

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3rd approach: VNIR multispectral imaging: acquisition

- 383 images (1658 spikes) acquired in laboratory by GEVES
- 560 images acquired on 7 sites in field by GEVES

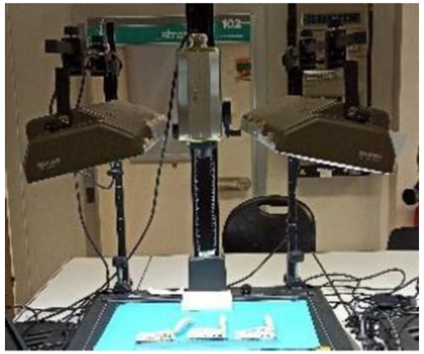
SILIOS TECHNOLOGIES

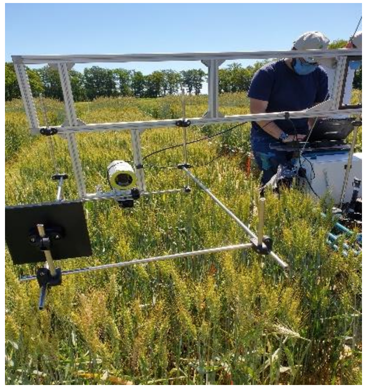
Multispectral imaging - plane scan
CMS 4: 4 wavelenghts for FHB detection (3 RGB & 1 NIR bands)

Image of wavelength 1 | Image of wavelength 2 | Image of wavelength 3 | Image of wavelength 4

Based mainly on the Chlorophyl content
Green and yellow ears (until 550°day post inoculation)
Proximal sensing ☺
Rather specific of FHB (≠Microdochium or Yellow rust) ☺
High cost ☹
Time consuming ☹
Image on full ears acquired in frontal view (1 row of ears) ☺
Possible early detection when one spikelet is infected ☺

In laboratory





In field

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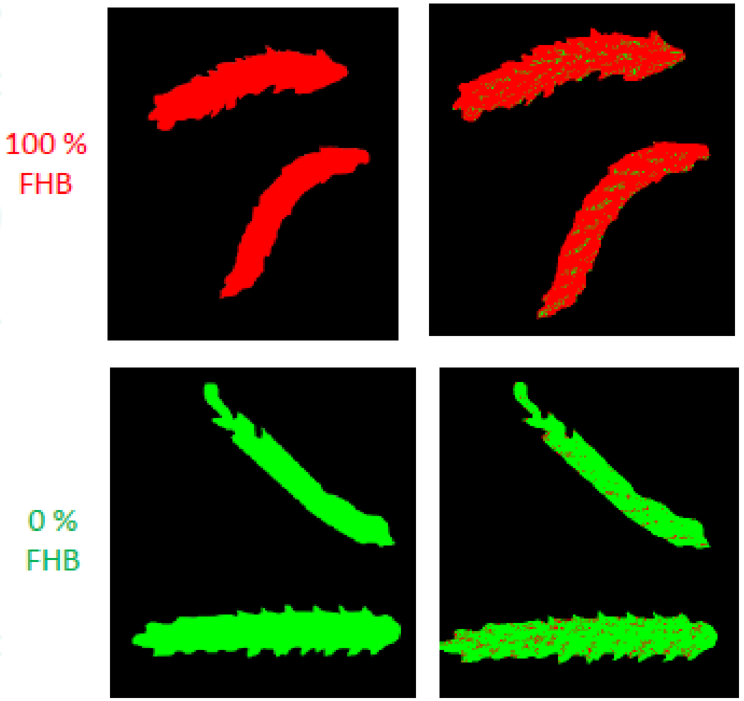
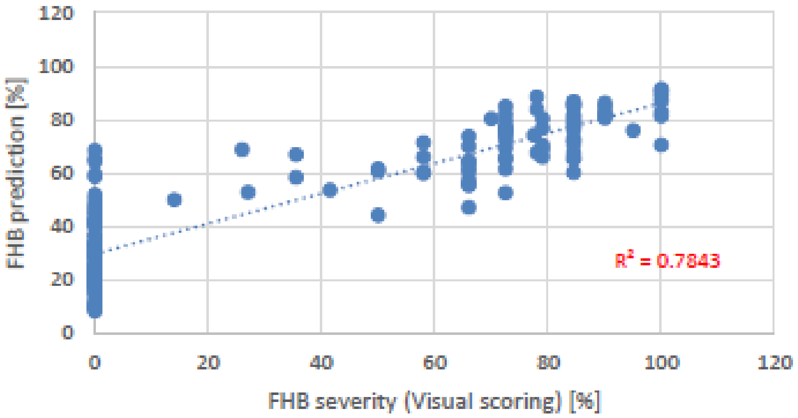
3rd approach: VNIR multispectral imaging: results

In laboratory

Annotated and predicted images





H. Garbouge (2022). Deep learning applied to multi-componet imagery for variety testing problems. Thesis in U.Angers

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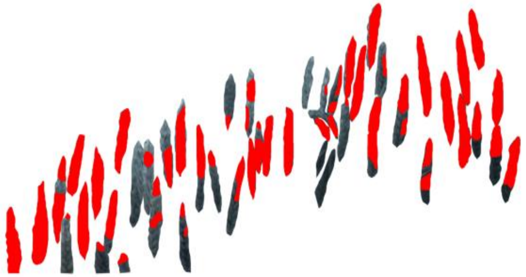
3rd approach: VNIR multispectral imaging: results

In field in frontal view

Annotations

Annotations of the 1st row of ears

Fusarium annotations



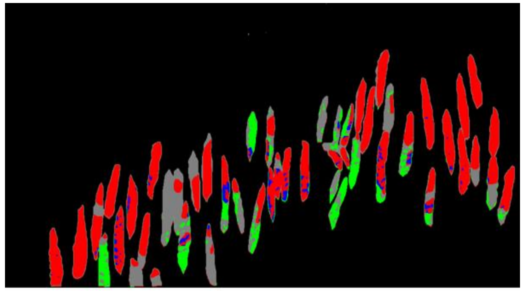
Fusarium pixels

Creation of 2 algorithms :

Ear segmentation (U-NET)

H. Garbouge (2022). Thesis in U.Angers

Fusarium quantification prediction (Machine learning)



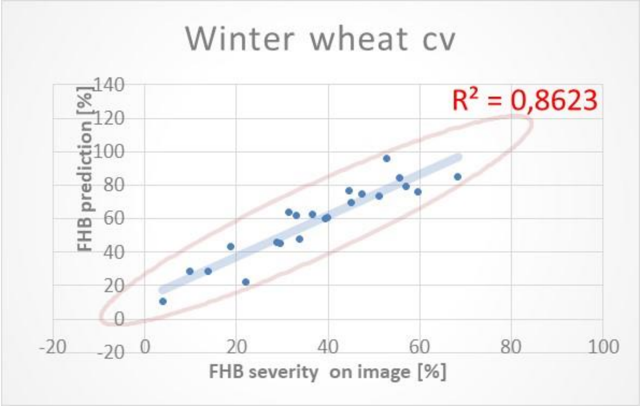
VP='Fusarium' pixels predicted as 'Fusarium'

FP='Healthy' pixels predicted as 'Fusarium

FN=Healthy' predicted 'Fusarium' pixels

FN='Healthy' pixels predicted as 'Healthy'

FHB prediction results



- Usable for assesment of FHB cv resistance
- High correlation with annotations: in case of good acquisition conditions & high FHB pressure

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3rd approach: VNIR multispectral imaging: next steps

- ➢Develop a semi-automatic annotation method to assess biotic stress

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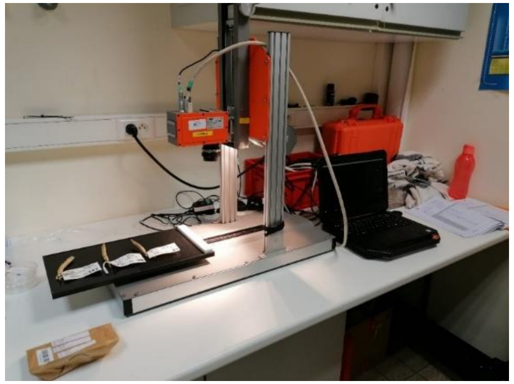
4th approach: VNIR hyperspectral imaging: acquisition

- 614 images acquired in laboratory by CRA-W
- 100 images acquired on 1 site in field by CRA-W

Based on the chlorophyl and water content
Green and at maturity ears
Proximal sensing ☺
High cost ☹
Time consuming ☹
Image on ears acquired in vertical view (line scan camera) ☺
Possible detection on a wider area (100 ears or 1m2/plot) ☺

Hyperspectral imaging - line scan (Specim)
(400-1000, 1000-1700, 1000-2500 nm)

In laboratory



In field

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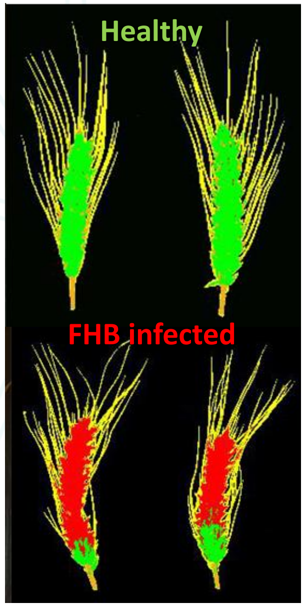
4th approach: VNIR hyperspectral imaging: results

In laboratory

NIR-HSI predicted images

MODEL VALIDATION (PLSDA)



Predicted results by ear

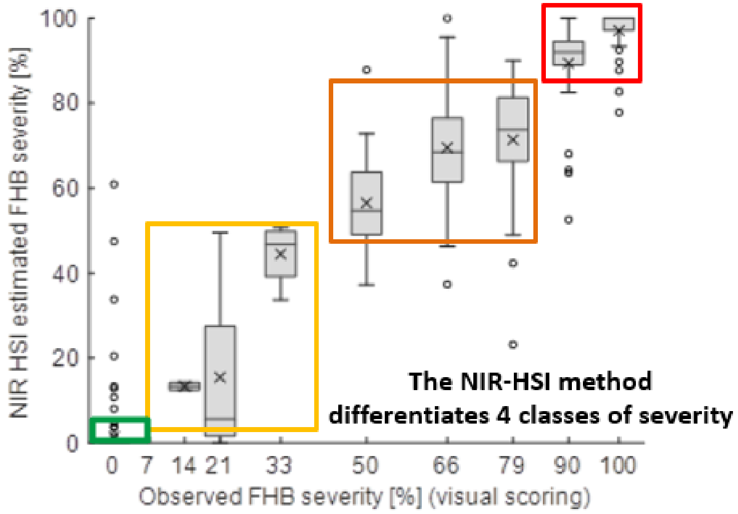
Infected or not

	Actual class	
	FHB-infected	Healthy
Predicted as FHB-infected	152	13
Predicted as Healthy	2	141

Sensitivity: 98,7%

Specificity: 91,6 %

Severity



D. Vincke et al. (2023). Near infrared hyperspectral imaging method to assess Fusarium Head Blight infection on winter wheat ears. Michrochmeical Journal 191, 108812

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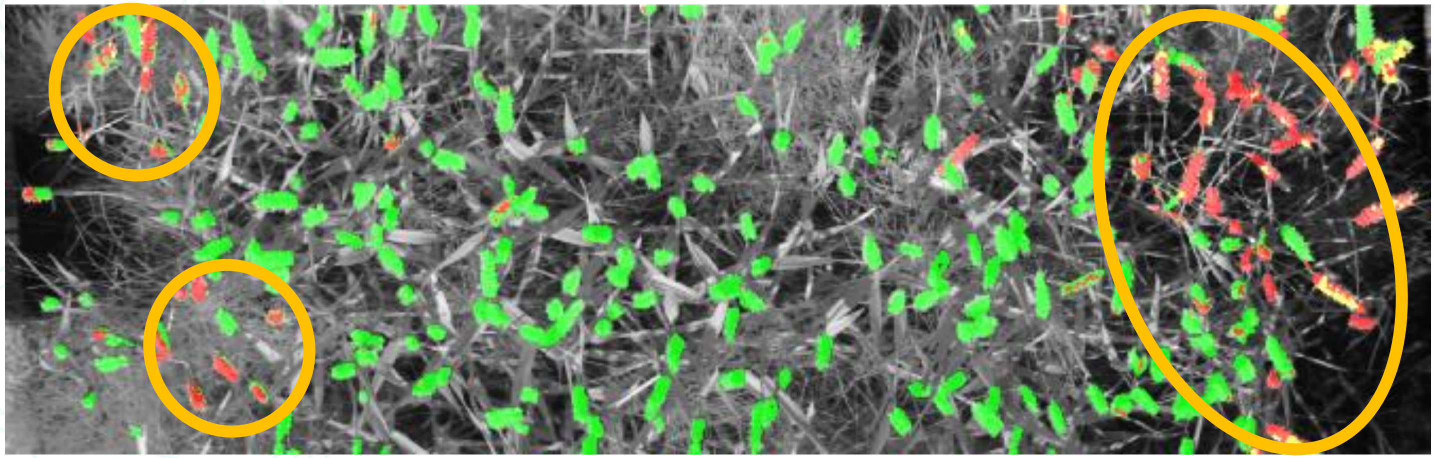
4th approach: VNIR hyperspectral imaging: results

In field

Predicted images



Healthy
FHB infected
Take-all infected

	FHB		Take-all		Overall stress	
Date	RMSE	R^2	RMSE	R^2	RMSE	R^2
28-06-22	0,7	0,08	4,1	0,39	2,0	0,85
04-07-22	0,6	0,26	7,8	0,56	4,2	0,87
14-07-22	0,5	0,42	5,4	0,79	1,8	0,98

D. Vincke (2024). Evaluation of fusarium head blight infection on winter wheat using near infrared hyperspectral imaging from the laboratory to the field. Thesis in U.Liège Gembloux Agro-Bio Tech

The method can assess the overall stress of the ears but …
It is not specific enough to differentiate two diseases with similar symptoms.

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4th approach: VNIR hyperspectral imaging: next steps

- Transfer to a tractor platform
  - & adaptation
    - with blackout box (natural light control)
    - with angle 45 or vertical view

- Model optimisation:
  - specificity
  - prediction in real time

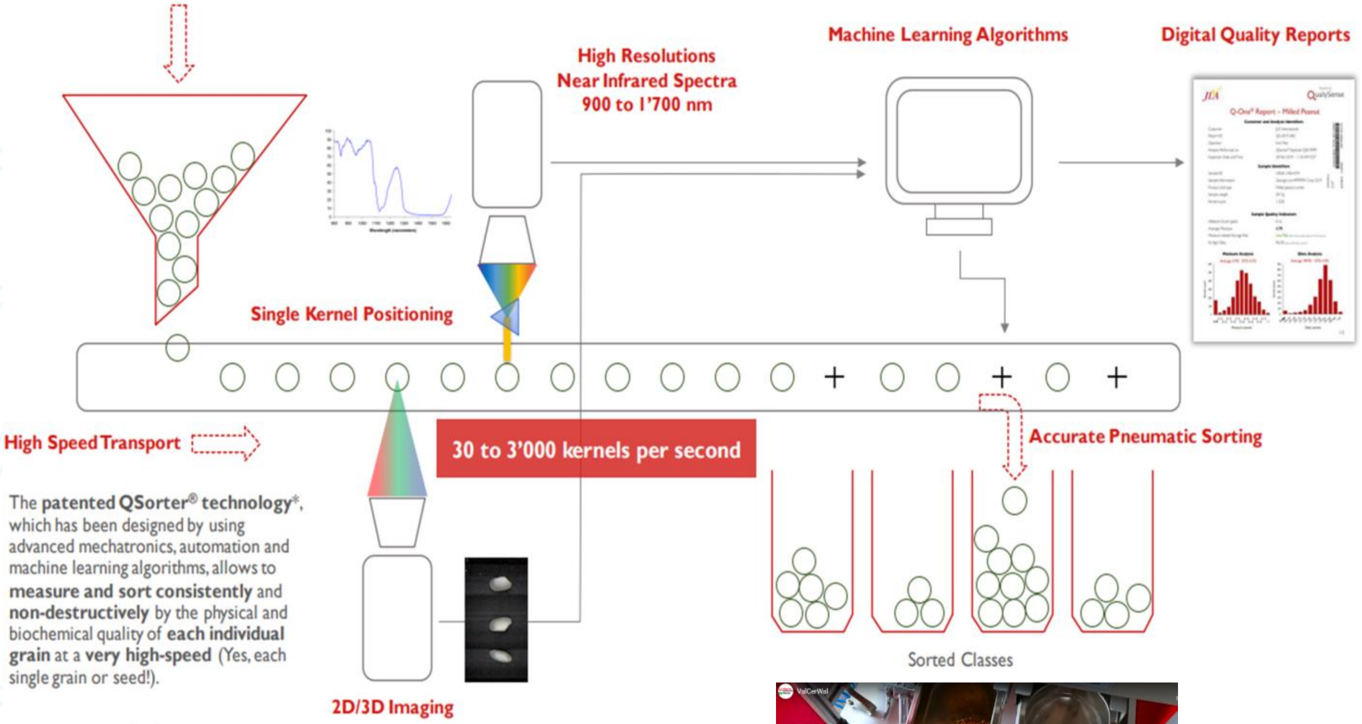
5th approach: NIR + RGB imaging for sorting grains

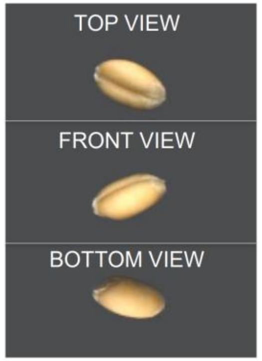
➢Single-kernel analyzer: Qsorter explorer (Qualisense)

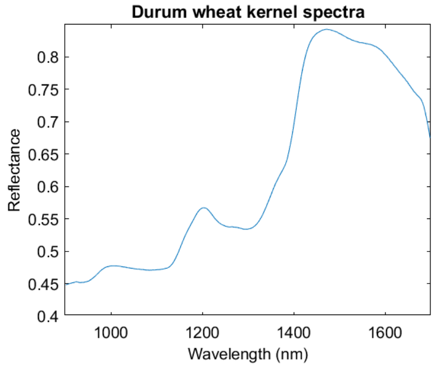
-NIR range 900-1700 nm

-3D RGB imaging

-Information acquired from each individual grain







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Wallonie Relance

5th approach: NIR + RGB imaging for sorting grains

➢High-speed pneumatic sorting system

- Sorting based on **physical** and/or **biochemical** characteristics of grains
- Quality inspection in real time at **high throughput**
- In-depth batch **characterization** and better contaminant **management**
- **Individual grain** phenotyping for the development of new varieties

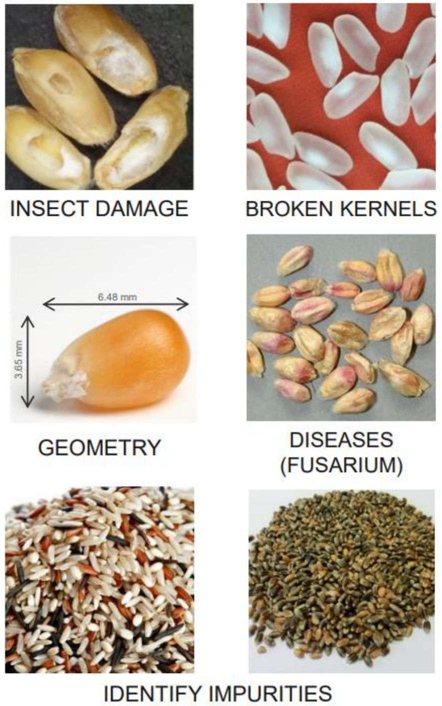

Image	Spectra	Protein [%]	Moisture [%]	Length [mm]	Width [mm]	Area [sqmm]	Elongation Factor [-]	Prediction Index	Label
		12.23	12.34	9.21	2.45	22.58	4.58	1.02	Oat
		13.65	11.21	8.76	2.76	24.21	4.48	1.12	Oat
		11.42	12.13	7.78	2.57	20.00	3.85	1.08	Oat
		15.35	11.05	7.25	3.97	28.78	3.97	0.92	Contaminant
		12.78	10.98	11.58	3.12	36.17	4.72	1.01	Oat

Various compositional properties:
protein, fatty acids, sugar…

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Readiness of the tools

RGB images in field
NIR hyperspectral in field

Handheld fluorometer in field
Multispectral in lab
NIR hyperspectral in lab
Qsorter in lab

Multispectral in field

1	Basic principles observed
2	Technology concept formulated
3	Experimental proof of concept
4	Technology validated in lab
5	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
6	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
7	System prototype demonstration in operational environment
8	System complete and qualified
9	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Academic and applied research

Development and validation for variety testing

Use in variety testing

"Technology readiness levels (TRL); Extract from Part 19 - Commission Decision C(2014)4995" (PDF). ec.europa.eu.

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Next steps

Extension to other diseases

❑ Head diseases

Bunt (Tilletia caries): contamination of grain lots by spores
transfer methodology to other head disease (CRA-W)

Orange wheat blossom midge larvae – Cecidomyia – Yield loss
counting of larvae from RGB image (CRA-W, GEVES)

❑ Leaf diseases

Barley yellow dwarf virus (BYDV)- Vector: aphids - Yield loss
assess BYDV symptoms on leaves with the perch Phenoman (GEVES)

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