Color and Spectral Imaging for High-throughput Field FHB Detection and Lab DON Assessment

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Outline

- Field FHB detection using color imaging and deep neural network
- Lab DON detection in wheat/barley seeds using hyperspectral imaging
- Future work for field FHB and lab DON detection

Introduction

- FHB attacks wheat and barley spikes, which causes yield losses as high as 40% under severe epidemics.
- FHB pathogens produce mycotoxins that can contaminate the grain, often rendering it unusable.
- Deoxynivalenol (DON) in the seed is toxic to humans and animals.
- Manual phenotyping of FHB severity on hundreds of lines in the field - a costly, labor intensive, and time consuming process

Color imaging for FHB detection

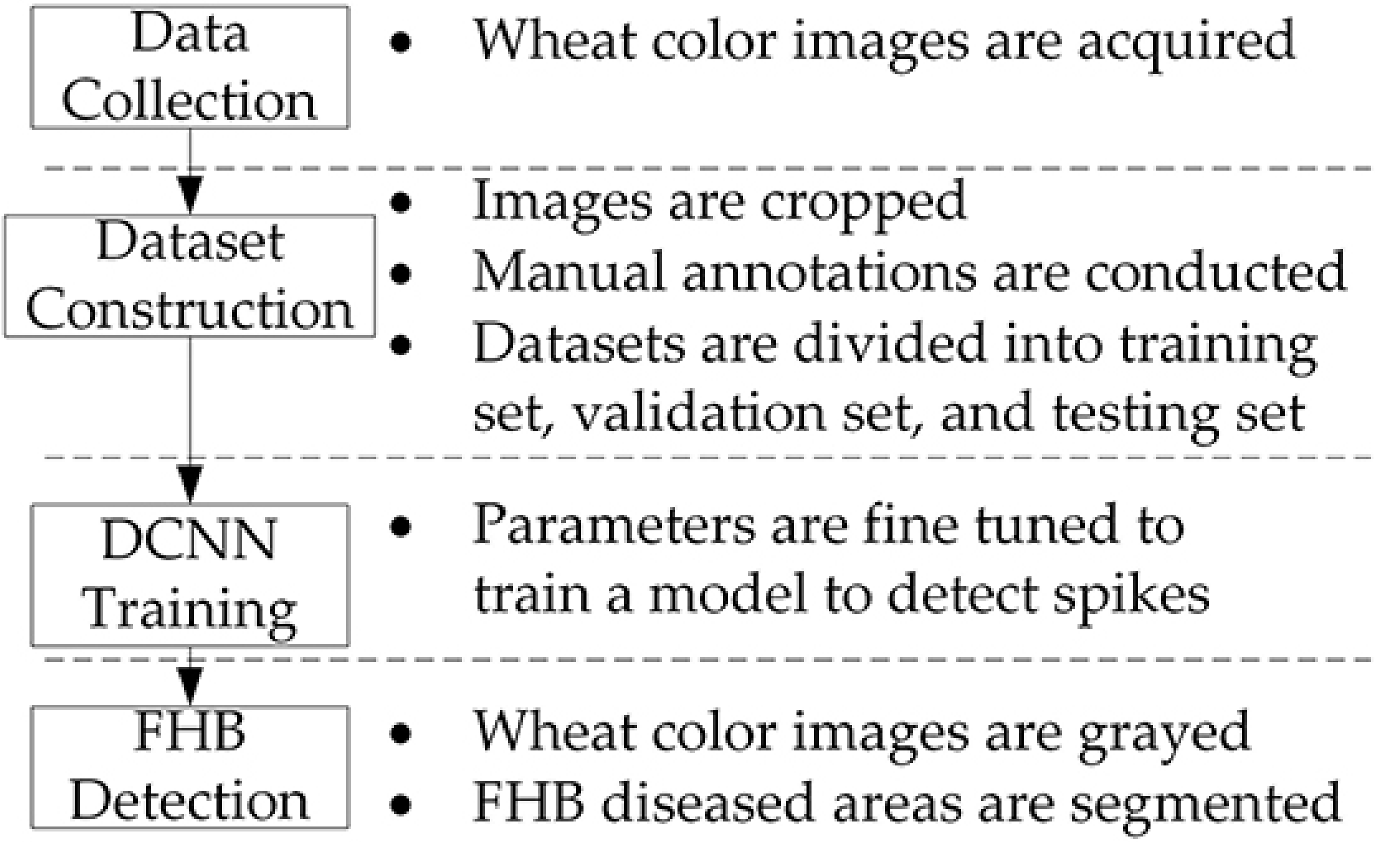
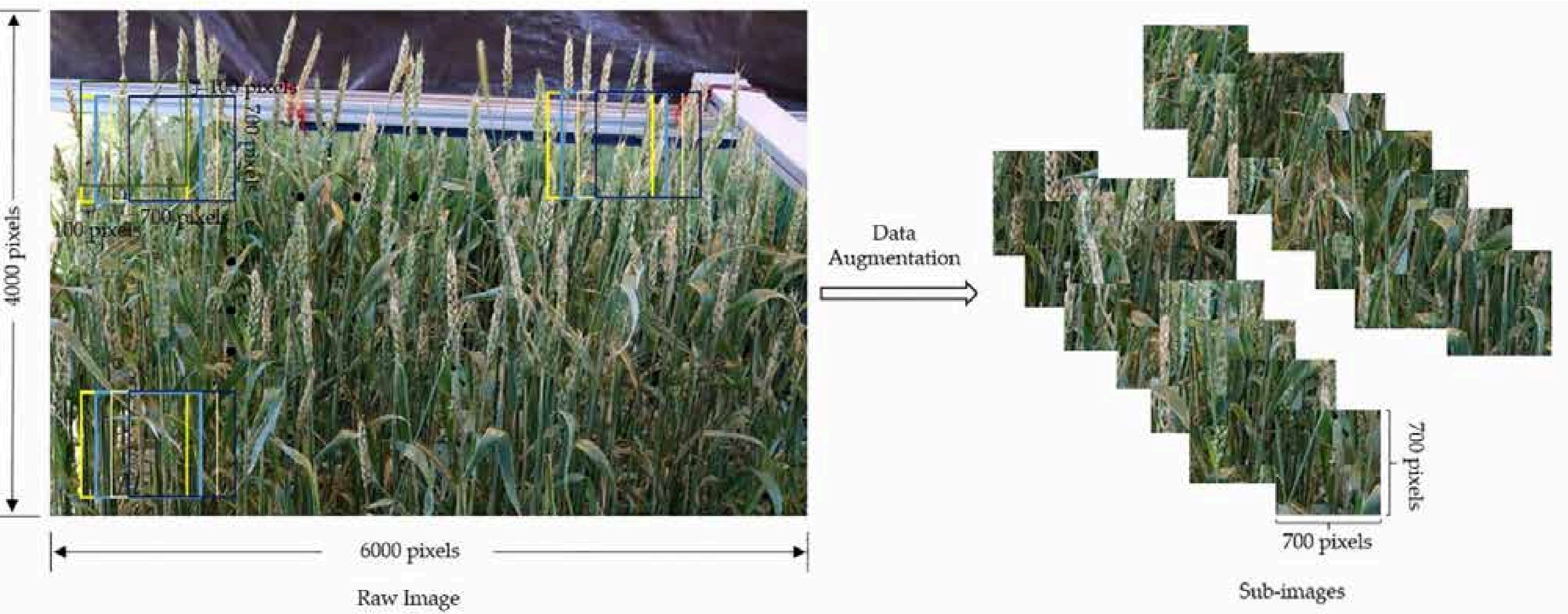


Image collection

- In summer 2018, we collected color (side-view) and hyperspectral (nadir-view) images from the barley and wheat trials in the St Paul, MN

- Nadir-view images were not helpful because the symptoms are on the side of the spikes
- Therefore, the hyperspectral images are not used for now.

Data Augmentation



2829 sub-images were generated.

Spike annotation

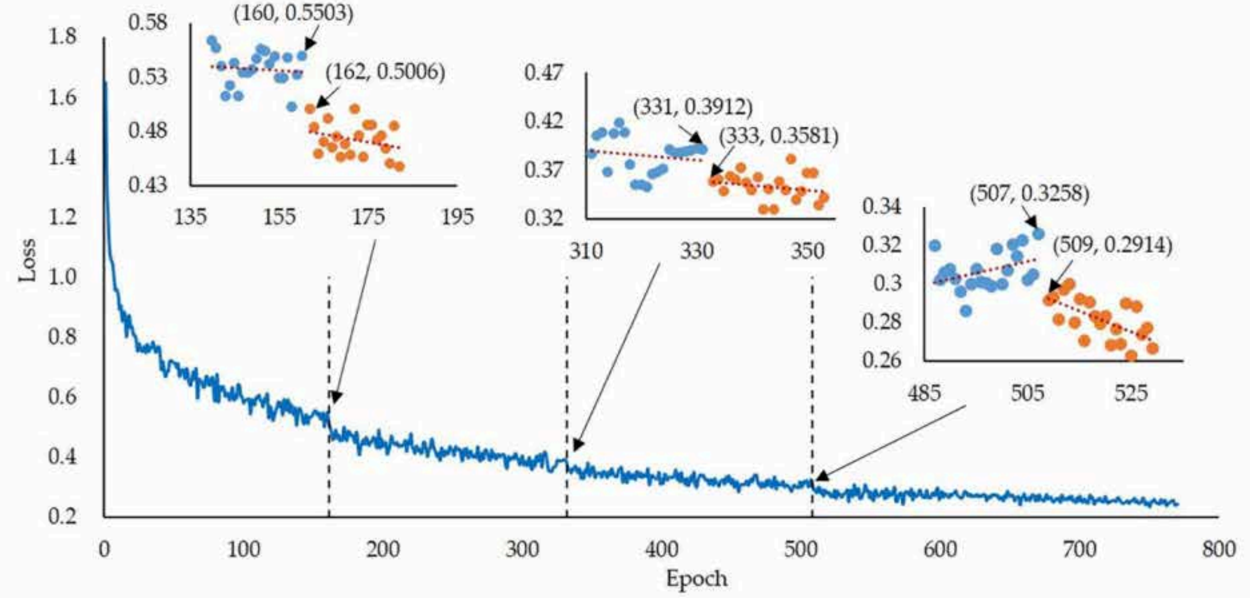
Labelme from MIT was used for labeling the images.

Spike Detection - Deep Convolutional Neural Network

- Maximum epoch 770 with a momentum of 0.9
- 100 iterations per epoch
- Weight decay 0.01
- Learning rate 0.002 -> 0.001 -> 0.0005 -> 0.0002
- Model parameters: recall and precision
- Statistical parameters: RMSE, rRMSE and R^2

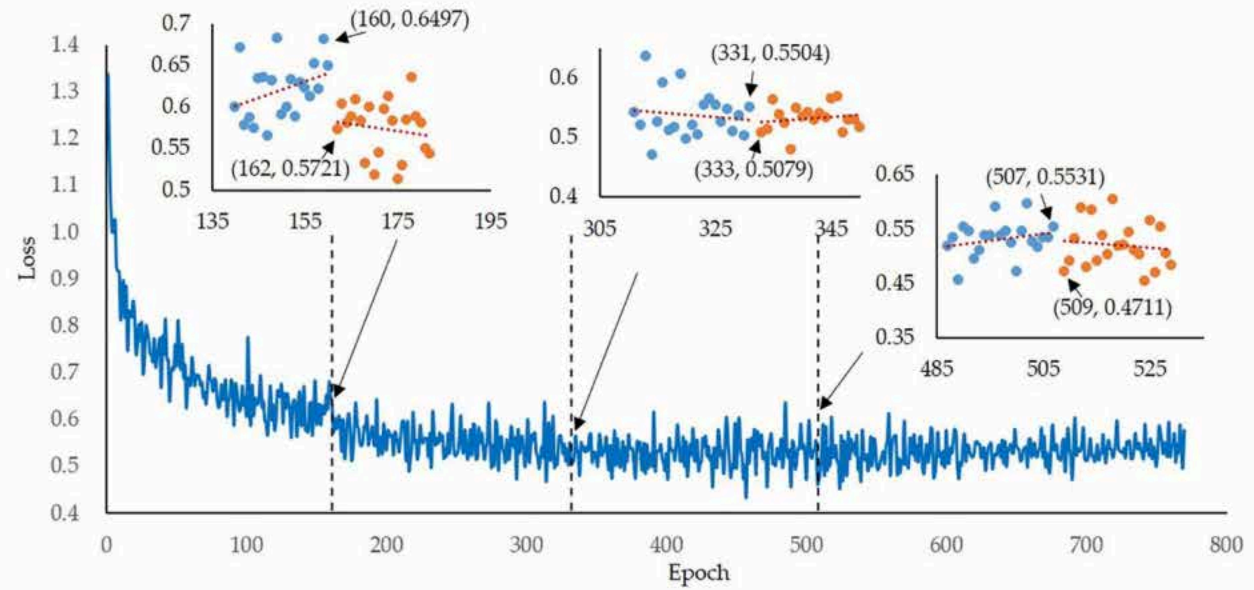
- 1959 sub-images were used for training
- 420 sub-images were for calibration
- 450 sub-images were for testing

Training Loss



(a)

Validation Loss



(b)

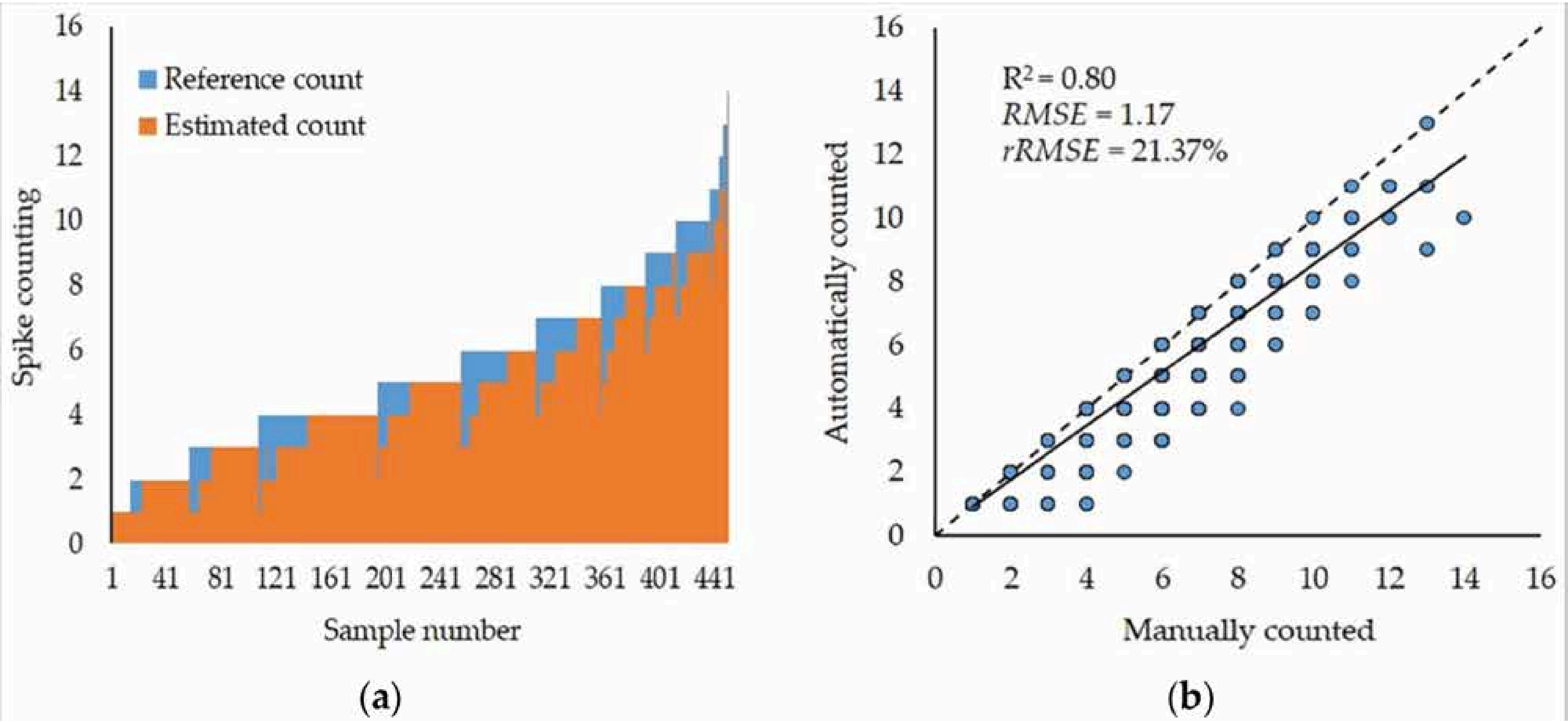
Spike Detection – Model Testing

- Mean Average Precision (mAP) from Mask RCNN was 0.92.

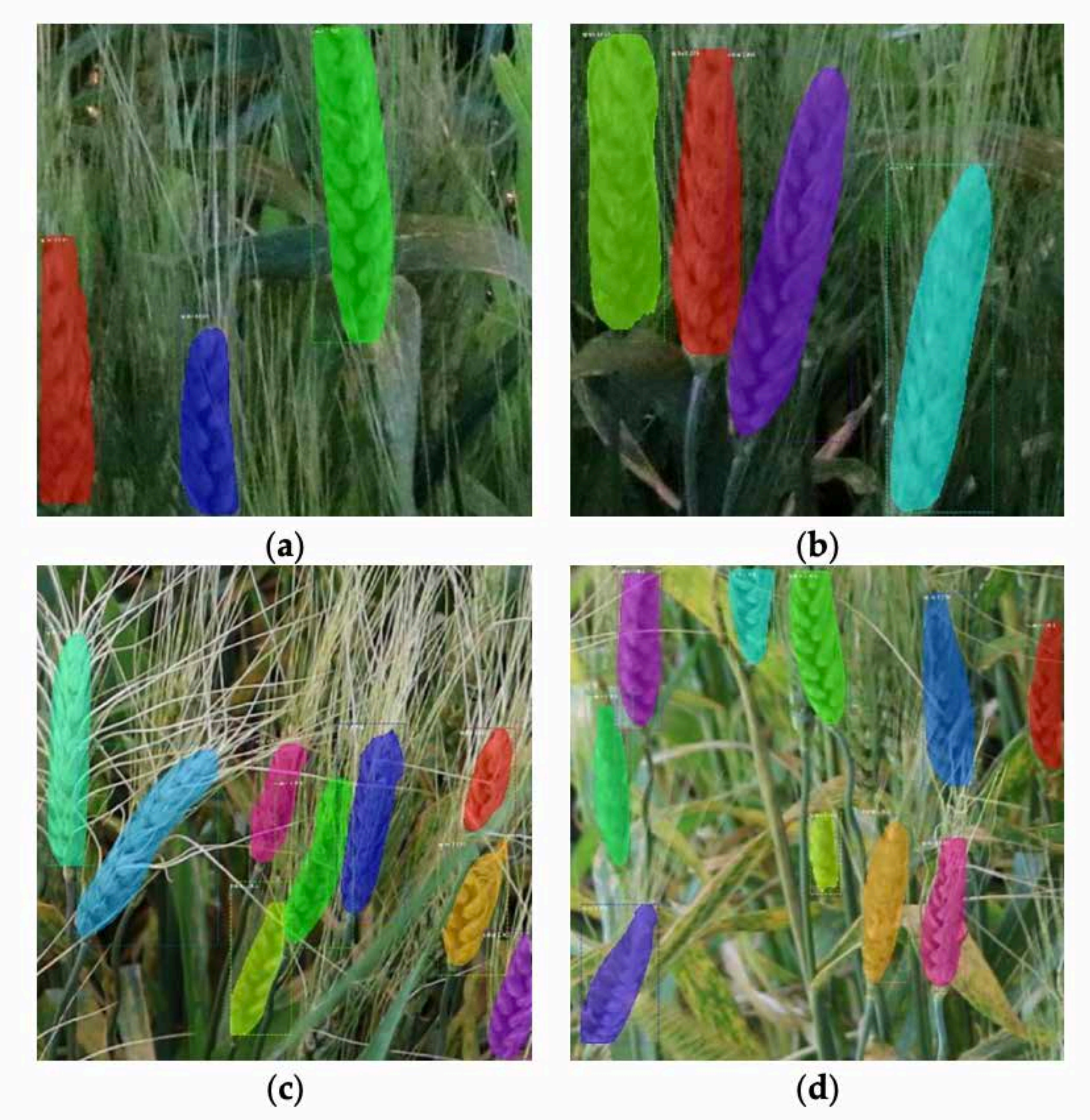
$$mAP = \frac{TP}{TP + FP}$$

This value indicated that the retrained model could reliably detect wheat spikes with different shapes and features.

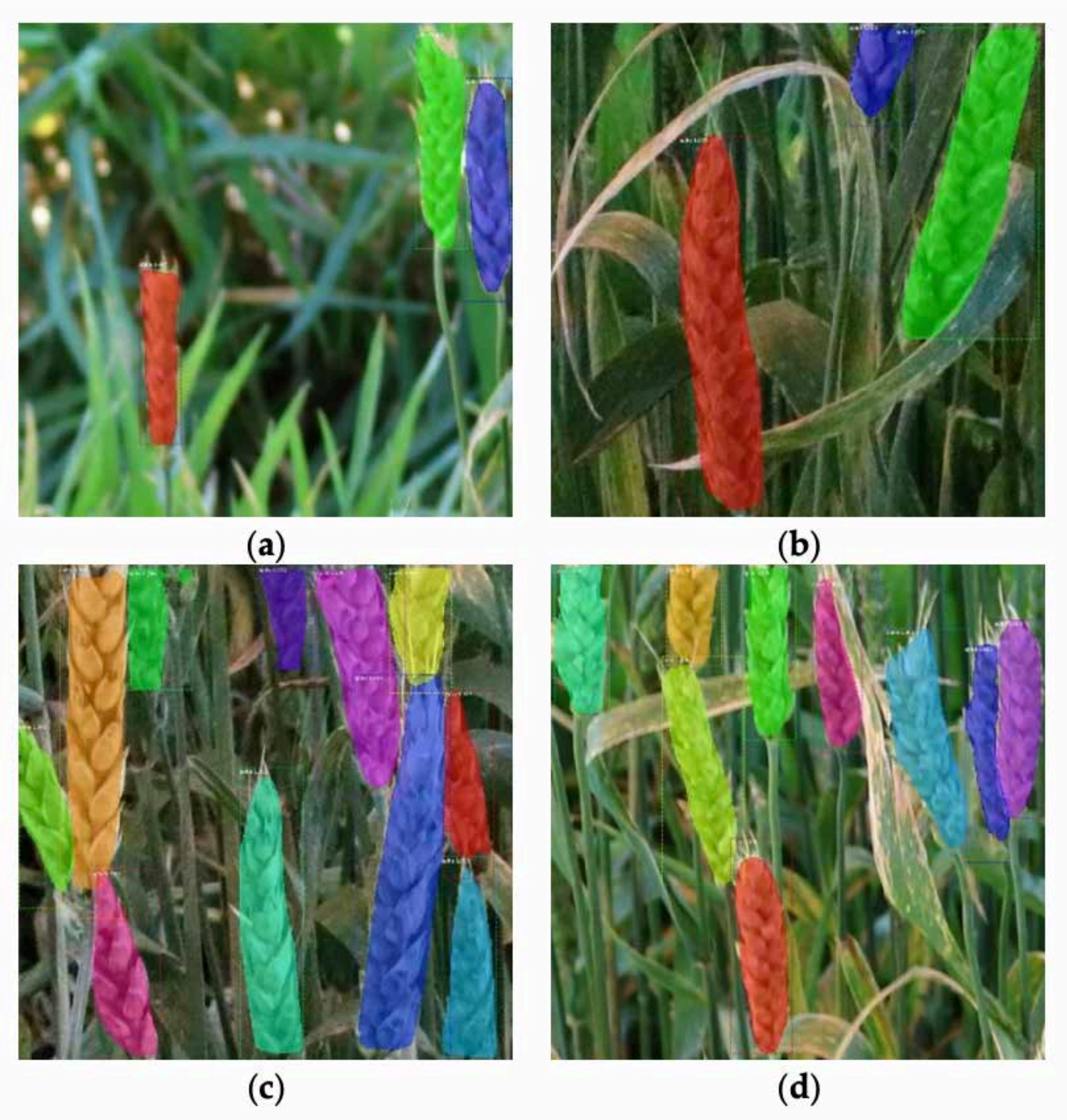
Spike Detection - Counts



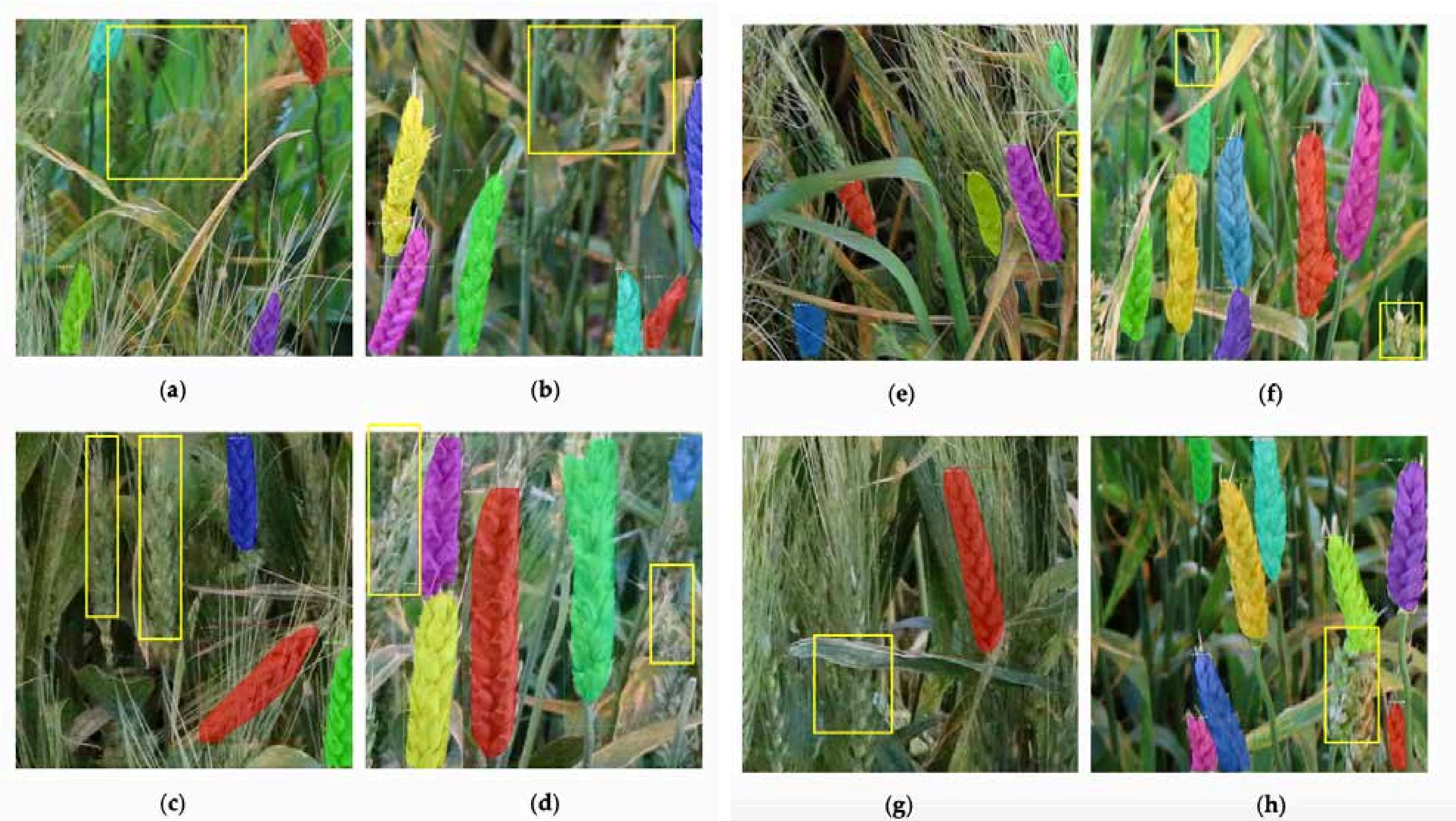
Detection of awned spikes



Detection of awnless spikes



Spikes that escaped detection



FHB Symptom on Detected Spikes

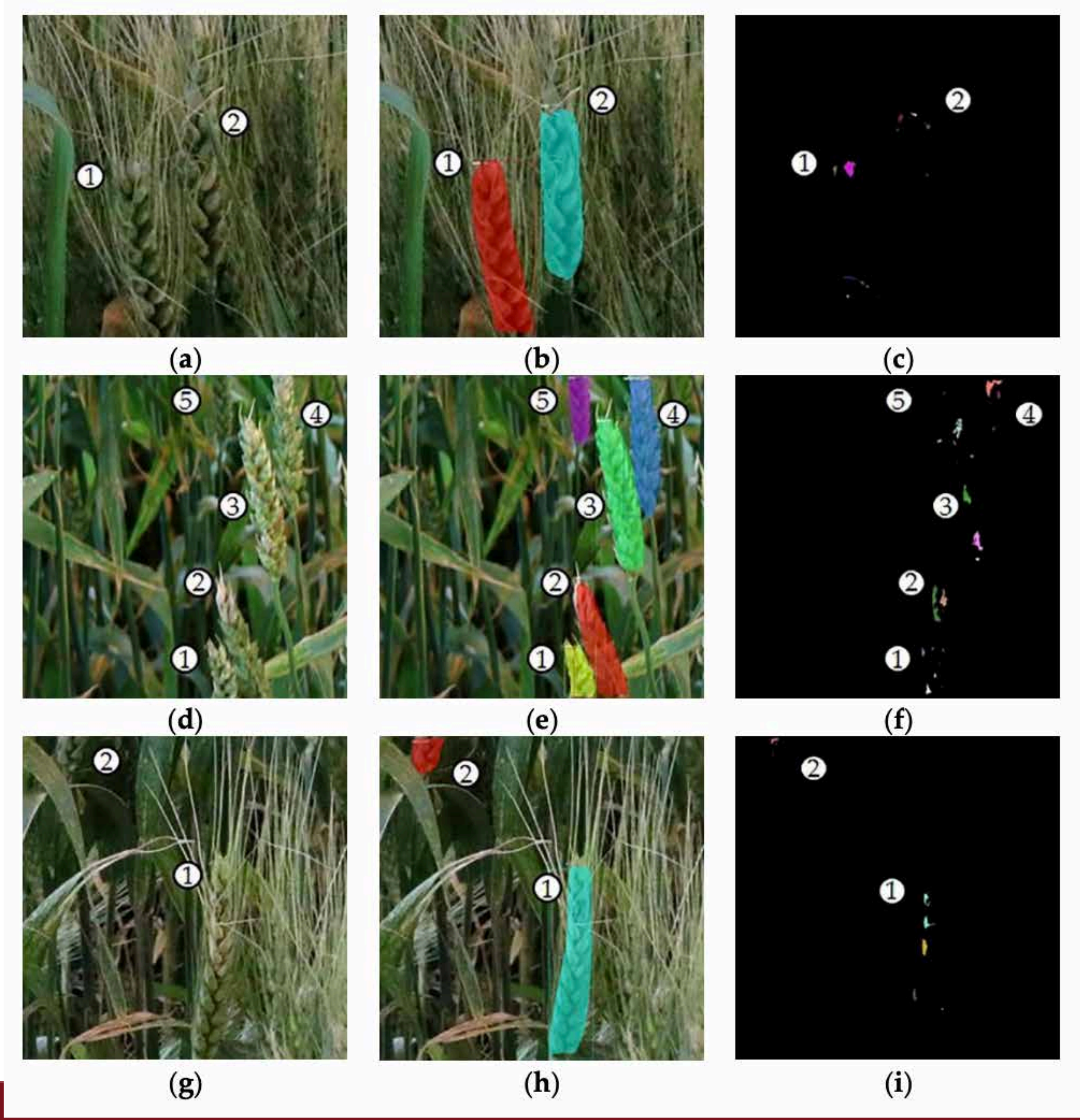
- GB feature in pixels for discoloration detection.

$$GB = \alpha * B - G$$

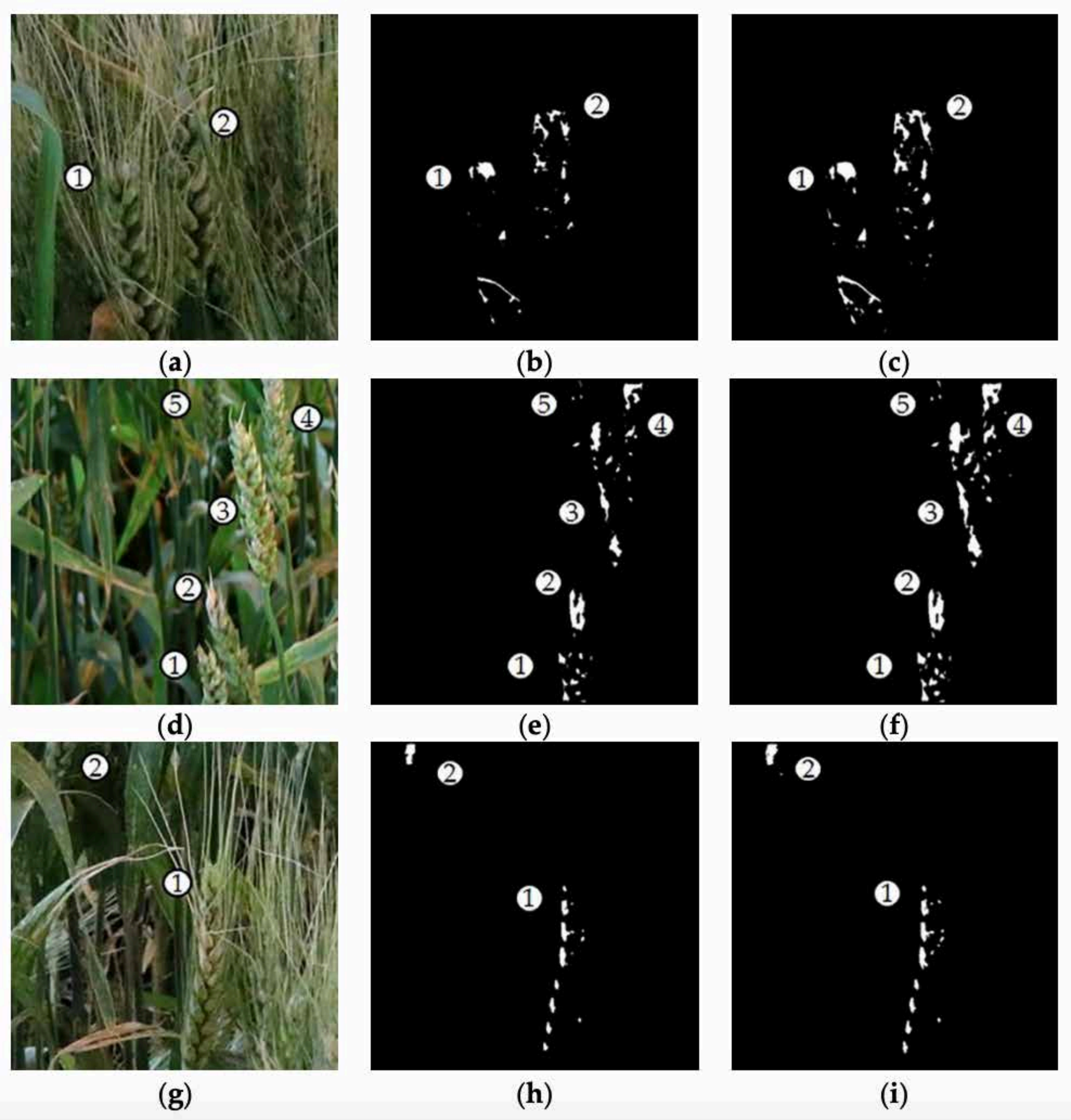
B: Blue channel; G: Green channel; α: color coefficient

- Region growing algorithm was used for diseased area detection.
- K-means and Otsu's algorithms were implemented to process the gray spike images used for the comparative tests v.s. the region growing algorithm.

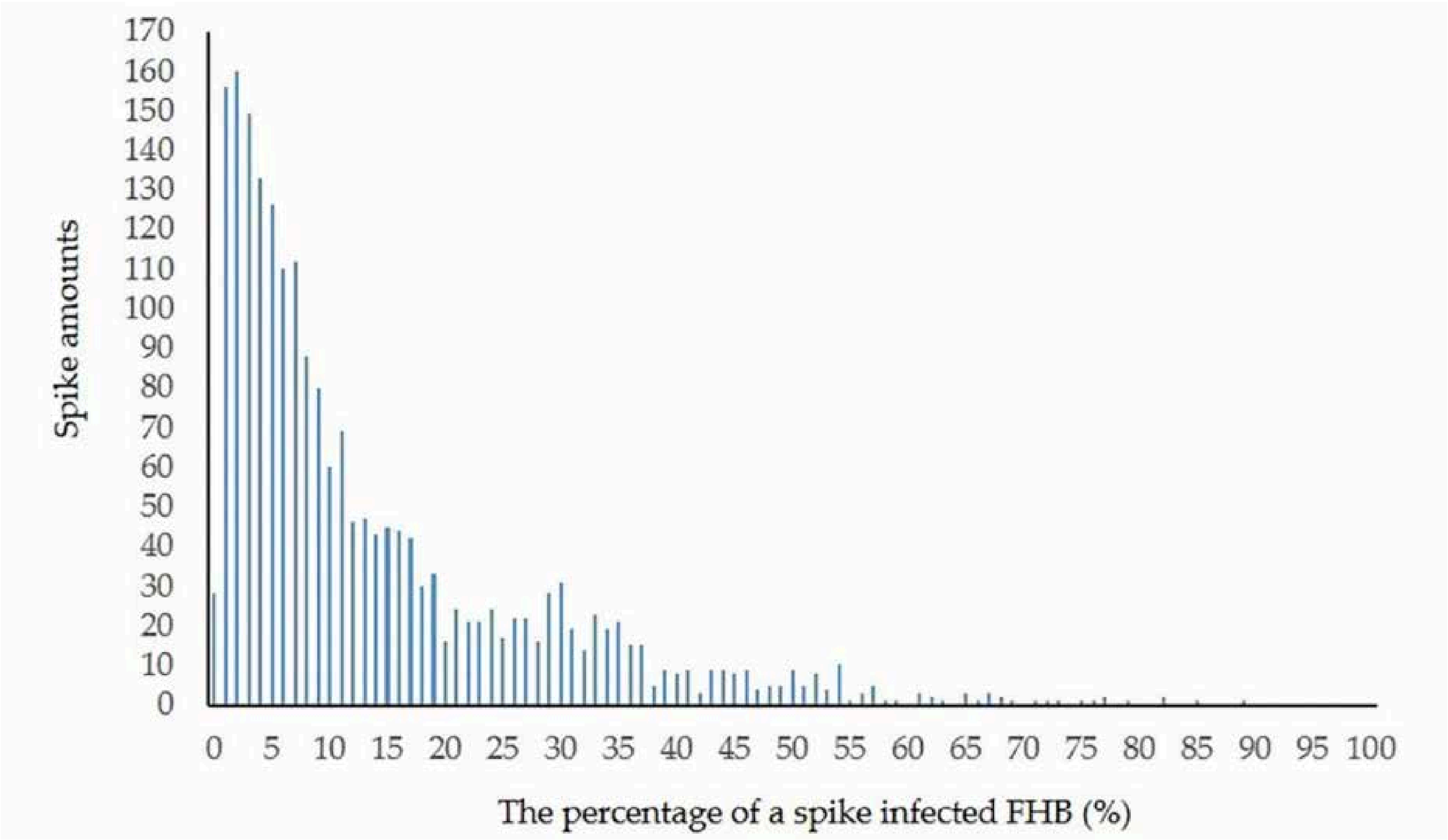
Region growing algorithm



K-means and Otsu algorithms



Overview of FHB Infection in Spikes



Next Steps

- Additional images of wheat spikes from diverse lines (i.e., with different shapes, sizes, and hues), with different views, should be captured and tested, to enlarge the training dataset and improve the robustness and applicability of the trained model and FHB detection.
- In summer 2019, we used Canon DSLR cameras to take 927 high-resolution close-up photos; we also took two photos for each test plot in St Paul and Crookston fields to correlate the imaging result with manual scoring in the field.

Next Steps

- In each photo, there are different numbers of spikes of Wheat or Barley. The number varies from 4 to 40+;
- Those photos are divided into three parts:
  - Training dataset (670 photos),
  - Validation dataset (211 photos)
  - And inferring dataset (46 photos).
- Better annotation than year 2018 data.

Image Annotation

Image Annotation

- Currently, we labeled 400 photos.
- We used a portion of the labeled photos as input to train the Fast-RCNN network and get better inferred results.
- Barley is more challenging than wheat in field FHB detection.

Image Annotation

- To classify normal wheat/diseased spikes, normal barley/diseased spikes, we will collaborate with Steffenson's group to help check if we make the correct annotation for each infected area.

Future Work

- Analysis of 2018 data: field manual scoring has been shown to have poor correlation with post-harvest lab DON assay.
- There is very limited room for improvement in manual scoring.
- There is a large room to improve the deep learning model by direct validation by lab DON assay.

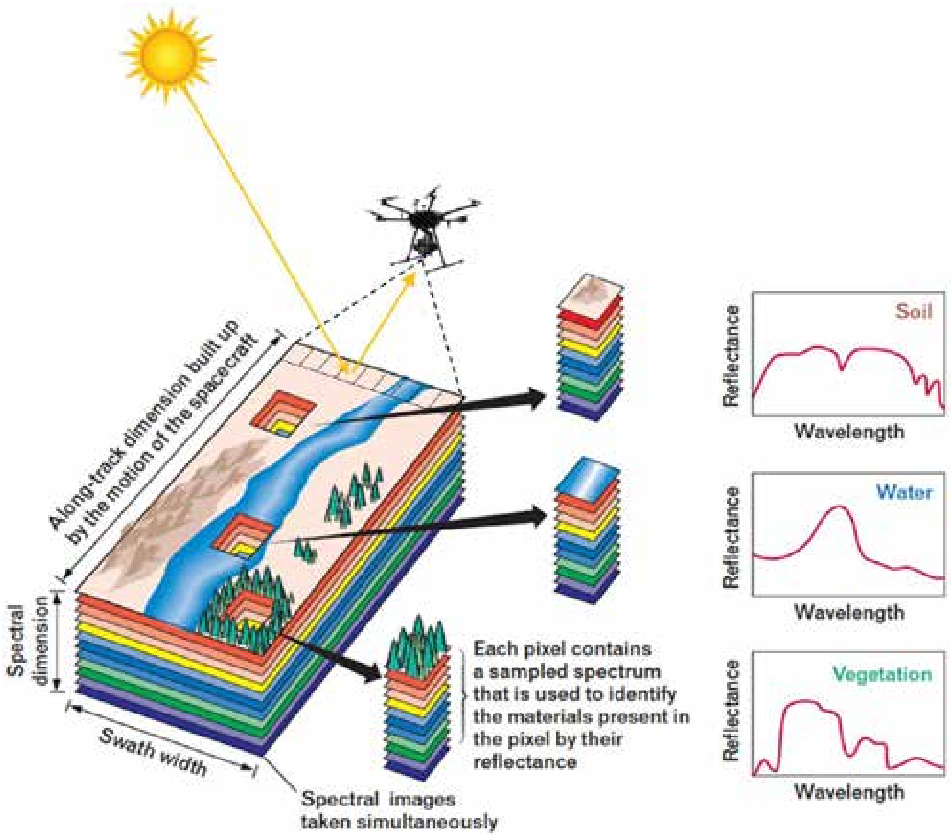
Future Work

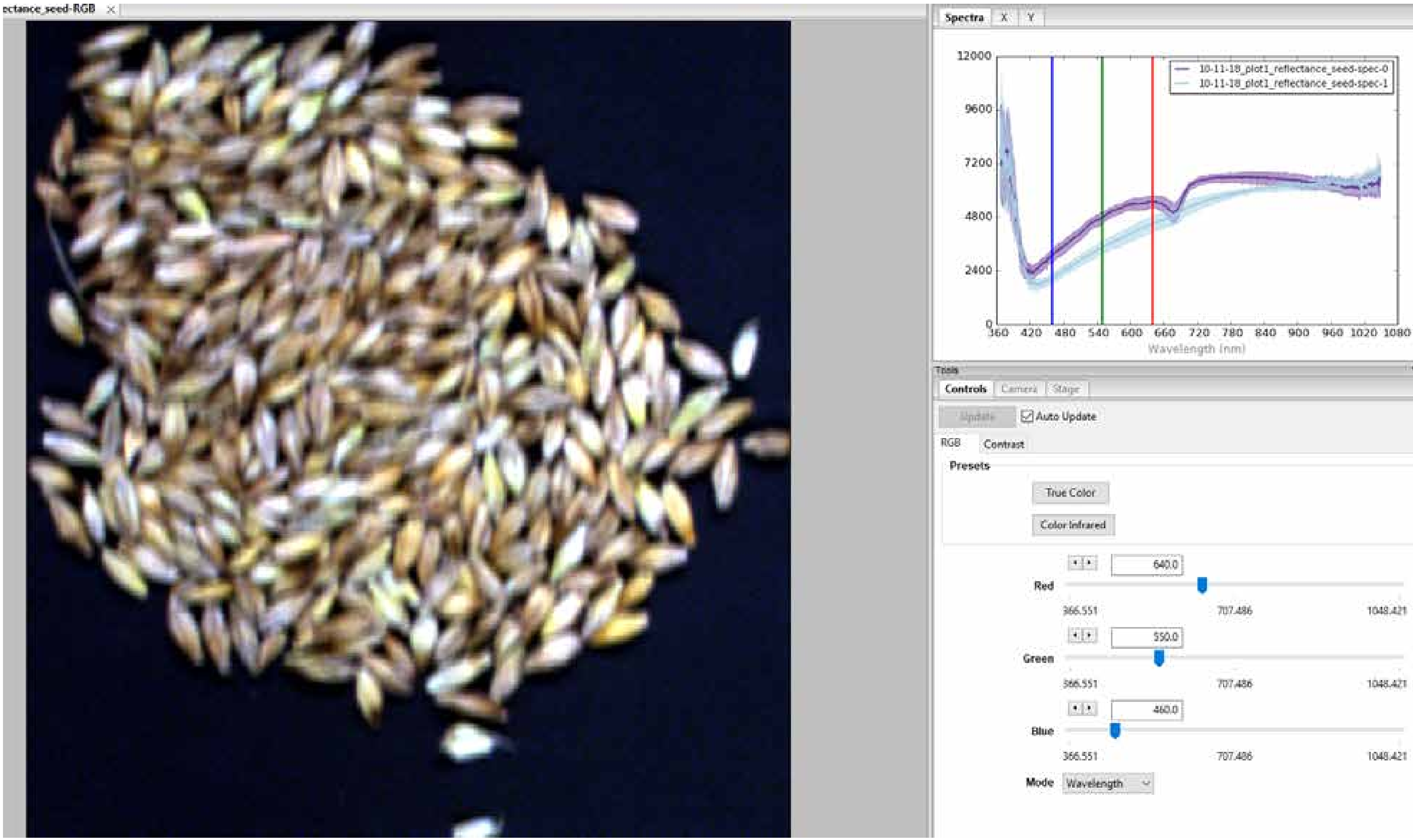
- On-board real-time FHB level detection based on color imaging by a phenocart platform.
- Try a new narrow-band RGB camera that provides naturally enhanced color images. Camera will be provided by a local collaborator Sentera (a sensor company).
- Redesign drone imaging to achieve higher throughput in the air than on the ground.

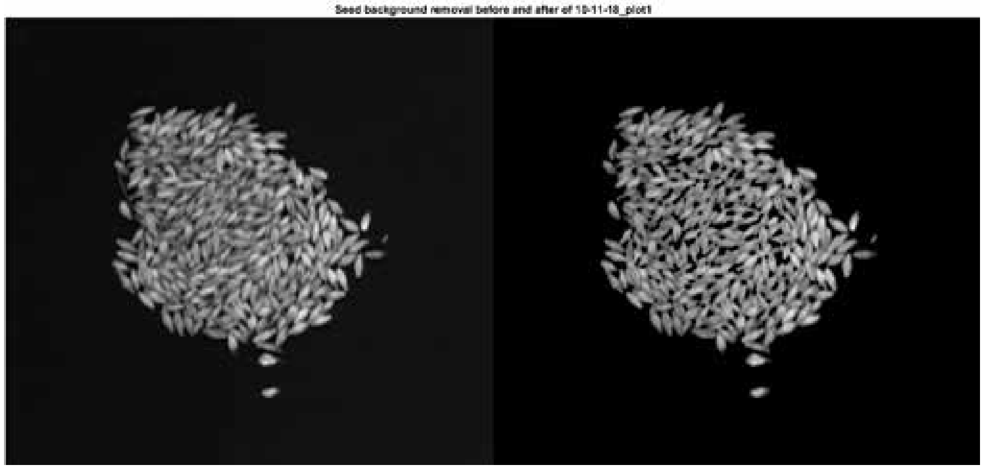
DON HTP

- We collected ~1500 seed hyperspectral image samples for DON assessment in crop seasons of 2018 and ~2000 samples in 2019 and will process them by advanced machine learning and deep learning algorithms. The results will be validated by the lab GC-MS tests.
- We collected ~2000 seed fluorescent image samples for DON assessment in crop season of 2019. The results will be validated by the lab GC-MS tests.

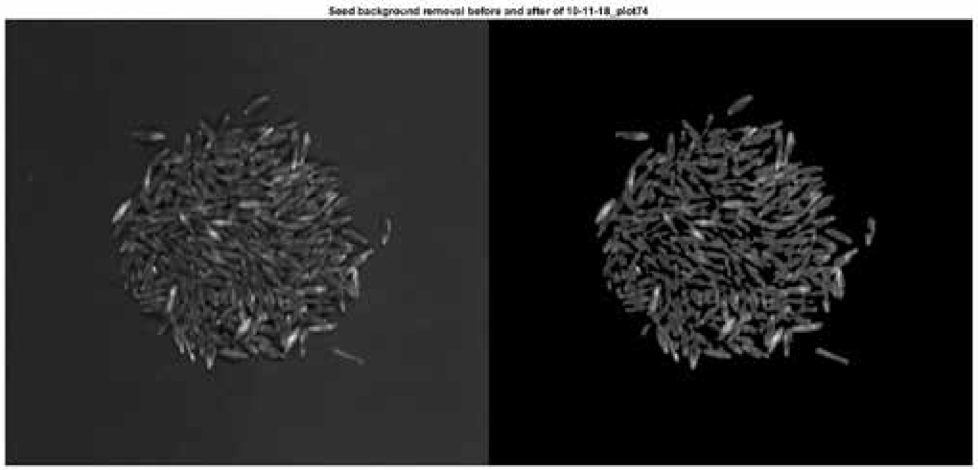
Hyperspectral imaging




ectance_seed-RGB
Spectra
X
Y
12000
9600
7200
4800
2400
0
360
420
480
540
600
660
720
780
840
900
960
1020
1080
Wavelength (nm)
10-11-18_plot1_reflectance_seed-spec-0
10-11-18_plot1_reflectance_seed-spec-1
Tools
Controls
Camera
Stage
Update
Auto Update
RGB
Contrast
Presets
True Color
Color Infrared
640.0
Red
366.551
707.486
1048.421
550.0
Green
366.551
707.486
1048.421
460.0
Blue
366.551
707.486
1048.421
Mode
Wavelength



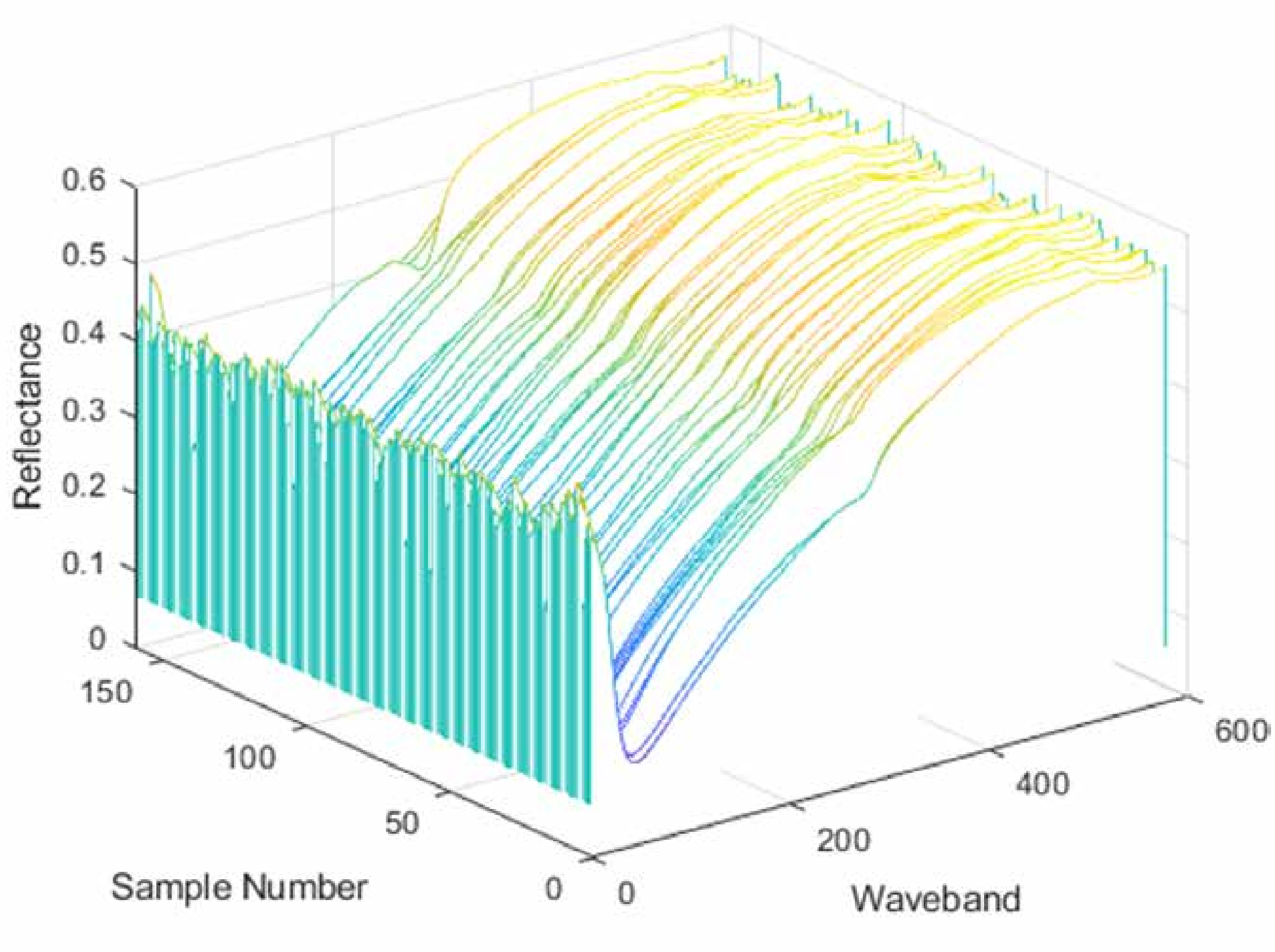
Plot 1
(bright original image)



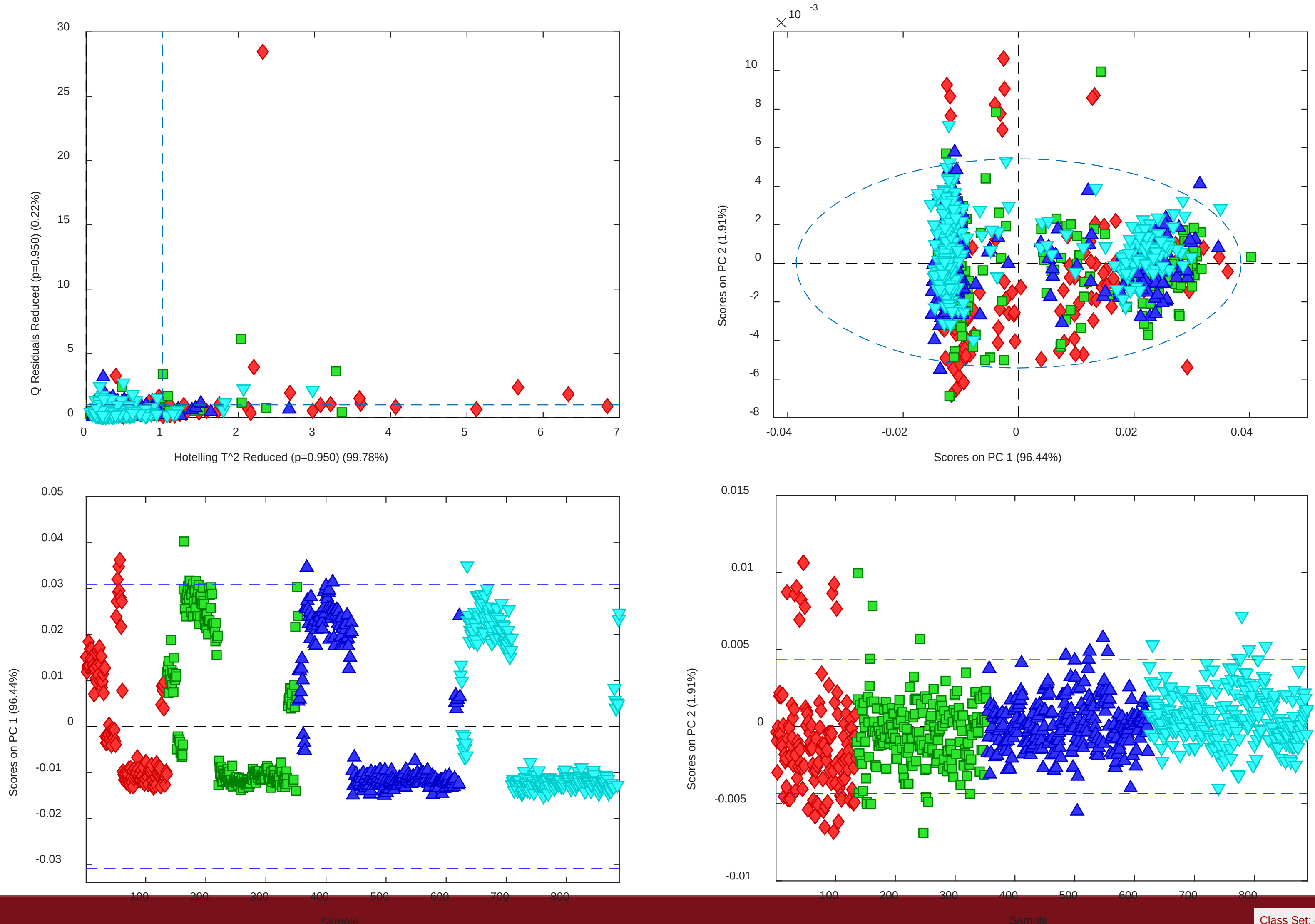
Plot 74
(dark original image)

Image before and after background removal

Average spectra of selective samples



PCA for classification of 4 DON levels



Full-wavelength models for DON level detection

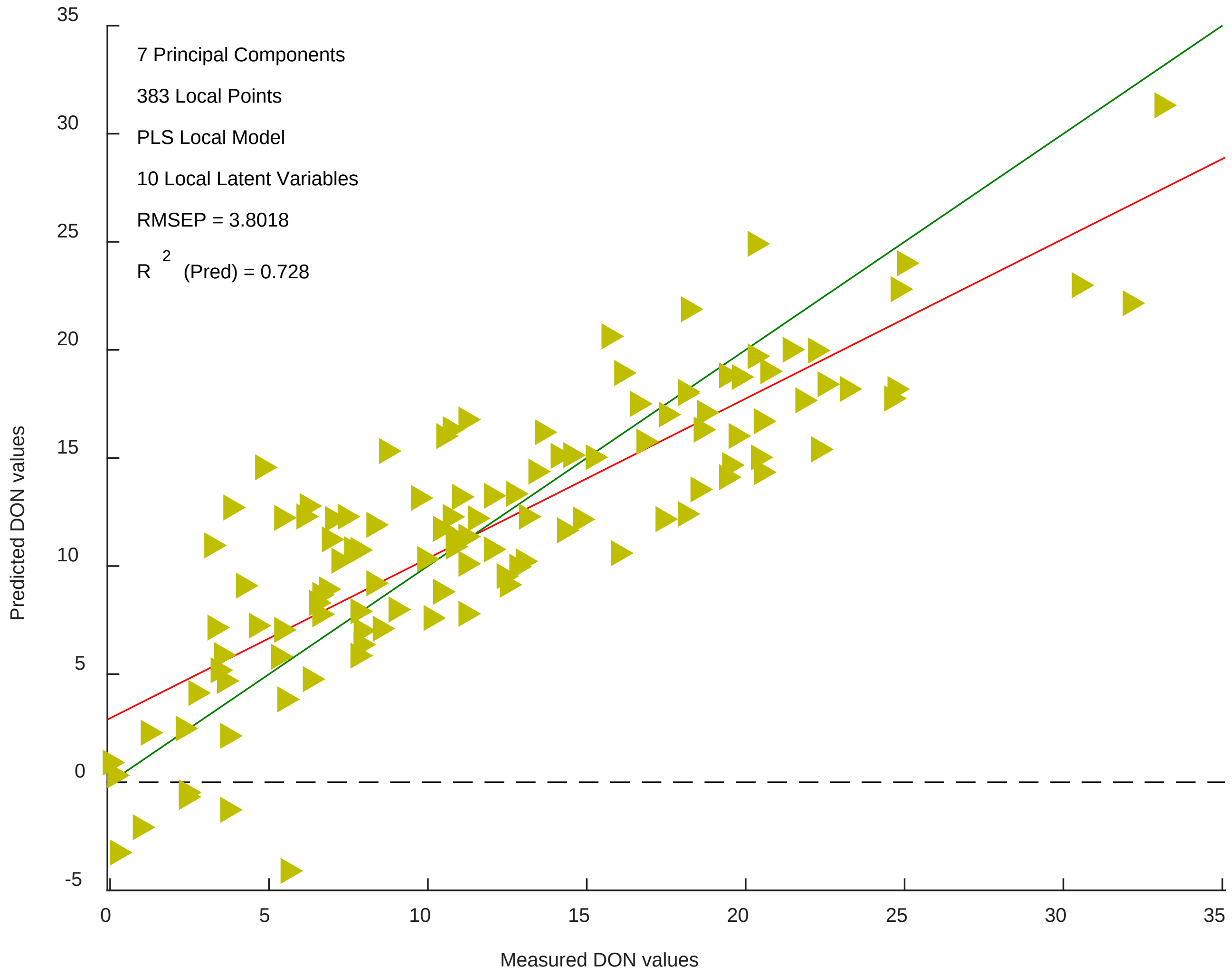
Reference values of DON contents measured by GC-MS.

Sample set	Calibration				
	No.	Max	Min	Mean ± SD	Range
Calibration	888	33.9	0	12.105 ± 6.599	33.9
Prediction	116	33.1	0	12.224 ± 7.282	33.1

Model	No. LV	Calibration			Cross-validation			Prediction		
		NO.	R^2_C	RMSEC	NO.	R^2_{CV}	RMSECV	NO.	R^2_P	RMSEP
SVMR	-	888	0.539	4.528	888	0.468	4.866	116	0.543	5.023
PLSR	10	888	0.533	4.510	888	0.517	4.585	116	0.579	4.746
PCR	7	888	0.412	5.062	888	0.400	5.110	116	0.491	5.240
ANN	-	888	0.617	4.242	888	0.518	4.772	116	0.645	4.384
LWPLSR	**-**	**888**	**0.800**	**2.958**	**888**	**0.623**	**4.083**	**116**	**0.728**	**3.802**

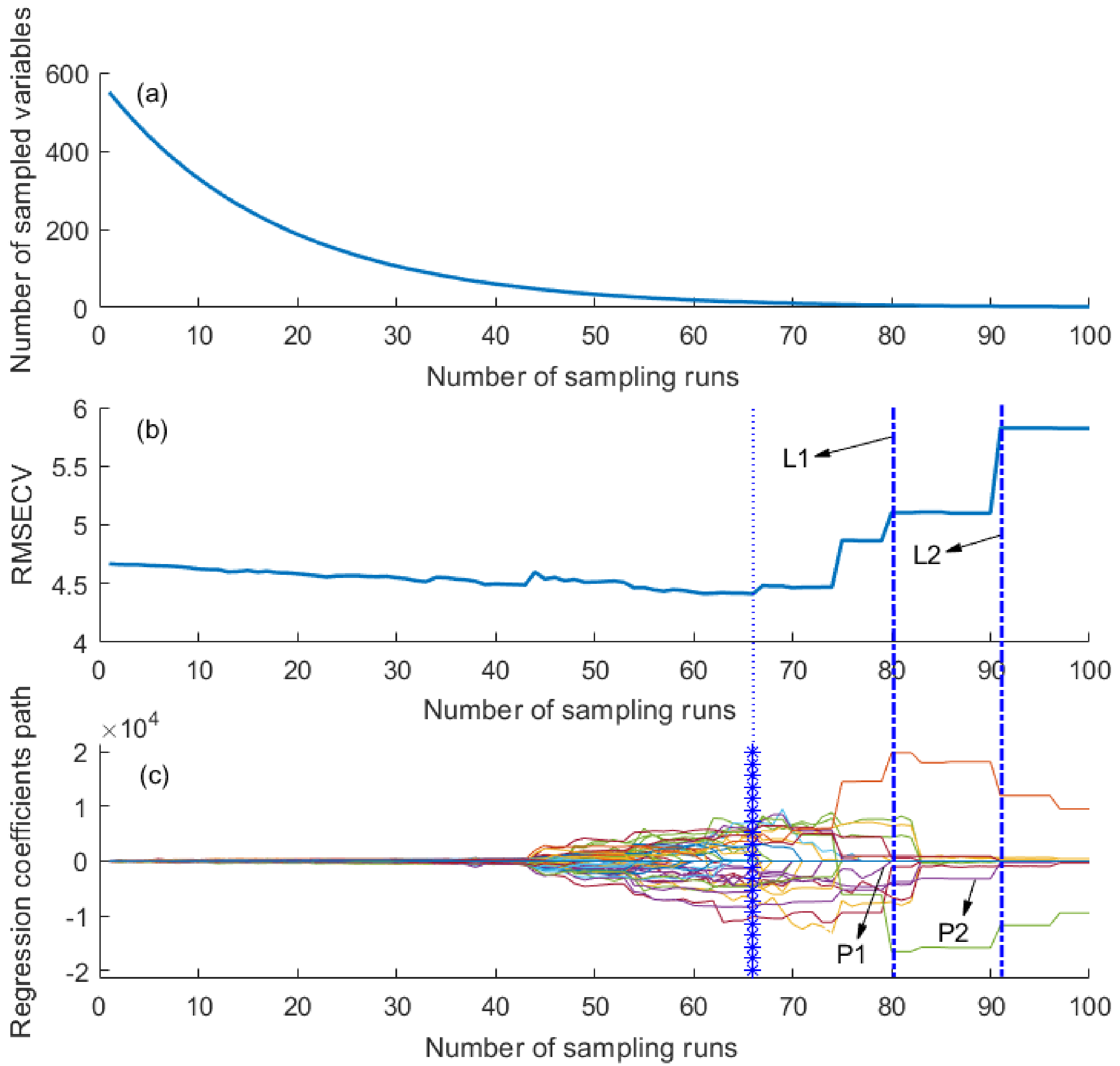
PLSR: Partial least squares regression, SVMR: Support vector machine regression, PCR: Principal component regression, LWPLSR: Locally weighted partial least square regression, ANN: Artificial neural network, R^2_C: Coefficient of determination in calibration, RMSEC: Root mean square error of calibration, R^2_{CV}: Coefficient of determination in cross validation, RMSECV: Root mean square error of cross validation, R^2_P: Coefficient of determination in prediction, RMSEP: Root mean square error of prediction.

LWPLSR model for determination of DON level

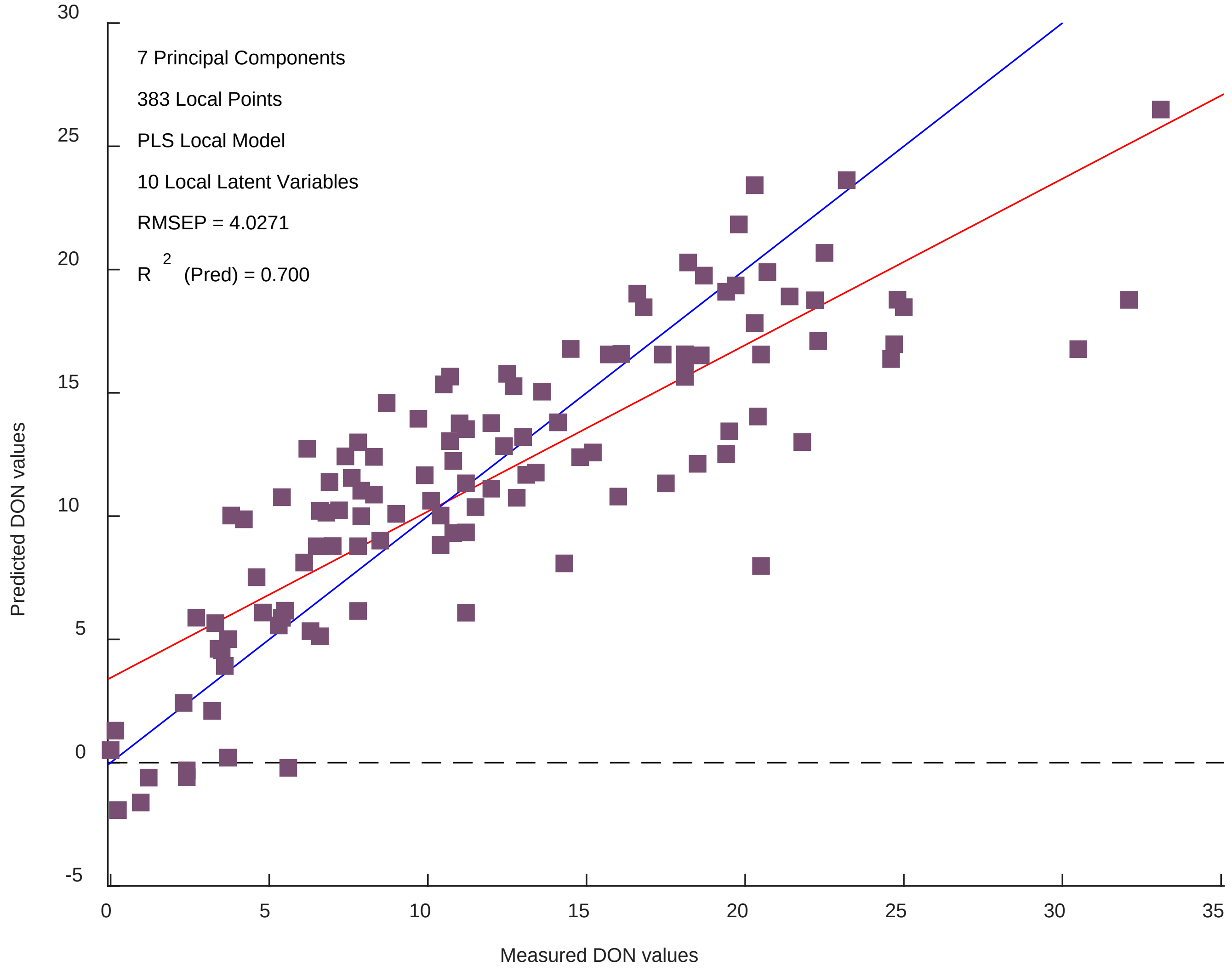


Feature wavelength selection by Competitive Adaptive Reweighted Sampling (CARS)

Selected wavelengths (14): 596 627 628 637 697 702 706 753 758 759 810 925 926 957 nm



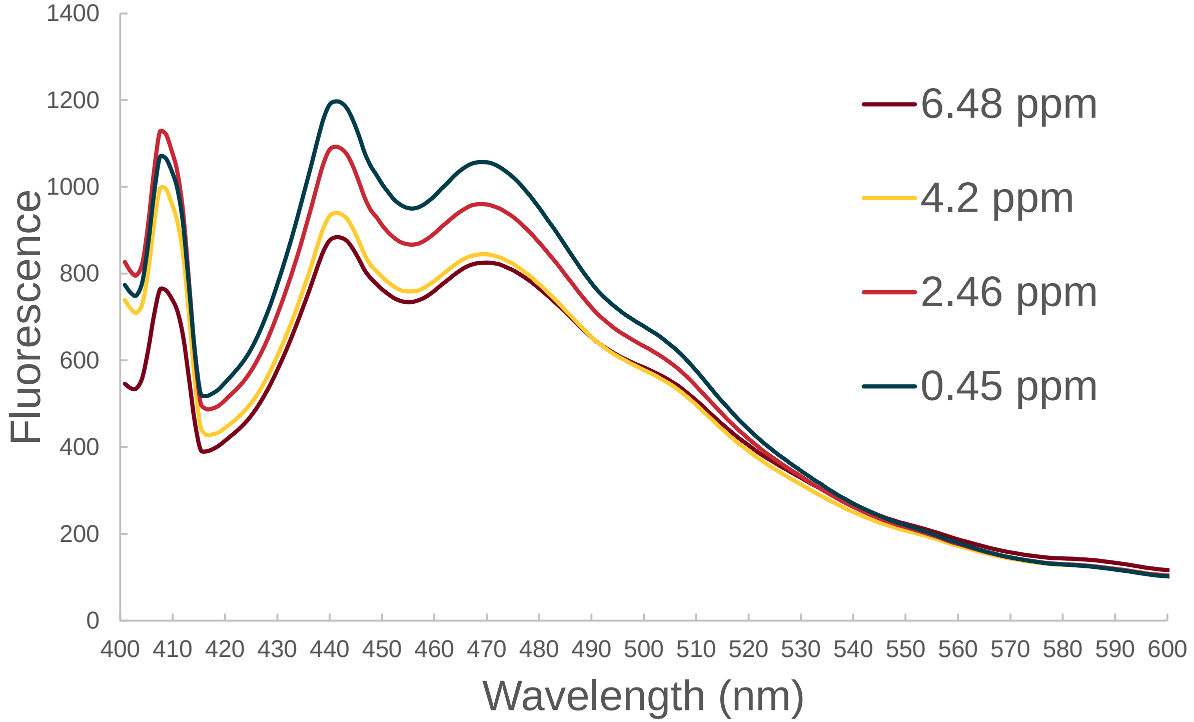
CARS-LWPLSR model for determination of DON level



Future work - fluorescence spectral imaging

The fluorescence emission spectrum of wheat and barley FLOURS with DON levels from 0.45 to 6.48 ppm

A higher DON level is associated with a lower fluorescence in the spectrum.



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