

Plant Leaf Diseases Diagnosis with Deep Learning

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Why This Project?

Automated Agricultural Systems



<https://images.pexels.com/photos/96715/pexels-photo-96715.jpeg?cs=srgb&dl=pexels-alejandro-barr%C3%B3n-96715.jpg&fm=jpg>

Mobile App for Houseplant Hobbyists



https://hips.hearstapps.com/hmg-prod/images/man-watering-houseplants-royalty-free-image-1678736179.jpg?crop=0.668xw:1.00xh;0.136xw,0&resize=640:*

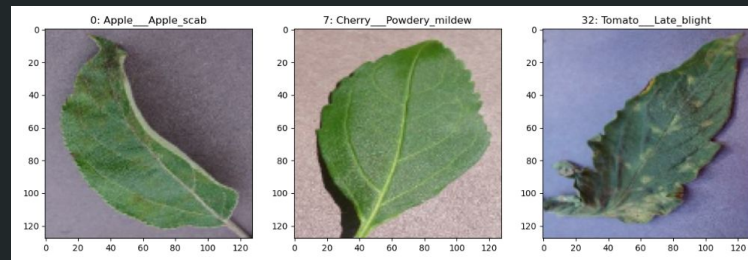


Data

Images of Plant Leaves

- Source: [Mendeley Data](#), originally from a journal paper.¹
- Total Class: 39, including 1 background (not plants)
- Total Images: 61,486
- Total Species: 15

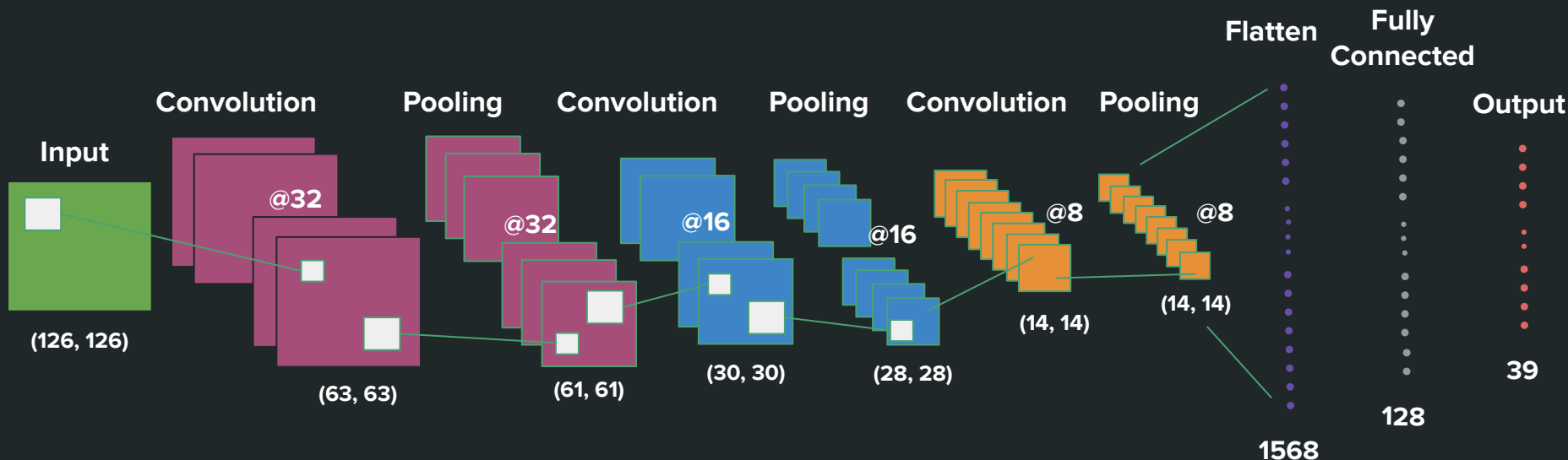
Crops	Corn	Soybean								
Vegetables	Pepper	Potato	Squash	Tomato						
Fruits	Apple	Blueberry	Cherry	Grape	Orange	Peach	Raspberry	Strawberry		



¹Geetharamani G., Arun Pandian J., "Identification of plant leaf diseases using a nine-layer deep convolutional neural network", Computers & Electrical Engineering, V76, p323-338, June 2019

Method

Convolutional Neural Network



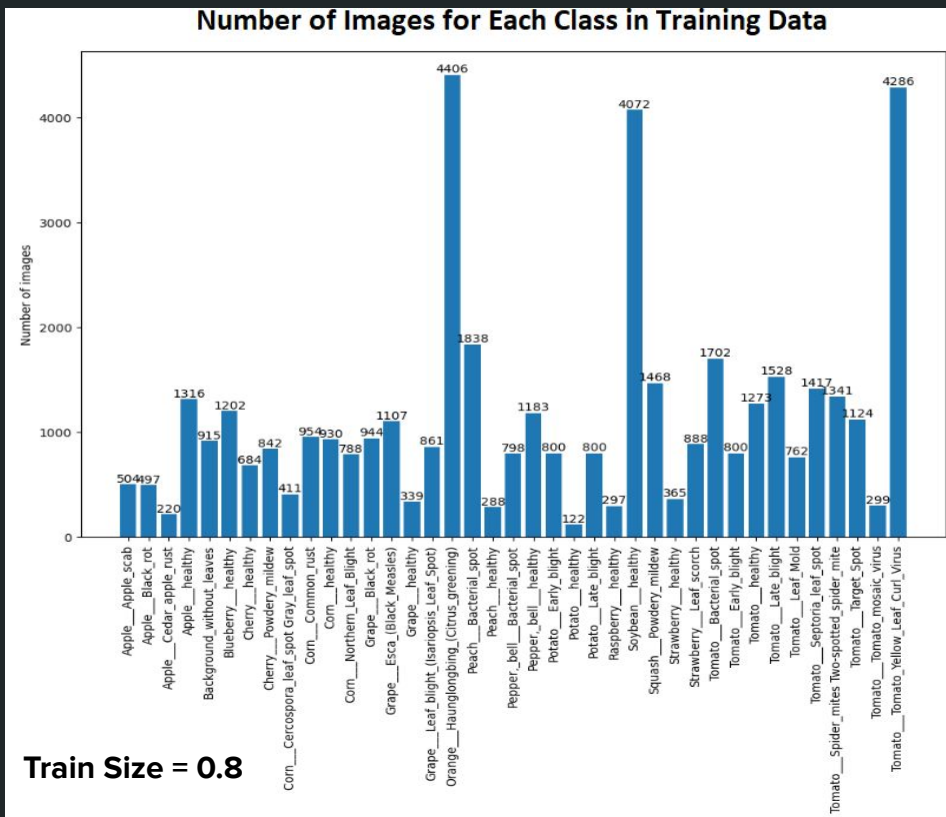
A 9-layer Structure

Data Challenges

Imbalance Class

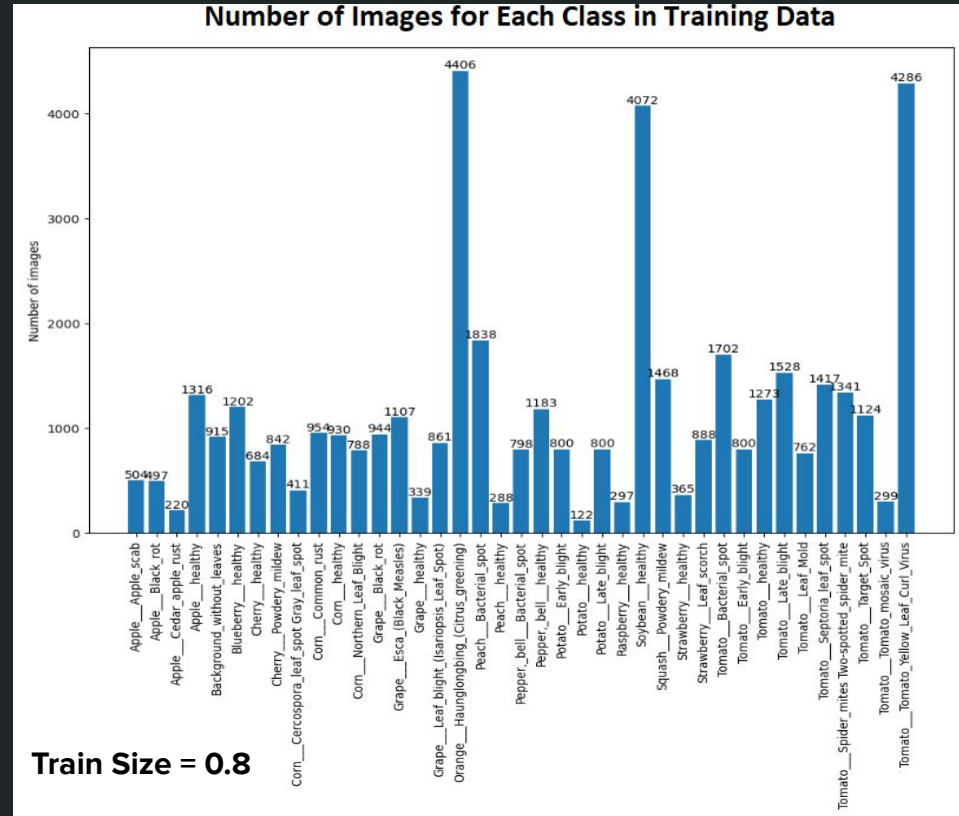
Wavy distribution

Varies from 122 to 4406



Insufficient Data

Potato_heathy only has 122 images in the training data.



Solutions

Hybrid approaches listed below:

Approaches	Upsampling (Data Augmentation*)	Data Ensembling (Bootstrapping)	Model Ensembling (Bagging)	Data Imbalanced	Class Sample Size
1	No	No	No	Yes	122-4406
2	Yes	No	No	Yes	915-4406
3	No	Yes (5 times)	Yes (5 times)	No	200
4	Yes	Yes (5 times)	Yes (5 times)	No	900

* *Data augmentation: rotating, flipping, scaling, adding noises, etc. of existing data.*

Models & Evaluation

Model Metrics

TensorFlow.Keras.Models

```
# create a model
model = Sequential()
# Add layers to the model
model.add(Conv2D(32, (3,3), 1, activation = 'relu', input_shape = (128,128,3)))
model.add(MaxPooling2D())
model.add(Conv2D(16, (3,3), 1, activation = 'relu'))
model.add(MaxPooling2D())
model.add(Conv2D(8, (3,3), 1, activation = 'relu'))
model.add(MaxPooling2D())
model.add(Flatten())
model.add(Dense(128, activation = 'relu'))
model.add(Dropout(0.2))
model.add(Dense(39, activation = 'softmax'))
# compile the model
model.compile('adam', loss = 'sparse_categorical_crossentropy', metrics = ['accuracy'])
# train the model
model.fit(train, epochs = 15, validation_data = val)
```



Model Evaluation

Models	Accuracy	Cross Entropy	Upsampling (Data Augmentation)	Data Ensembling (Bootstrapping)	Model Ensembling (Bagging)	Data Imbalanced	Class Sample Size
1	0.871	0.426	No	No	No	Yes	122-4406
2	0.858	0.452	Yes	No	No	Yes	915-4406
3	0.795*	0.853*	No	Yes (5 times)	Yes (5 times)	No	200
4	0.883*	0.460*	Yes	Yes (5 times)	Yes (5 times)	No	900

** Majority vote was used for Model 3 and Model 4*

Winner: Model 1 & Model 4

Classification Reports

Testing Data also imbalanced

Classification Reports are helpful

Upsampling + Ensembling
(Model 4)

Performs better for most classes
with less images

Except for Potato_healthy(23),
which has too less images

Model 1

Model 4

	precision	recall	f1-score	support		precision	recall	f1-score	support
0	0.80	0.65	0.72	126	0	0.69	0.80	0.74	126
1	0.77	0.85	0.81	124	1	0.80	0.85	0.83	124
2	0.74	0.36	0.49	55	2	0.71	0.64	0.67	55
3	0.74	0.88	0.80	329	3	0.80	0.79	0.79	329
4	0.91	0.89	0.90	228	4	0.92	0.89	0.90	228
5	0.92	0.89	0.90	300	5	0.90	0.94	0.92	300
6	0.91	0.79	0.84	210	6	0.91	0.95	0.93	210
7	0.87	0.88	0.87	170	7	0.84	0.92	0.88	170
8	0.58	0.66	0.61	102	8	0.67	0.54	0.60	102
9	0.97	1.00	0.98	238	9	0.95	1.00	0.97	238
10	0.87	0.65	0.75	197	10	0.80	0.86	0.83	197
11	0.97	0.98	0.98	232	11	0.97	0.99	0.98	232
12	0.88	0.84	0.86	236	12	0.83	0.92	0.87	236
13	0.93	0.92	0.93	276	13	0.95	0.91	0.93	276
14	0.93	0.94	0.94	215	14	0.95	0.96	0.96	215
15	0.94	0.80	0.86	84	15	0.92	0.92	0.92	84
16	0.97	0.98	0.98	1101	16	0.97	0.96	0.97	1101
17	0.89	0.85	0.87	459	17	0.90	0.85	0.88	459
18	0.84	0.88	0.86	72	18	0.78	0.88	0.82	72
19	0.75	0.69	0.72	199	19	0.66	0.84	0.74	199
20	0.94	0.81	0.87	295	20	0.80	0.91	0.85	295
21	0.86	0.94	0.90	200	21	0.88	0.95	0.92	200
22	0.72	0.70	0.71	200	22	0.80	0.72	0.76	200
23	0.79	0.73	0.76	30	23	0.69	0.60	0.64	30
24	0.78	0.80	0.79	74	24	0.95	0.82	0.88	74
25	0.92	0.98	0.95	1018	25	0.99	0.93	0.96	1018
26	0.89	0.93	0.91	367	26	0.93	0.96	0.95	367
27	0.90	0.81	0.85	221	27	0.92	0.84	0.88	221
28	0.92	0.86	0.89	91	28	0.87	0.90	0.89	91
29	0.91	0.87	0.89	425	29	0.90	0.83	0.86	425
30	0.65	0.46	0.53	200	30	0.53	0.67	0.59	200
31	0.78	0.65	0.71	381	31	0.75	0.76	0.75	381
32	0.81	0.64	0.71	190	32	0.77	0.75	0.76	190
33	0.59	0.81	0.68	354	33	0.81	0.70	0.75	354
34	0.81	0.90	0.85	335	34	0.89	0.84	0.87	335
35	0.81	0.83	0.82	280	35	0.83	0.84	0.84	280
36	0.94	0.97	0.96	1071	36	0.96	0.94	0.95	1071
37	0.82	0.92	0.87	74	37	0.95	0.93	0.94	74
38	0.90	0.98	0.94	318	38	0.97	0.97	0.97	318
accuracy			0.87	11077	accuracy			0.88	11077
macro avg	0.84	0.82	0.83	11077	macro avg	0.85	0.85	0.85	11077
weighted avg	0.87	0.87	0.87	11077	weighted avg	0.89	0.88	0.88	11077

Apple__Apple_scab	-82	4	0	15	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	3	4	0	0	0	3	0	0	1	0	1	3	5	0	0	0	0	1			
Apple__Black_rot	-1	106	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	4	0	0	0	2	0	0	2	0	0	2	0	0	2	0		
Apple__Cedar_apple_rust	-0	0	20	0	0	0	5	2	1	0	0	0	0	0	0	0	7	1	0	0	0	0	0	0	0	0	1	0	0	0	2	0	3	0	2	0	0	11	0	0	0			
Apple__healthy	-4	3	0	209	1	7	0	0	0	0	0	0	0	0	0	0	0	1	3	0	1	1	2	0	0	7	0	0	0	0	1	3	0	2	1	2	0	0	1	0	0			
Background_without_leaves	-0	0	0	3	203	0	0	0	1	0	4	0	0	0	0	0	0	4	0	0	0	0	0	1	0	0	0	0	3	0	0	1	7	0	0	0	0	0	1	0	0			
Blueberry__healthy	-3	2	0	10	0	266	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	3	0	1	0	3	7	2	1	0	0	0			
Cherry__healthy	-1	1	3	10	0	0	165	2	0	0	0	0	0	0	0	0	1	6	2	0	1	0	0	4	0	0	0	1	0	0	0	8	0	0	0	0	5	0	0	0				
Cherry__Powdery_mildew	-0	1	0	0	0	1	149	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	15	0	0	0	0	0	0	1	0	0	0	0			
Corn__Cercospora_leaf_spot Gray_leaf_spot	-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	67	2	13	0	0	0	1	0	0	2	0	0	0	0	0	0	11	1	0	1	0	2	0	0	0	0		
Corn__Common_rust	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Corn__healthy	-0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	45	0	129	3	0	0	0	0	0	0	0	0	0	0	0	10	3	0	0	1	2	0	0	0	0	0		
Corn__Northern_Leaf_Blight	-0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	227	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0		
Grape__Black_rot	-0	0	0	0	0	2	0	1	0	0	0	0	199	17	9	1	0	1	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	1	0	1	0	0	1	0	0	
Grape__Esca_(Black_Measles)	-0	0	0	0	0	0	0	0	0	0	0	0	17	254	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0		
Grape__healthy	-0	0	0	0	0	0	0	0	0	0	0	0	5	0	202	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0		
Grape__Leaf_blight_(Isariopsis_Leaf_Spot)	-0	0	0	0	0	0	0	3	0	0	0	0	1	0	0	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Orange__Haunglongbing_(Citrus_greening)	-0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	1	2	1	5	0	0	
Peach__Bacterial_spot	-2	3	1	11	2	0	3	2	0	0	0	0	0	0	0	0	0	4	360	1	2	1	1	5	0	0	0	0	0	0	0	8	7	5	5	6	0	0	1	0	0	0		
Peach__healthy	-0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0	2	0	0	0
Pepper__bell__Bacterial_spot	-1	5	0	0	0	1	0	2	0	0	0	0	1	0	0	2	3	0	138	7	2	2	0	2	3	0	0	0	0	0	0	1	3	20	2	2	1	1	0	0	0	0		
Pepper__bell__healthy	-0	0	0	0	0	3	1	5	0	0	0	0	0	0	0	0	0	0	8	239	0	0	1	7	21	0	0	0	0	0	0	1	1	0	6	0	2	0	0	0	0	0		
Potato__Early_blight	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	189	1	0	0	2	0	0	0	0	0	0	0	3	0	4	0	0	0	0	0	0	0	0		
Potato__Late_blight	-2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	5	0	2	141	1	0	3	1	2	1	1	2	6	0	16	1	5	0	0	1	0	0		
Potato__healthy	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	22	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Raspberry__healthy	-0	2	0	0	0	1	0	0	0	0	0	2	0	0	0	0	1	0	2	1	0	0	1	59	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	0
Soybean__healthy	-0	0	0	5	1	1	0	4	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	1	0	0
Squash__Powdery_mildew	-0	0	0	1	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	342	2	0	3	0	3	0	4	0	0	1	0	5	0	0		
Strawberry__healthy	-0	0	0	0	9	0	0	0	0	0	1	0	0	0	2	0	0	1	0	0	0	2	0	0	0	0	0	11	180	2	0	0	4	1	8	0	0	0	0	0	0	0		
Strawberry__Leaf_scorch	-1	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	2	76	0	0	0	0	0	2	0	0	0	0	0		
Tomato__Bacterial_spot	-1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1	3	0	0	6	1	2	0	0	365	0	3	0	15	1	2	15	0	1	0		
Tomato__Early_blight	-0	1	0	10	1	0	0	0	0	0	0	0	0	0	0	0	0	1	10	2	8	0	2	3	0	0	1	0	0	0	0	0	1	91	11	0	19	12	15	11	1	0	0	
Tomato__healthy	-0	2	1	7	2	0	3	0	0	5	2	1	2	1	1	0	0	4	3	6	2	6	13	0	3	1	3	4	0	0	16	266	3	28	3	1	4	0	8	0	0	0		
Tomato__Late_blight	-1	1	0	11	0	2	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	0	0	0	2	0	0	0	0	0	4	0	121	26	11	1	0	1	1	0	1			
Tomato__Leaf_Mold	-0	5	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	3	1	0	1	0	5	3	1	1	2	2	1	7	6	2	8	285	6	2	0	4	3	0	0			
Tomato__Septoria_leaf_spot	-0	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	1	1	0	0	2	300	16	2	3	2	0			
Tomato__Spider_mites Two-spotted_spider_mite	-1	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	3	0	0	0	0	1	0	0	5	14	233	0	2	13	0			
Tomato__Target_Spot	-0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	2	0	0	2	0	0	1	0	0	0	5	3	0	0	1	9	0	104	1	0	0		
Tomato__Tomato_mosaic_virus	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	68	0		
Tomato__Tomato_Yellow_Leaf_Curl_Virus	-0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	0	

Confusion Matrix

Model 1

Misclassification within
the same species

Apple__Apple_scab	-101	3	2	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	0	1	0	0	0	2	0	0	1	0	1	1	2	0	0	0	0	0					
Apple__Black_rot	-1	106	0	7	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0					
Apple__Cedar_apple_rust	-0	0	35	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	3	0				
Apple__healthy	-15	6	0	259	0	13	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	4	5	0	3	0	0	0	0	0	0	5	1	5	2	1	3	0	0	0				
Background_without_leaves	-2	0	0	203	0	0	0	0	1	0	7	1	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	1	0	2	0	0	2	2	1	0	0	0	0	0	0			
Blueberry__healthy	-0	0	0	5	0	263	0	2	0	0	0	0	0	0	0	0	0	0	1	3	2	0	0	0	0	0	1	0	0	1	0	0	0	0	2	0	0	0	0	0	0			
Cherry__healthy	-1	0	1	1	0	0	200	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0			
Cherry__Powdery_mildew	-0	2	0	0	0	0	0	157	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6	0	0	0	0	3	0	0	0	0	0	1	0	0	0	0	0	0	0			
Corn__Cercospora_leaf_spot Gray_leaf_spot	-0	0	0	0	1	0	0	0	55	6	33	6	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Corn__Common_rust	-0	0	0	0	0	0	0	0	0	257	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Corn__healthy	-0	0	0	0	2	0	0	0	16	0	169	1	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0		
Corn__Northern_Leaf_Blight	-0	0	0	0	0	0	0	0	1	0	0	230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0		
Grape__Black_rot	-0	0	0	0	0	0	0	0	0	0	0	0	0	216	11	3	1	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	2	0	1	0	0	0	0	0	0	0		
Grape__Esca_(Black_Measles)	-0	0	0	0	0	0	0	0	0	0	0	0	0	19	252	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0		
Grape__healthy	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Grape__Leaf_blight_(Isariopsis_Leaf_Spot)	-1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	77	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	
Orange__Haunglongbing_(Citrus_greening)	-2	0	1	2	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	0	2	3	1	0	6	0	0		
Peach__Bacterial_spot	-9	0	3	4	5	2	0	0	0	0	0	0	0	0	0	0	0	0	2	36	2	8	7	1	0	0	0	0	1	0	3	4	12	3	3	0	0	1	0	0	0	0		
Peach__healthy	-0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	63	2	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0		
Pepper__bell__Bacterial_spot	-1	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	167	10	2	1	0	0	0	0	0	0	0	2	5	1	1	0	0	0	0	0	0		
Pepper__bell__healthy	-0	2	0	0	0	1	1	6	0	0	0	0	0	0	0	0	0	0	0	0	0	11	269	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Potato__Early_blight	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	191	3	0	0	1	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0		
Potato__Late_blight	-6	0	0	2	0	0	4	0	0	0	0	0	3	1	0	1	0	0	0	6	1	4	144	5	0	0	0	1	2	0	5	11	0	4	0	0	0	0	0	0	0	0		
Potato__healthy	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	4	18	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Raspberry__healthy	-0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	4	5	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0		
Soybean__healthy	-2	3	0	9	1	1	0	13	0	0	0	0	0	0	0	0	0	2	0	1	2	26	0	0	2	0	0	0	0	0	0	0	0	0	3	0	0	1	2	2	1	1	1	0
Squash__Powdery_mildew	-0	0	0	0	0	0	0	2	0	0	5	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	
Strawberry__healthy	-0	0	0	7	0	0	0	3	0	2	0	1	0	3	0	0	0	0	1	0	0	1	0	0	0	0	0	9	195	3	0	0	1	0	4	0	0	0	0	0	0	0	0	
Strawberry__Leaf_scorch	-2	2	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Bacterial_spot	-2	0	1	3	0	0	2	0	0	0	0	5	0	2	0	5	3	0	1	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Early_blight	-0	0	0	7	1	0	0	0	1	0	0	0	1	0	0	0	1	3	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__healthy	-0	0	4	2	1	0	1	0	2	7	1	0	1	2	1	1	1	3	0	5	6	8	0	0	0	1	5	0	1	29	200	5	4	0	1	0	0	0	0	0	0	0	0	
Tomato__Late_blight	-0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	5	4	143	17	6	0	1	0	0	0		
Tomato__Leaf_Mold	-2	5	0	1	0	3	0	5	0	0	0	0	2	0	0	1	2	7	4	3	1	7	7	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Septoria_leaf_spot	-0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Spider_mites Two-spotted_spider_mite	-0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Target_Spot	-0	0	1	5	0	0	0	0	0	0	0	0	2	0	0	0	9	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Tomato_mosaic_virus	-0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Tomato_Yellow_Leaf_Curl_Virus	-0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Confusion Matrix

Model 4

Misclassification within
the same species

Apple__Apple_scab	-82	4	0	15	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	1	0	3	4	0	0	0	3	0	0	1	0	1	3	5	0	0	0	0	1	
Apple__Black_rot	-1	105	0	3	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	4	0	0	0	0	2	0	0	2	0	0	0	2	0	
Apple__Cedar_apple_rust	-0	0	20	0	0	0	5	2	1	0	0	0	0	0	0	0	7	1	0	0	0	0	0	0	0	0	1	0	0	0	2	0	3	0	2	0	0	11	0	0		
Apple__healthy	-4	3	0	209	1	7	0	0	0	0	0	0	0	0	0	0	0	1	3	0	1	1	2	0	0	7	0	0	0	0	1	3	0	2	1	2	0	0	1			
Background_without_leaves	-0	0	0	3	203	0	0	0	1	0	4	0	0	0	0	0	4	0	0	0	0	0	0	1	0	0	0	0	0	0	3	0	0	1	7	0	0	0	1	0		
Blueberry__healthy	-3	2	0	10	0	266	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	3	0	1	0	3	7	2	1	0	0	
Cherry__healthy	-1	1	3	10	0	0	165	2	0	0	0	0	0	0	0	0	1	6	2	0	1	0	0	4	0	0	0	1	0	0	0	0	8	0	0	0	0	5	0	0		
Cherry__Powdery_mildew	-0	1	0	0	0	1	149	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	15	0	0	0	0	0	1	0	0	0	0	
Corn__Cercospora_leaf_spot Gray_leaf_spot	-2	0	0	0	0	0	0	67	2	13	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	11	1	0	1	0	2	0	0	0	0	0	0	
Corn__Common_rust	-0	0	0	0	0	0	0	0	237	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Corn__healthy	-0	0	0	0	1	0	0	0	45	0	129	3	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	10	3	0	0	1	2	0	0	0	0	0	0	
Corn__Northern_Leaf_Blight	-0	0	0	0	3	0	0	0	0	0	227	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Grape__Black_rot	-0	0	0	0	0	2	0	1	0	0	0	199	17	9	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	1	0	1	0	1	0	0	1	0	0
Grape__Esca_(Black_Measles)	-0	0	0	0	0	0	0	0	0	0	0	17	254	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Grape__healthy	-0	0	0	0	0	0	0	0	0	0	0	5	0	202	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Grape__Leaf_blight_(Isariopsis_Leaf_Spot)	-0	0	0	0	0	0	3	0	0	0	0	1	0	0	67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Orange__Haunglongbing_(Citrus_greening)	-0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Peach__Bacterial_spot	-2	3	1	11	2	0	3	2	0	0	0	0	0	0	0	0	4	369	1	2	1	1	5	0	0	0	0	0	0	0	8	7	5	5	6	0	0	1	0	0	0	
Peach__healthy	-0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	68	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Pepper__bell__Bacterial_spot	-1	5	0	0	0	1	0	2	0	0	0	0	0	0	0	1	0	2	3	0	138	7	2	2	0	2	3	0	0	0	0	0	1	3	20	2	2	1	1	0	0	
Pepper__bell__healthy	-0	0	0	0	0	3	1	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	239	0	0	1	7	21	0	0	0	0	0	0	0	0	0	0	0	0
Potato__Early_blight	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	189	1	0	0	2	0	0	0	0	0	0	0	3	0	4	0	0	0
Potato__Late_blight	-2	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	5	0	2	141	1	0	3	1	2	1	1	2	6	0	16	1	5	0	0	1			
Potato__healthy	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	5	22	0	2	0	0	0	0	0	0	0	0	0	0	
Raspberry__healthy	-0	2	0	0	0	1	0	0	0	0	2	0	0	0	0	0	1	0	2	1	0	0	1	59	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Soybean__healthy	-0	0	0	5	1	1	0	4	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Squash__Powdery_mildew	-0	0	0	1	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	342	2	0	3	0	3	0	4	0	0	1	0	5
Strawberry__healthy	-0	0	0	0	9	0	0	0	0	0	1	0	0	0	2	0	1	0	0	0	0	2	0	0	0	0	0	0	11	180	2	0	0	4	1	8	0	0	0	0	0	
Strawberry__Leaf_scorch	-1	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	2	0	2	76	0	0	0	0	0	0	0	
Tomato__Bacterial_spot	-1	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	3	0	0	6	1	2	0	356	0	3	0	15	1	2	15	0	1	
Tomato__Early_blight	-0	1	0	10	1	0	0	0	0	0	0	0	0	0	0	0	0	1	10	2	8	0	2	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__healthy	-0	2	1	7	2	0	3	0	0	5	2	1	2	1	1	0	4	3	6	2	6	13	0	3	1	3	4	0	0	18	506	3	28	3	1	4	0	8	0	0		
Tomato__Late_blight	-1	1	0	11	0	2	0	0	0	0	0	0	0	0	0	0	0	2	2	1	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Leaf_Mold	-0	5	0	1	0	1	1	0	1	0	0	0	0	0	0	0	0	3	1	0	1	0	5	3	1	1	2	2	2	1	7	6	2	8	285	6	2	0	4	3	0	
Tomato__Septoria_leaf_spot	-0	0	0	2	0	3	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Spider_mites Two-spotted_spider_mite	-1	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Target_Spot	-0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1	0	2	0	0	2	0	0	1	0	0	0	5	3	0	0	1	9	0	104	1	0	0	
Tomato__Tomato_mosaic_virus	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Tomato__Tomato_Yellow_Leaf_Curl_Virus	-0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Confusion Matrix

Model 1

Misclassification within
the same species

Apple__Apple_scab	-101	3	2	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	2	0	1	1	0	0	0	2	0	0	1	0	1	1	2	0	0	0	0	0					
Apple__Black_rot	-1	106	0	7	0	1	0	3	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0	0					
Apple__Cedar_apple_rust	-0	0	35	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	3	2	1	0	0	0	0	3	0	0				
Apple__healthy	-15	6	0	259	0	13	0	0	0	0	0	0	0	0	0	0	0	0	2	5	4	5	0	3	0	0	0	0	0	0	0	0	5	1	5	2	1	3	0	0	0	0				
Background_without_leaves	-2	0	0	2	203	0	0	0	1	0	7	1	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	1	0	2	0	0	2	2	1	0	0	0	0	0	0	0				
Blueberry__healthy	-0	0	5	0	263	0	2	0	0	0	0	0	0	0	0	0	0	0	1	3	2	0	0	0	0	1	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0				
Cherry__healthy	-1	0	1	1	0	0	200	0	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0				
Cherry__Powdery_mildew	-0	2	0	0	0	0	157	0	0	0	0	0	0	0	0	0	0	1	0	0	0	6	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0			
Corn__Cercospora_leaf_spot Gray_leaf_spot	-0	0	0	0	1	0	0	0	55	6	33	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	5	1	0	0	0	0	0	0	0	0	0	0	0	0	0		
Corn__Common_rust	-0	0	0	0	0	0	0	0	237	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Corn__healthy	-0	0	0	0	2	0	0	0	16	0	169	1	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0		
Corn__Northern_Leaf_Blight	-0	0	0	0	0	0	0	1	0	0	236	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0		
Grape__Black_rot	-0	0	0	0	0	0	0	0	0	0	0	216	11	3	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0		
Grape__Esca_(Black_Measles)	-0	0	0	0	0	0	0	0	0	0	0	19	252	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0		
Grape__healthy	-0	0	0	0	0	0	0	0	0	0	0	6	0	297	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Grape__Leaf_blight_(Isariopsis_Leaf_Spot)	-1	0	0	0	0	0	0	0	0	0	0	1	0	0	77	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0		
Orange__Haunglongbing_(Citrus_greening)	-2	0	1	2	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	65	3	0	9	0	0	2	0	0	0	0	0	0	1	2	0	2	3	1	0	6	0	0			
Peach__Bacterial_spot	-9	0	3	4	5	2	0	0	0	0	0	0	0	0	0	0	0	0	2	36	2	8	7	1	0	0	0	0	0	0	0	1	0	3	4	12	3	3	0	0	1	0	0			
Peach__healthy	-0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2	63	2	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0			
Pepper__bell__Bacterial_spot	-1	3	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	2	3	0	167	10	2	1	0	0	0	0	0	0	0	2	5	1	1	0	0	0	0	0	0	0			
Pepper__bell__healthy	-0	2	0	0	0	1	1	6	0	0	0	0	0	0	0	0	0	0	0	11	269	0	0	0	0	0	1	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Potato__Early_blight	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	191	3	0	0	1	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0			
Potato__Late_blight	-6	0	0	2	0	0	4	0	0	0	0	3	1	0	1	0	0	0	6	1	4	144	5	0	0	0	1	2	0	5	11	0	4	0	0	0	0	0	0	0	0	0	0			
Potato__healthy	-0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	1	4	18	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Raspberry__healthy	-0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	4	5	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	1	0	0	0				
Soybean__healthy	-2	3	0	9	1	1	0	13	0	0	0	0	0	0	0	0	0	0	2	0	0	1	2	26	0	0	2	0	0	0	0	0	0	0	0	0	3	0	0	1	2	2	1	1	0	0
Squash__Powdery_mildew	-0	0	0	0	0	0	0	2	0	0	5	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	2			
Strawberry__healthy	-0	0	0	0	7	0	0	3	0	2	0	1	0	3	0	0	0	0	1	0	0	1	0	0	0	9	195	3	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	
Strawberry__Leaf_scorch	-2	2	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Tomato__Bacterial_spot	-2	0	1	3	0	0	2	0	0	0	0	5	0	2	0	5	3	0	1	0	0	2	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Tomato__Early_blight	-0	0	0	7	1	0	0	0	1	0	0	0	0	0	0	0	0	0	1	3	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		
Tomato__healthy	-0	0	4	2	1	0	1	0	2	7	1	0	1	2	1	1	1	3	0	5	6	8	0	0	0	1	5	0	1	29	0	0	0	5	4	0	1	0	0	0	0	0	0			
Tomato__Late_blight	-0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Tomato__Leaf_Mold	-2	5	0	1	0	3	0	5	0	0	0	0	2	0	0	1	2	7	4	3	1	7	7	1	1	0	0	7	0	3	15	7	14	248	0	4	1	2	1	0	0	0				
Tomato__Septoria_leaf_spot	-0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Tomato__Spider_mites Two-spotted_spider_mite	-0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	0	0	1	0	0	0	2	7	3	0	2	13	236	0	0	0	0	0	0				
Tomato__Target_Spot	-0	0	1	5	0	0	0	0	0	0	0	0	2	0	0	0	9	3	0	3	0	0	0	0	0	0	0	2	0	0	15	11	2	2	0	30	0	0	0	0	0	0				
Tomato__Tomato_mosaic_virus	-0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			
Tomato__Tomato_Yellow_Leaf_Curl_Virus	-0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0			

Confusion Matrix

Model 4

Misclassification within
the same species

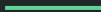
Takeaways

- Simple CNN model works well
- Image quality and quantity are key
- Bootstrapping and bagging help improve model performance



Next Steps

- Collect more data
- Find sweet spot for Bootstrapping sample size
- Is 5-time ensemble a good number
- Hyper-parameter tuning for CNN
- Reduce cost: gray scale?



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