1. Data import and device

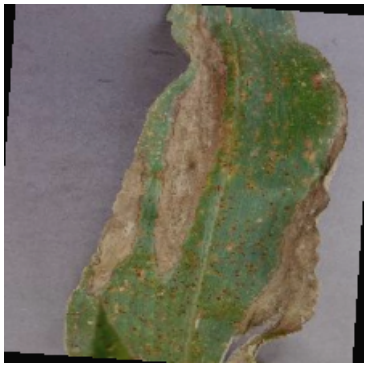
```
Drive already mounted at /content/drive; to attempt to forcibly remount, call drive.mount("/content/drive", force_remo
unt=True).
```

2.Data visualization

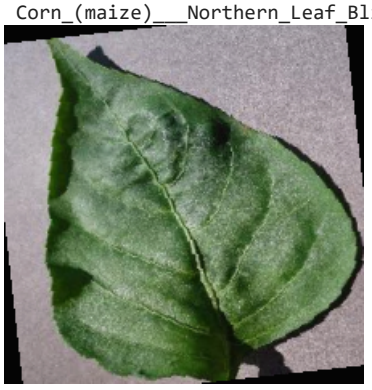
show image amount, show class amount,and batch size

```
Total images: 35725  |  Train: 28580  Val: 7145
Num classes: 23
Classes: ['Apple___Apple_scab', 'Apple___Black_rot', 'Apple___Cedar_apple_rust', 'Apple___healthy', 'Corn_(maize)___Ce
rcospora_leaf_spot Gray_leaf_spot', 'Corn_(maize)___Common_rust_', 'Corn_(maize)___Northern_Leaf_Blight', 'Corn_(maiz
e)___healthy', 'Pepper__bell___Bacterial_spot', 'Pepper__bell___healthy', 'Potato___Early_blight', 'Potato___Late_blig
ht', 'Potato___healthy', 'Tomato_Bacterial_spot', 'Tomato_Early_blight', 'Tomato_Late_blight', 'Tomato_Leaf_Mold', 'To
mato_Septoria_leaf_spot', 'Tomato_Spider_mites_Two_spotted_spider_mite', 'Tomato__Target_Spot', 'Tomato__Tomato_Yellow
Leaf__Curl_Virus', 'Tomato__Tomato_mosaic_virus', 'Tomato_healthy']
Batch: torch.Size([256, 3, 224, 224]) torch.Size([256])
```

Display the first 10 images from the dataset.



Corn_(maize)___Northern_Leaf_Blight



Pepper__bell___healthy

Apple___Cedar_apple_rust

Tomato__Tomato_YellowLeaf__Curl_Virus

Corn_(maize)___healthy

Tomato__Tomato_YellowLeaf__Curl_Virus

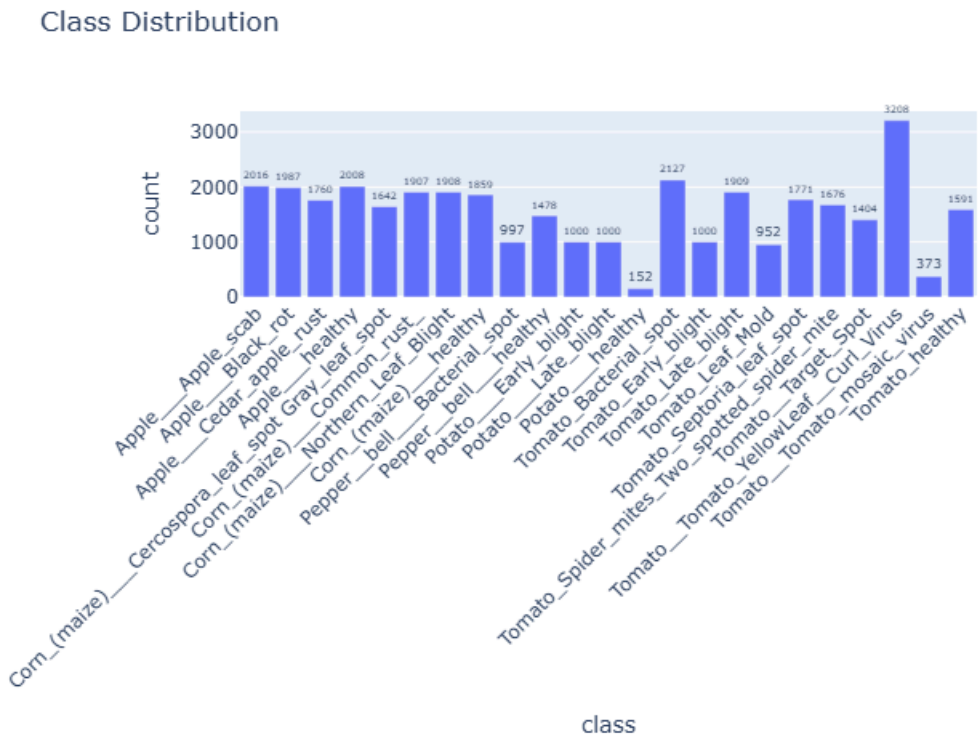
Tomato_Early_blight

```
Apple___healthy
```

```
Corn_(maize)___Cercospora_leaf_spot Gray_leaf_spot
```

Count images per class to check class balance.

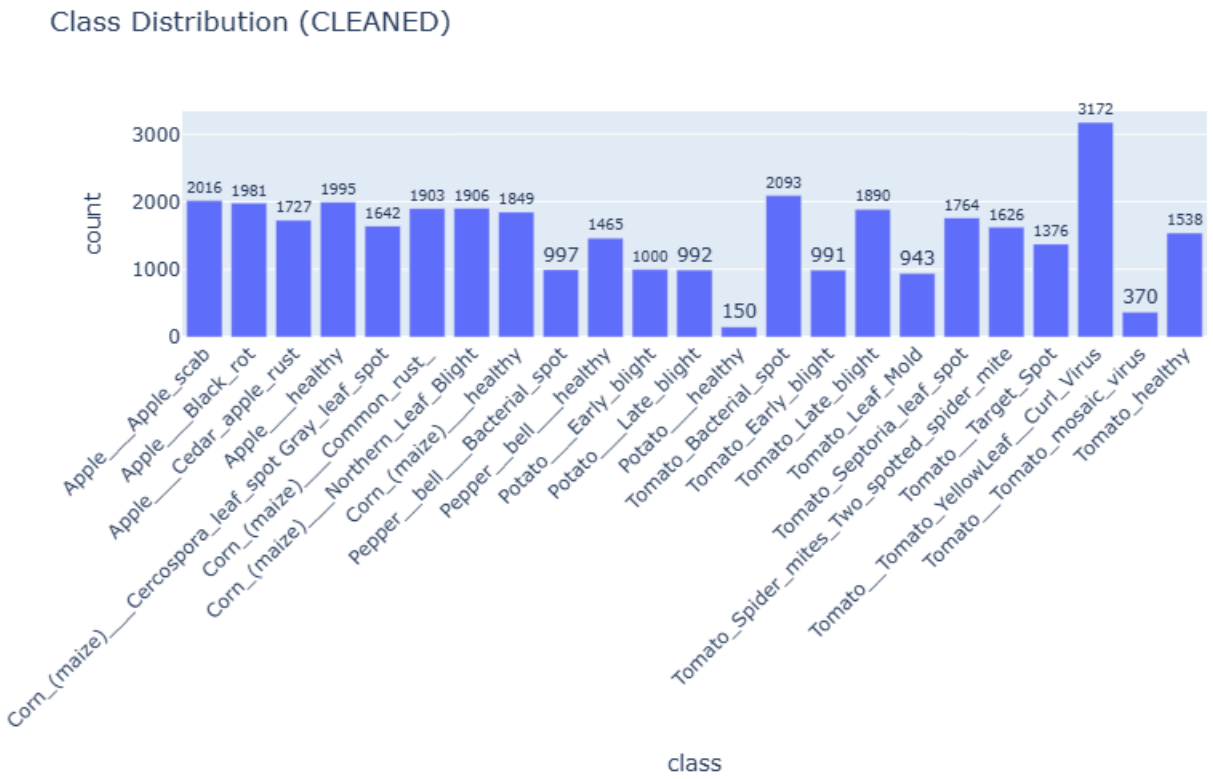
```
Counter({'Tomato__Tomato_YellowLeaf__Curl_Virus': 3208, 'Tomato_Bacterial_spot': 2127, 'Apple___Apple_scab': 2016, 'Apple___healthy': 2008, 'Apple___Black_rot': 1987, 'Tomato_Late_blight': 1909, 'Corn_(maize)___Northern_Leaf_Blight': 1908, 'Corn_(maize)___Common_rust_': 1907, 'Corn_(maize)___healthy': 1859, 'Tomato_Septoria_leaf_spot': 1771, 'Apple___Cedar_apple_rust': 1760, 'Tomato_Spider_mites_Two_spotted_spider_mite': 1676, 'Corn_(maize)___Cercospora_leaf_spot Gray_leaf_spot': 1642, 'Tomato_healthy': 1591, 'Pepper__bell___healthy': 1478, 'Tomato__Target_Spot': 1404, 'Potato___Early_blight': 1000, 'Potato___Late_blight': 1000, 'Tomato_Early_blight': 1000, 'Pepper__bell___Bacterial_spot': 997, 'Tomato_Leaf_Mold': 952, 'Tomato__Tomato_mosaic_virus': 373, 'Potato___healthy': 152})
```



3. Data cleaning

```
Scanning: 100%|██████████| 35725/35725 [00:55<00:00, 642.42it/s]
=== Clean Summary ===
{'total_found': 35725, 'copied': 35386, 'skipped_unreadable': 0, 'skipped_too_small': 0, 'skipped_other': 339, 'by_cla
ss': {'Apple___Apple_scab': 2016, 'Apple___Black_rot': 1981, 'Apple___Cedar_apple_rust': 1727, 'Apple___healthy': 199
5, 'Corn_(maize)___Cercospora_leaf_spot Gray_leaf_spot': 1642, 'Corn_(maize)___Common_rust_': 1903, 'Corn_(maize)___No
rthern_Leaf_Blight': 1906, 'Corn_(maize)___healthy': 1849, 'Pepper__bell___Bacterial_spot': 997, 'Pepper__bell___healt
hy': 1465, 'Potato___Early_blight': 1000, 'Potato___Late_blight': 992, 'Potato___healthy': 150, 'Tomato_Bacterial_spo
t': 2093, 'Tomato_Early_blight': 991, 'Tomato_Late_blight': 1890, 'Tomato_Leaf_Mold': 943, 'Tomato_Septoria_leaf_spo
t': 1764, 'Tomato_Spider_mites_Two_spotted_spider_mite': 1626, 'Tomato__Target_Spot': 1376, 'Tomato__Tomato_YellowLeaf
__Curl_Virus': 3172, 'Tomato__Tomato_mosaic_virus': 370, 'Tomato_healthy': 1538}}
Unreadable: 0 | Too small: 0 | Dup(same class): 179 | Dup(cross class): 160
```

```
-- unreadable (showing up to 5) --

-- too_small (showing up to 5) --

-- dup_same_class (showing up to 5) --
('Apple___Black_rot', '/content/Dataset/Apple___Black_rot/769283e3-f7ec-4e62-b907-4b22d1bda1ea___JR_FrgE.S 8618.JPG',
'/content/Dataset/Apple___Black_rot/68566f26-8158-4fd5-9c5f-0a29eec5225a___JR_FrgE.S 8746.JPG')
('Apple___Black_rot', '/content/Dataset/Apple___Black_rot/6f38c615-281d-4bf5-8d92-7c02d3ef9e1b___JR_FrgE.S 8753_270de
g.JPG', '/content/Dataset/Apple___Black_rot/4db50338-6897-4d69-8147-717cae13879c___JR_FrgE.S 8645_270deg.JPG')
('Apple___Black_rot', '/content/Dataset/Apple___Black_rot/3d33710d-c091-4dae-a491-ef813ea2d34b___JR_FrgE.S 2885_90deg.
JPG', '/content/Dataset/Apple___Black_rot/977c9b03-47f2-412d-a73d-7e647e973336___JR_FrgE.S 2887_90deg.JPG')
('Apple___Black_rot', '/content/Dataset/Apple___Black_rot/68566f26-8158-4fd5-9c5f-0a29eec5225a___JR_FrgE.S 8746_270de
g.JPG', '/content/Dataset/Apple___Black_rot/769283e3-f7ec-4e62-b907-4b22d1bda1ea___JR_FrgE.S 8618_270deg.JPG')
('Apple___Black_rot', '/content/Dataset/Apple___Black_rot/b371e9c4-177b-4bfb-9430-e14f9f30a06d___JR_FrgE.S 2803_new30d
egFlipLR.JPG', '/content/Dataset/Apple___Black_rot/f3bbe1b6-4a5c-45d4-9660-d24b8c43f2fc___JR_FrgE.S 2806_new30degFlipL
R.JPG')

-- dup_cross_class (showing up to 5) --
('Apple___Black_rot', '/content/Dataset/Apple___Black_rot/65e6c212-6363-4ba2-8245-52c5266efad0___JR_FrgE.S 8625_90deg.
JPG', 'Apple___Apple_scab', '/content/Dataset/Apple___Apple_scab/e8f5c962-6f40-443e-9913-5a43b5f2ef07___FREC_Scab 319
1.JPG')
('Apple___healthy', '/content/Dataset/Apple___healthy/2b21526f-9ab0-444b-829a-fa97cd727733___RS_HL 7844.JPG', 'Apple__
_Cedar_apple_rust', '/content/Dataset/Apple___Cedar_apple_rust/85f1b51d-ad5e-4ec2-a46b-2a9dade22e2a___FREC_C.Rust 9971
_newGRR.JPG')
('Corn_(maize)___healthy', '/content/Dataset/Corn_(maize)___healthy/515cfd7f-995c-4843-93f7-dc2c012db476___R.S_HL 7877
copy 2_flipLR.jpg', 'Apple___healthy', '/content/Dataset/Apple___healthy/d76e79e5-2cd5-4a03-9354-5759b2741210___RS_HL
7980.JPG')
('Corn_(maize)___healthy', '/content/Dataset/Corn_(maize)___healthy/5a2800a4-15ed-43a5-864d-01d16d37ed67___R.S_HL 8219
copy.jpg', 'Apple___Cedar_apple_rust', '/content/Dataset/Apple___Cedar_apple_rust/d4547913-b1ce-4620-b078-dbf24ea71764
___FREC_C.Rust 4197_newGRR.JPG')
('Corn_(maize)___healthy', '/content/Dataset/Corn_(maize)___healthy/ab90a3d7-ab29-4efe-a5f1-b9817b09d4e2___R.S_HL 5541
copy 2_flipLR.jpg', 'Apple___Cedar_apple_rust', '/content/Dataset/Apple___Cedar_apple_rust/57a522fe-b1f4-47e0-9b4c-b30
635b402f7___FREC_C.Rust 4226_90deg.JPG')
```



```
Total after cleaning: 35386

Class order: {'Apple___Apple_scab': 0, 'Apple___Black_rot': 1, 'Apple___Cedar_apple_rust': 2, 'Apple___healthy': 3, 'C
orn_(maize)___Cercospora_leaf_spot Gray_leaf_spot': 4, 'Corn_(maize)___Common_rust_': 5, 'Corn_(maize)___Northern_Leaf
_Blight': 6, 'Corn_(maize)___healthy': 7, 'Pepper__bell___Bacterial_spot': 8, 'Pepper__bell___healthy': 9, 'Potato___E
arly_blight': 10, 'Potato___Late_blight': 11, 'Potato___healthy': 12, 'Tomato_Bacterial_spot': 13, 'Tomato_Early_bligh
t': 14, 'Tomato_Late_blight': 15, 'Tomato_Leaf_Mold': 16, 'Tomato_Septoria_leaf_spot': 17, 'Tomato_Spider_mites_Two_sp
otted_spider_mite': 18, 'Tomato__Target_Spot': 19, 'Tomato__Tomato_YellowLeaf__Curl_Virus': 20, 'Tomato__Tomato_mosaic
_virus': 21, 'Tomato_healthy': 22}
Counts: [2016 1981 1727 1995 1642 1903 1906 1849  997 1465 1000  992  150 2093
  991 1890  943 1764 1626 1376 3172  370 1538] | imbalance ratio (max/min): 21.147
USE_SAMPLER = True
RandAugment enabled.

CLEAN train batch: torch.Size([256, 3, 224, 224]) | y type: <class 'torch.Tensor'>
```

4. Model and comparison model

ResNet50

EfficientNetB0

Our own 20-layer CNN Model

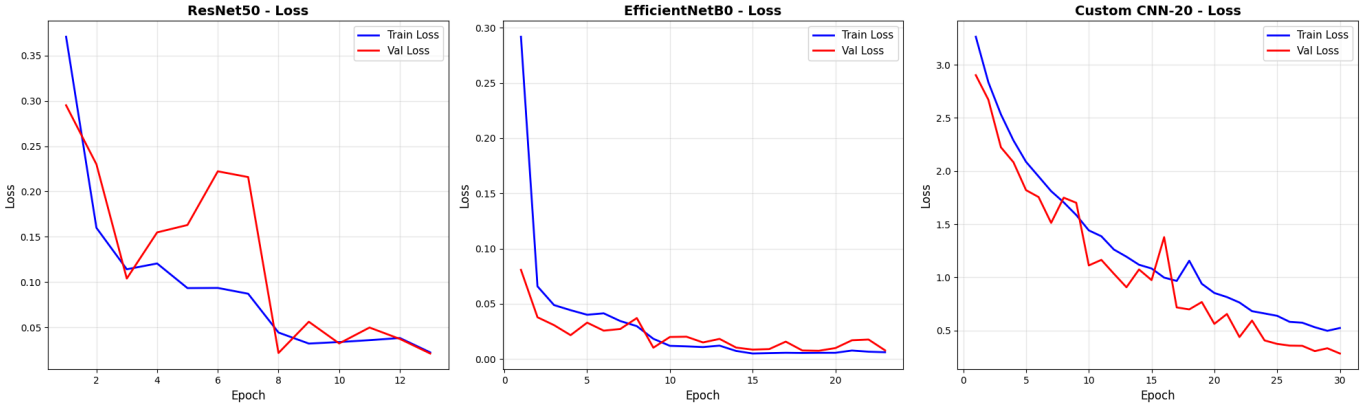
5. Model training

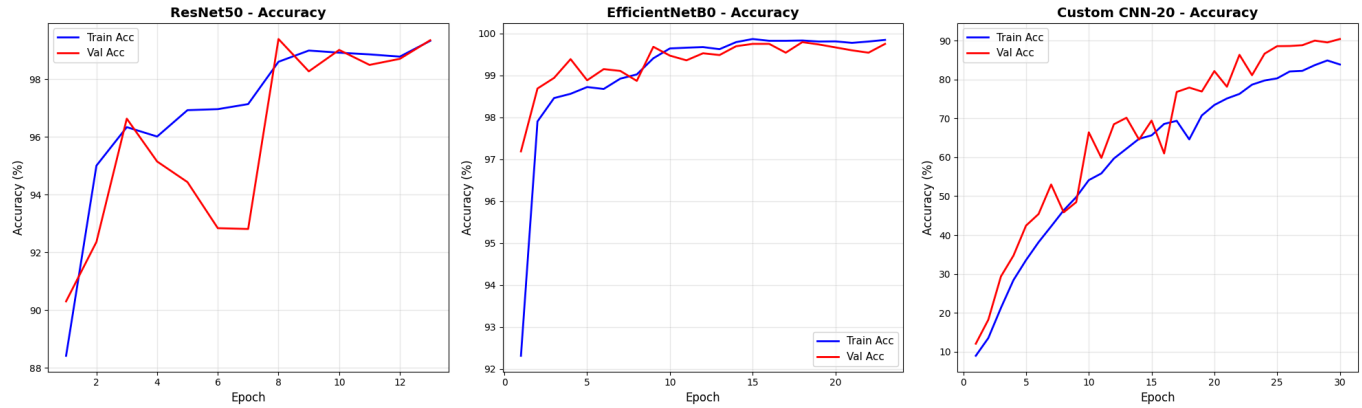
```
Training on: cuda

✓ CUDA cache cleared
✓ Data loaders recreated successfully
  Train samples: 28580
  Val samples: 7145
  Classes: 23
```

```
======================================================================
TRAINING RESNET50
======================================================================
Downloading: "https://download.pytorch.org/models/resnet50-0676ba61.pth" to /root/.cache/torch/hub/checkpoints/resnet5
0-0676ba61.pth
100%|██████████| 97.8M/97.8M [00:00<00:00, 246MB/s]
Starting training for resnet50...
----------------------------------------------------------------------
Epoch  1/30 | Train Loss: 0.3706 Acc:  88.41% | Val Loss: 0.2950 Acc:  90.30% ✓ [Best: 90.30%]
Epoch  2/30 | Train Loss: 0.1599 Acc:  95.00% | Val Loss: 0.2300 Acc:  92.36% ✓ [Best: 92.36%]
Epoch  3/30 | Train Loss: 0.1142 Acc:  96.33% | Val Loss: 0.1040 Acc:  96.63% ✓ [Best: 96.63%]
Epoch  4/30 | Train Loss: 0.1206 Acc:  96.01% | Val Loss: 0.1549 Acc:  95.14%
Epoch  5/30 | Train Loss: 0.0934 Acc:  96.92% | Val Loss: 0.1630 Acc:  94.43%
Epoch  6/30 | Train Loss: 0.0936 Acc:  96.96% | Val Loss: 0.2222 Acc:  92.83%
Epoch  7/30 | Train Loss: 0.0872 Acc:  97.13% | Val Loss: 0.2159 Acc:  92.81%
Epoch  8/30 | Train Loss: 0.0444 Acc:  98.60% | Val Loss: 0.0219 Acc:  99.38% ✓ [Best: 99.38%]
Epoch  9/30 | Train Loss: 0.0323 Acc:  98.99% | Val Loss: 0.0563 Acc:  98.26%
Epoch 10/30 | Train Loss: 0.0339 Acc:  98.91% | Val Loss: 0.0324 Acc:  99.01%
Epoch 11/30 | Train Loss: 0.0360 Acc:  98.85% | Val Loss: 0.0499 Acc:  98.49%
Epoch 12/30 | Train Loss: 0.0384 Acc:  98.78% | Val Loss: 0.0374 Acc:  98.70%
Epoch 13/30 | Train Loss: 0.0225 Acc:  99.32% | Val Loss: 0.0213 Acc:  99.34%

Early stopping at epoch 13
Best validation accuracy: 99.38% (epoch 8)

Training complete! Best model saved as 'best_resnet50.pth'
----------------------------------------------------------------------

======================================================================
TRAINING EFFICIENTNETB0
======================================================================
Downloading: "https://download.pytorch.org/models/efficientnet_b0_rwightman-7f5810bc.pth" to /root/.cache/torch/hub/ch
eckpoints/efficientnet_b0_rwightman-7f5810bc.pth
100%|██████████| 20.5M/20.5M [00:00<00:00, 226MB/s]
Starting training for efficientnet_b0...
----------------------------------------------------------------------
Epoch  1/30 | Train Loss: 0.2919 Acc:  92.32% | Val Loss: 0.0807 Acc:  97.19% ✓ [Best: 97.19%]
Epoch  2/30 | Train Loss: 0.0658 Acc:  97.90% | Val Loss: 0.0378 Acc:  98.68% ✓ [Best: 98.68%]
Epoch  3/30 | Train Loss: 0.0488 Acc:  98.46% | Val Loss: 0.0306 Acc:  98.94% ✓ [Best: 98.94%]
Epoch  4/30 | Train Loss: 0.0442 Acc:  98.56% | Val Loss: 0.0215 Acc:  99.38% ✓ [Best: 99.38%]
Epoch  5/30 | Train Loss: 0.0400 Acc:  98.72% | Val Loss: 0.0329 Acc:  98.88%
Epoch  6/30 | Train Loss: 0.0413 Acc:  98.67% | Val Loss: 0.0256 Acc:  99.15%
Epoch  7/30 | Train Loss: 0.0343 Acc:  98.92% | Val Loss: 0.0271 Acc:  99.10%
Epoch  8/30 | Train Loss: 0.0297 Acc:  99.02% | Val Loss: 0.0370 Acc:  98.87%
Epoch  9/30 | Train Loss: 0.0182 Acc:  99.41% | Val Loss: 0.0102 Acc:  99.68% ✓ [Best: 99.68%]
Epoch 10/30 | Train Loss: 0.0119 Acc:  99.64% | Val Loss: 0.0199 Acc:  99.47%
Epoch 11/30 | Train Loss: 0.0114 Acc:  99.66% | Val Loss: 0.0201 Acc:  99.36%
Epoch 12/30 | Train Loss: 0.0108 Acc:  99.67% | Val Loss: 0.0149 Acc:  99.52%
Epoch 13/30 | Train Loss: 0.0120 Acc:  99.62% | Val Loss: 0.0182 Acc:  99.48%
Epoch 14/30 | Train Loss: 0.0072 Acc:  99.79% | Val Loss: 0.0103 Acc:  99.69% ✓ [Best: 99.69%]
Epoch 15/30 | Train Loss: 0.0049 Acc:  99.86% | Val Loss: 0.0084 Acc:  99.75% ✓ [Best: 99.75%]
Epoch 16/30 | Train Loss: 0.0053 Acc:  99.82% | Val Loss: 0.0089 Acc:  99.75%
Epoch 17/30 | Train Loss: 0.0056 Acc:  99.82% | Val Loss: 0.0157 Acc:  99.54%
Epoch 18/30 | Train Loss: 0.0054 Acc:  99.83% | Val Loss: 0.0077 Acc:  99.79% ✓ [Best: 99.79%]
Epoch 19/30 | Train Loss: 0.0056 Acc:  99.80% | Val Loss: 0.0074 Acc:  99.73%
Epoch 20/30 | Train Loss: 0.0056 Acc:  99.81% | Val Loss: 0.0099 Acc:  99.66%
Epoch 21/30 | Train Loss: 0.0076 Acc:  99.77% | Val Loss: 0.0169 Acc:  99.59%
Epoch 22/30 | Train Loss: 0.0066 Acc:  99.80% | Val Loss: 0.0176 Acc:  99.54%
Epoch 23/30 | Train Loss: 0.0061 Acc:  99.84% | Val Loss: 0.0078 Acc:  99.75%

Early stopping at epoch 23
Best validation accuracy: 99.79% (epoch 18)

Training complete! Best model saved as 'best_efficientnet_b0.pth'
----------------------------------------------------------------------
```

```
======================================================================
TRAINING CUSTOM 20-LAYER CNN MODEL
======================================================================
Initializing 20-layer CNN for 23 classes on device: cuda

Starting training for cnn_20...
----------------------------------------------------------------------
Epoch  1/30 | Train Loss: 3.2638 Acc:   8.97% | Val Loss: 2.9024 Acc:  12.08% ✓ [Best: 12.08%]
Epoch  2/30 | Train Loss: 2.8357 Acc:  13.55% | Val Loss: 2.6715 Acc:  18.26% ✓ [Best: 18.26%]
Epoch  3/30 | Train Loss: 2.5336 Acc:  21.27% | Val Loss: 2.2238 Acc:  29.36% ✓ [Best: 29.36%]
Epoch  4/30 | Train Loss: 2.2880 Acc:  28.43% | Val Loss: 2.0830 Acc:  34.72% ✓ [Best: 34.72%]
Epoch  5/30 | Train Loss: 2.0870 Acc:  33.57% | Val Loss: 1.8207 Acc:  42.44% ✓ [Best: 42.44%]
Epoch  6/30 | Train Loss: 1.9494 Acc:  38.18% | Val Loss: 1.7556 Acc:  45.42% ✓ [Best: 45.42%]
Epoch  7/30 | Train Loss: 1.8111 Acc:  42.24% | Val Loss: 1.5125 Acc:  53.00% ✓ [Best: 53.00%]
Epoch  8/30 | Train Loss: 1.7058 Acc:  46.37% | Val Loss: 1.7497 Acc:  45.85%
Epoch  9/30 | Train Loss: 1.5864 Acc:  49.77% | Val Loss: 1.7015 Acc:  48.48%
Epoch 10/30 | Train Loss: 1.4419 Acc:  54.13% | Val Loss: 1.1121 Acc:  66.41% ✓ [Best: 66.41%]
Epoch 11/30 | Train Loss: 1.3865 Acc:  55.85% | Val Loss: 1.1643 Acc:  59.85%
Epoch 12/30 | Train Loss: 1.2615 Acc:  59.69% | Val Loss: 1.0336 Acc:  68.50% ✓ [Best: 68.50%]
Epoch 13/30 | Train Loss: 1.1941 Acc:  62.21% | Val Loss: 0.9066 Acc:  70.16% ✓ [Best: 70.16%]
Epoch 14/30 | Train Loss: 1.1183 Acc:  64.75% | Val Loss: 1.0739 Acc:  64.56%
Epoch 15/30 | Train Loss: 1.0833 Acc:  65.63% | Val Loss: 0.9740 Acc:  69.43%
Epoch 16/30 | Train Loss: 0.9974 Acc:  68.58% | Val Loss: 1.3780 Acc:  60.99%
Epoch 17/30 | Train Loss: 0.9664 Acc:  69.37% | Val Loss: 0.7170 Acc:  76.79% ✓ [Best: 76.79%]
Epoch 18/30 | Train Loss: 1.1563 Acc:  64.60% | Val Loss: 0.6982 Acc:  77.91% ✓ [Best: 77.91%]
Epoch 19/30 | Train Loss: 0.9393 Acc:  70.76% | Val Loss: 0.7675 Acc:  76.91%
Epoch 20/30 | Train Loss: 0.8528 Acc:  73.44% | Val Loss: 0.5623 Acc:  82.16% ✓ [Best: 82.16%]
Epoch 21/30 | Train Loss: 0.8145 Acc:  75.11% | Val Loss: 0.6550 Acc:  78.14%
Epoch 22/30 | Train Loss: 0.7632 Acc:  76.29% | Val Loss: 0.4381 Acc:  86.34% ✓ [Best: 86.34%]
Epoch 23/30 | Train Loss: 0.6816 Acc:  78.67% | Val Loss: 0.5934 Acc:  81.11%
Epoch 24/30 | Train Loss: 0.6601 Acc:  79.74% | Val Loss: 0.4062 Acc:  86.63% ✓ [Best: 86.63%]
Epoch 25/30 | Train Loss: 0.6381 Acc:  80.29% | Val Loss: 0.3737 Acc:  88.57% ✓ [Best: 88.57%]
Epoch 26/30 | Train Loss: 0.5811 Acc:  82.06% | Val Loss: 0.3577 Acc:  88.61% ✓ [Best: 88.61%]
Epoch 27/30 | Train Loss: 0.5732 Acc:  82.21% | Val Loss: 0.3557 Acc:  88.80% ✓ [Best: 88.80%]
Epoch 28/30 | Train Loss: 0.5305 Acc:  83.69% | Val Loss: 0.3059 Acc:  89.99% ✓ [Best: 89.99%]
Epoch 29/30 | Train Loss: 0.4969 Acc:  84.89% | Val Loss: 0.3326 Acc:  89.53%
Epoch 30/30 | Train Loss: 0.5234 Acc:  83.86% | Val Loss: 0.2833 Acc:  90.40% ✓ [Best: 90.40%]

Training complete! Best model saved as 'best_cnn_20.pth'
----------------------------------------------------------------------

======================================================================
SAVING MODELS
======================================================================
Saved resnet50 with metadata to 'resnet50_complete.pth'
Saved efficientnet_b0 with metadata to 'efficientnet_b0_complete.pth'
Saved cnn_20 with metadata to 'cnn_20_complete.pth'

Training complete for all models
Models saved with complete metadata
See Section 6 for detailed performance comparison and analysis
Use ModelInference.ipynb to reload models without retraining
```

6. Model performance comparison & CV



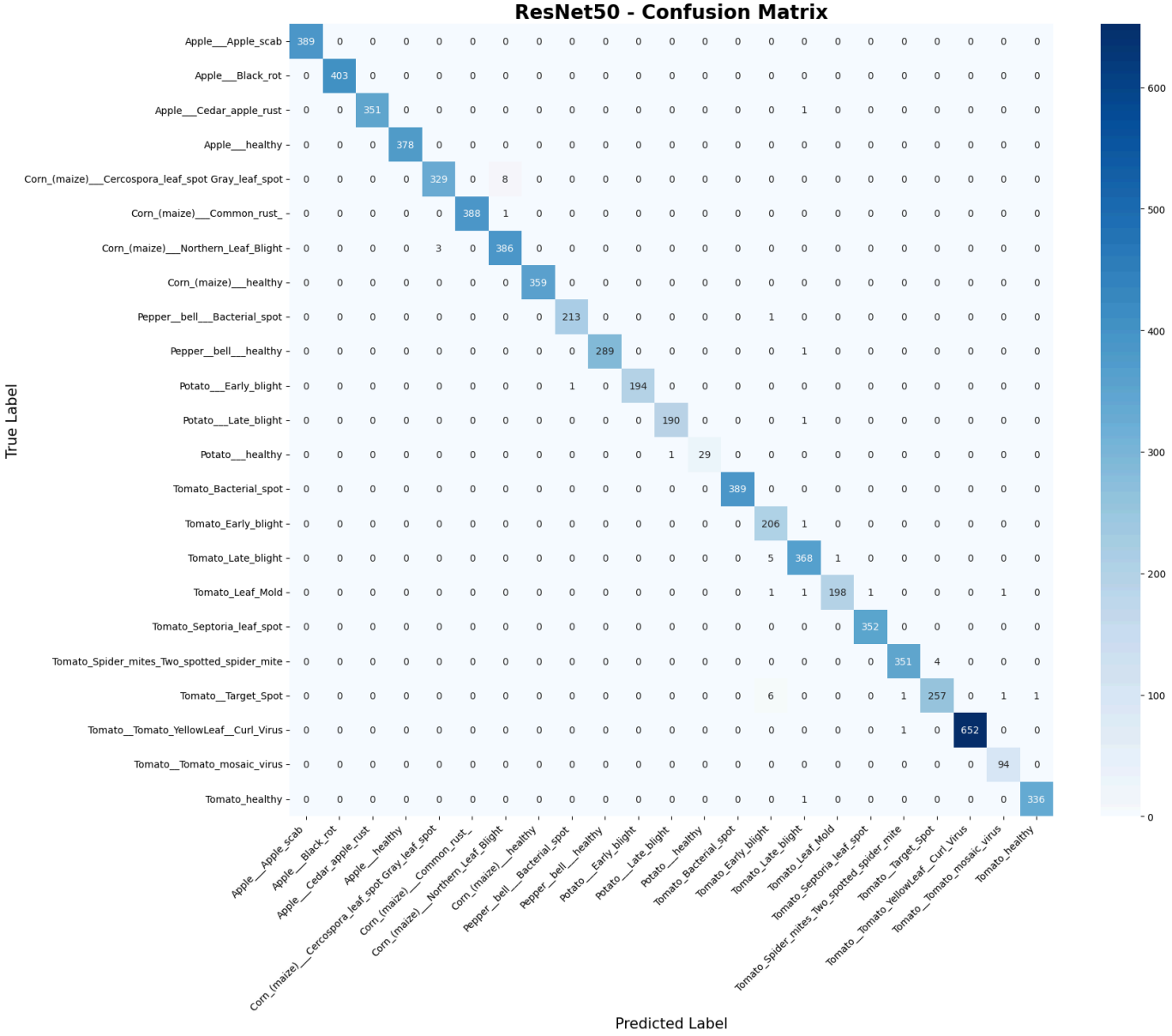


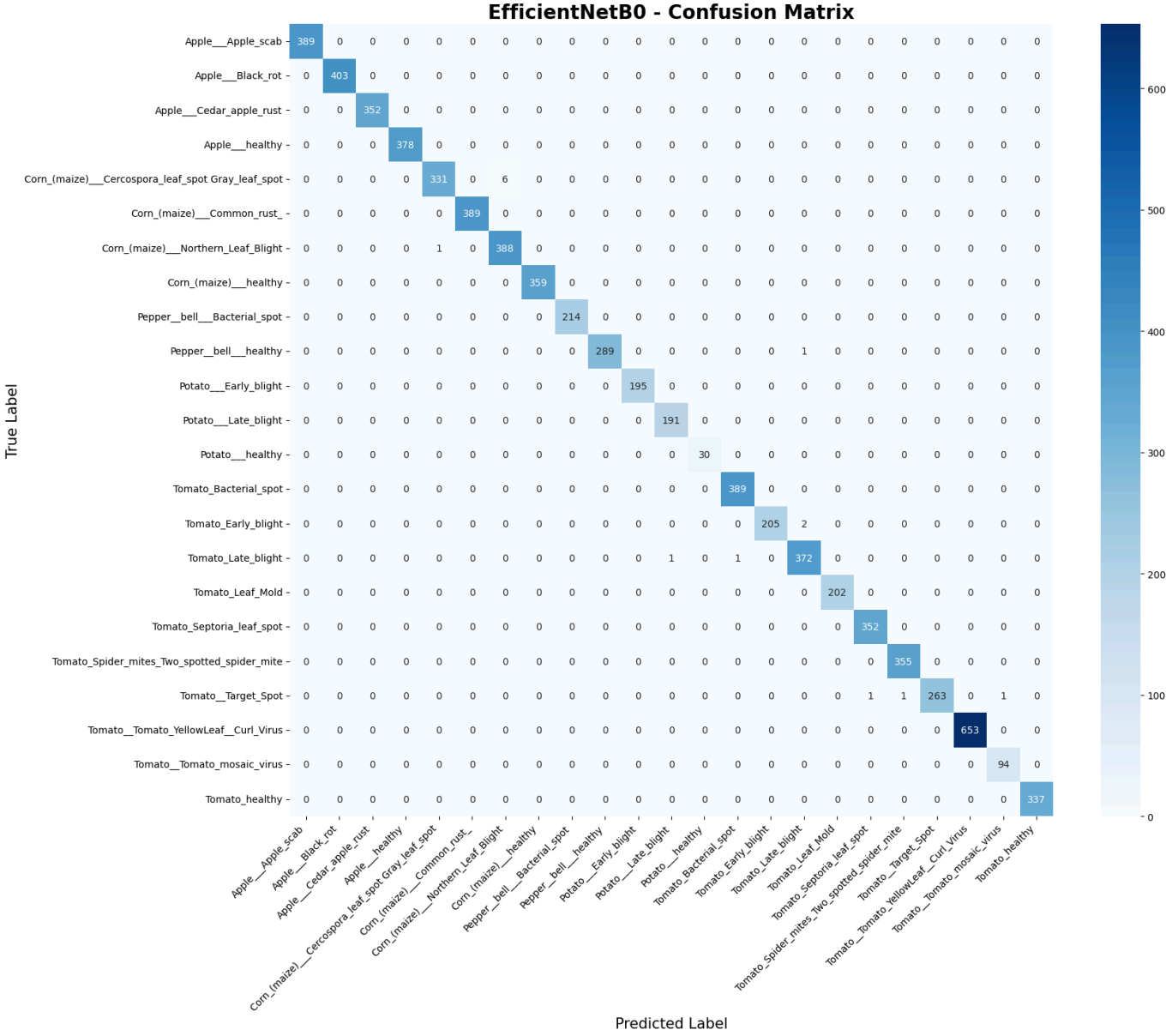

```
Evaluating ResNet50...
Evaluating EfficientNetB0...
Evaluating Custom CNN-20...

======================================================================
MODEL PERFORMANCE COMPARISON
======================================================================
```

Model	Validation Loss	Validation Accuracy (%)	Top-3 Accuracy (%)
ResNet50	0.0219	99.38	99.96
EfficientNetB0	0.0077	99.79	99.99
Custom CNN-20	0.2833	90.40	98.67

```
======================================================================
RESNET50 CLASSIFICATION REPORT
======================================================================
                                                precision    recall  f1-score   support

                                Apple___Apple_scab      1.000     1.000     1.000       389
                                 Apple___Black_rot      1.000     1.000     1.000       403
                           Apple___Cedar_apple_rust      1.000     0.997     0.999       352
                                    Apple___healthy      1.000     1.000     1.000       378
Corn_(maize)___Cercospora_leaf_spot Gray_leaf_spot      0.991     0.976     0.984       337
                         Corn_(maize)___Common_rust_      1.000     0.997     0.999       389
                Corn_(maize)___Northern_Leaf_Blight      0.977     0.992     0.985       389
                             Corn_(maize)___healthy      1.000     1.000     1.000       359
                      Pepper__bell___Bacterial_spot      0.995     0.995     0.995       214
                             Pepper__bell___healthy      1.000     0.997     0.998       290
                              Potato___Early_blight      1.000     0.995     0.997       195
                               Potato___Late_blight      0.995     0.995     0.995       191
                                   Potato___healthy      1.000     0.967     0.983        30
                             Tomato_Bacterial_spot      1.000     1.000     1.000       389
                               Tomato_Early_blight      0.941     0.995     0.967       207
                                Tomato_Late_blight      0.984     0.984     0.984       374
                                  Tomato_Leaf_Mold      0.995     0.980     0.988       202
                         Tomato_Septoria_leaf_spot      0.997     1.000     0.999       352
       Tomato_Spider_mites_Two_spotted_spider_mite      0.994     0.989     0.992       355
                               Tomato__Target_Spot      0.985     0.966     0.975       266
             Tomato__Tomato_YellowLeaf__Curl_Virus      1.000     0.998     0.999       653
                       Tomato__Tomato_mosaic_virus      0.979     1.000     0.989        94
                                   Tomato_healthy      0.997     0.997     0.997       337

                                         accuracy                          0.994      7145
                                        macro avg      0.993     0.992     0.992      7145
                                     weighted avg      0.994     0.994     0.994      7145


======================================================================
EFFICIENTNETB0 CLASSIFICATION REPORT
======================================================================
                                                precision    recall  f1-score   support

                                Apple___Apple_scab      1.000     1.000     1.000       389
                                 Apple___Black_rot      1.000     1.000     1.000       403
                           Apple___Cedar_apple_rust      1.000     1.000     1.000       352
                                    Apple___healthy      1.000     1.000     1.000       378
Corn_(maize)___Cercospora_leaf_spot Gray_leaf_spot      0.997     0.982     0.990       337
                         Corn_(maize)___Common_rust_      1.000     1.000     1.000       389
                Corn_(maize)___Northern_Leaf_Blight      0.985     0.997     0.991       389
                             Corn_(maize)___healthy      1.000     1.000     1.000       359
                      Pepper__bell___Bacterial_spot      1.000     1.000     1.000       214
                             Pepper__bell___healthy      1.000     0.997     0.998       290
                              Potato___Early_blight      1.000     1.000     1.000       195
                               Potato___Late_blight      0.995     1.000     0.997       191
                                   Potato___healthy      1.000     1.000     1.000        30
                             Tomato_Bacterial_spot      0.997     1.000     0.999       389
                               Tomato_Early_blight      1.000     0.990     0.995       207
                                Tomato_Late_blight      0.992     0.995     0.993       374
                                  Tomato_Leaf_Mold      1.000     1.000     1.000       202
                         Tomato_Septoria_leaf_spot      0.997     1.000     0.999       352
       Tomato_Spider_mites_Two_spotted_spider_mite      0.997     1.000     0.999       355
                               Tomato__Target_Spot      1.000     0.989     0.994       266
             Tomato__Tomato_YellowLeaf__Curl_Virus      1.000     1.000     1.000       653
                       Tomato__Tomato_mosaic_virus      0.989     1.000     0.995        94
                                   Tomato_healthy      1.000     1.000     1.000       337

                                         accuracy                          0.998      7145
                                        macro avg      0.998     0.998     0.998      7145
                                     weighted avg      0.998     0.998     0.998      7145


======================================================================
CUSTOM CNN-20 CLASSIFICATION REPORT
```

```
                                                    precision    recall  f1-score   support

                                Apple___Apple_scab      0.937     0.923     0.930       389
                                 Apple___Black_rot      0.937     0.998     0.966       403
                          Apple___Cedar_apple_rust      0.975     0.989     0.982       352
                                   Apple___healthy      0.928     0.989     0.958       378
Corn_(maize)___Cercospora_leaf_spot Gray_leaf_spot      0.926     0.887     0.906       337
                         Corn_(maize)___Common_rust_      0.990     0.997     0.994       389
                Corn_(maize)___Northern_Leaf_Blight      0.901     0.959     0.929       389
                         Corn_(maize)___healthy      0.992     1.000     0.996       359
                    Pepper__bell___Bacterial_spot      0.925     0.808     0.863       214
                           Pepper__bell___healthy      0.949     0.962     0.955       290
                            Potato___Early_blight      0.819     0.974     0.890       195
                             Potato___Late_blight      0.830     0.764     0.796       191
                                 Potato___healthy      1.000     0.767     0.868        30
                           Tomato_Bacterial_spot      0.877     0.956     0.915       389
                             Tomato_Early_blight      0.622     0.580     0.600       207
                              Tomato_Late_blight      0.821     0.797     0.809       374
                                Tomato_Leaf_Mold      0.990     0.510     0.673       202
                        Tomato_Septoria_leaf_spot      0.753     0.830     0.789       352
       Tomato_Spider_mites_Two_spotted_spider_mite      0.804     0.949     0.871       355
                              Tomato__Target_Spot      0.849     0.782     0.814       266
             Tomato__Tomato_YellowLeaf__Curl_Virus      0.978     0.971     0.975       653
                       Tomato__Tomato_mosaic_virus      0.981     0.564     0.716        94
                                   Tomato_healthy      0.991     0.976     0.984       337

                                         accuracy                          0.904      7145
                                        macro avg      0.903     0.867     0.877      7145
                                     weighted avg      0.907     0.904     0.901      7145
```


ResNet50 - Confusion Matrix
True Label
Predicted Label
Apple___Apple_scab
Apple___Black_rot
Apple___Cedar_apple_rust
Apple___healthy
Corn_(maize)___Cercospora_leaf_spot Gray_leaf_spot
Corn_(maize)___Common_rust_
Corn_(maize)___Northern_Leaf_Blight
Corn_(maize)___healthy
Pepper__bell___Bacterial_spot
Pepper__bell___healthy
Potato___Early_blight
Potato___Late_blight
Potato___healthy
Tomato_Bacterial_spot
Tomato_Early_blight
Tomato_Late_blight
Tomato_Leaf_Mold
Tomato_Septoria_leaf_spot
Tomato_Spider_mites_Two_spotted_spider_mite
Tomato__Target_Spot
Tomato__Tomato_YellowLeaf__Curl_Virus
Tomato__Tomato_mosaic_virus
Tomato_healthy
0
100
200
300
400
500
600


EfficientNetB0 - Confusion Matrix
True Label
Predicted Label
Apple___Apple_scab
Apple___Black_rot
Apple___Cedar_apple_rust
Apple___healthy
Corn_(maize)___Cercospora_leaf_spot Gray_leaf_spot
Corn_(maize)___Common_rust_
Corn_(maize)___Northern_Leaf_Blight
Corn_(maize)___healthy
Pepper__bell___Bacterial_spot
Pepper__bell___healthy
Potato___Early_blight
Potato___Late_blight
Potato___healthy
Tomato_Bacterial_spot
Tomato_Early_blight
Tomato_Late_blight
Tomato_Leaf_Mold
Tomato_Septoria_leaf_spot
Tomato_Spider_mites_Two_spotted_spider_mite
Tomato__Target_Spot
Tomato__Tomato_YellowLeaf__Curl_Virus
Tomato__Tomato_mosaic_virus
Tomato_healthy
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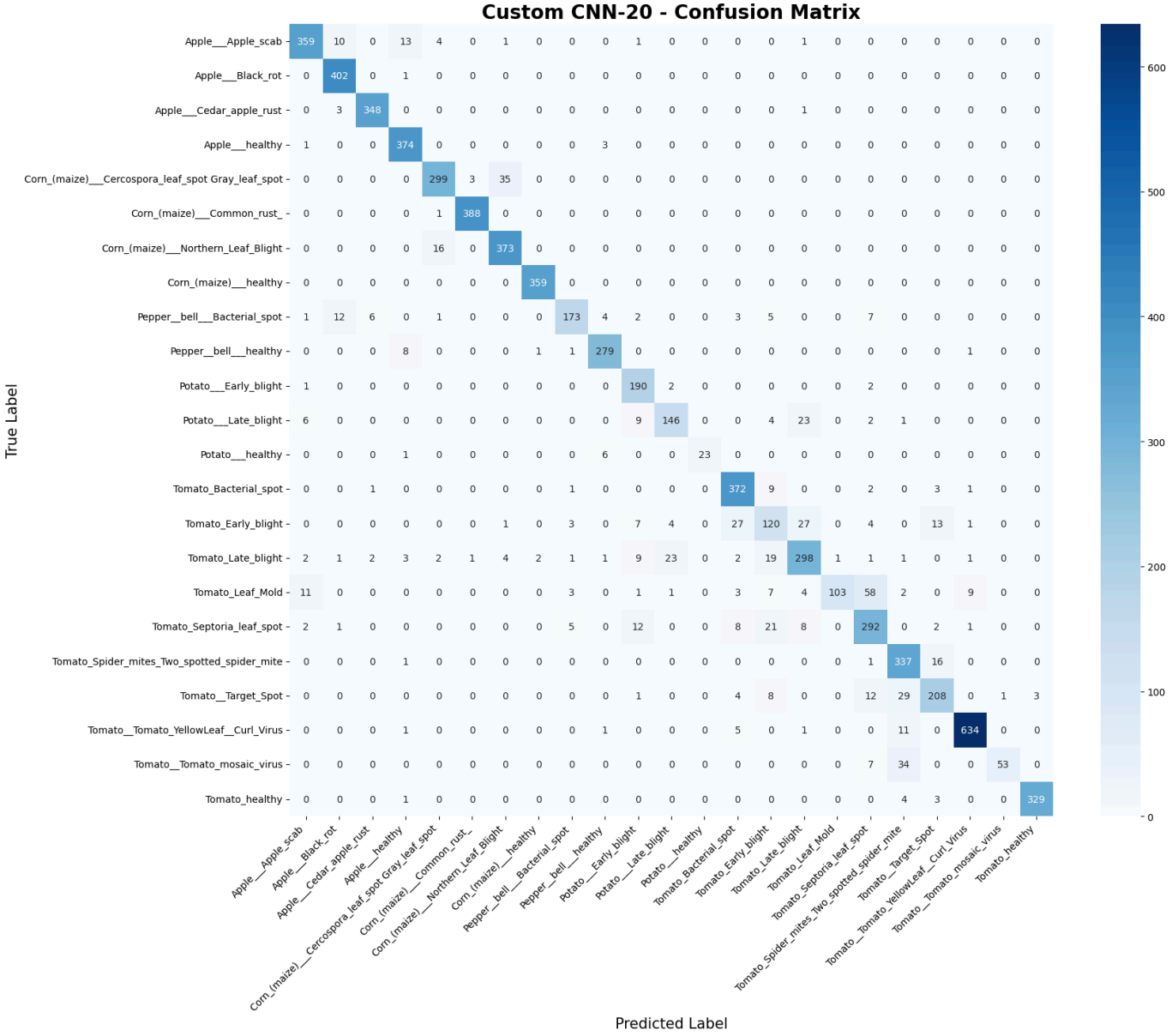
400
500
600


Custom CNN-20 - Confusion Matrix
True Label
Predicted Label
Apple___Apple_scab
Apple___Black_rot
Apple___Cedar_apple_rust
Apple___healthy
Corn_(maize)___Cercospora_leaf_spot Gray_leaf_spot
Corn_(maize)___Common_rust_
Corn_(maize)___Northern_Leaf_Blight
Corn_(maize)___healthy
Pepper__bell___Bacterial_spot
Pepper__bell___healthy
Potato___Early_blight
Potato___Late_blight
Potato___healthy
Tomato_Bacterial_spot
Tomato_Early_blight
Tomato_Late_blight
Tomato_Leaf_Mold
Tomato_Septoria_leaf_spot
Tomato_Spider_mites_Two_spotted_spider_mite
Tomato__Target_Spot
Tomato__Tomato_YellowLeaf__Curl_Virus
Tomato__Tomato_mosaic_virus
Tomato_healthy
0
100
200
300
400
500
600

```
======================================================================
STARTING 5-FOLD CROSS-VALIDATION
======================================================================

======================== FOLD 1/5 ========================

Training ResNet50...

Starting training for resnet50_fold1...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.3489 Acc:  89.19% | Val Loss: 0.2525 Acc:  91.52% ✓ [Best: 91.52%]
Epoch  2/10 | Train Loss: 0.1573 Acc:  94.93% | Val Loss: 0.1007 Acc:  96.88% ✓ [Best: 96.88%]
Epoch  3/10 | Train Loss: 0.1258 Acc:  95.84% | Val Loss: 0.1510 Acc:  94.90%
Epoch  4/10 | Train Loss: 0.1134 Acc:  96.15% | Val Loss: 0.1778 Acc:  94.60%
Epoch  5/10 | Train Loss: 0.0917 Acc:  96.91% | Val Loss: 0.1383 Acc:  95.82%

Early stopping at epoch 5
Best validation accuracy: 96.88% (epoch 2)

Training complete! Best model saved as 'best_resnet50_fold1.pth'
----------------------------------------------------------------------
  ResNet50 Fold 1 - Val Acc: 96.88%

Training EfficientNetB0...

Starting training for efficientnet_fold1...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.2981 Acc:  92.05% | Val Loss: 0.0763 Acc:  97.13% ✓ [Best: 97.13%]
Epoch  2/10 | Train Loss: 0.0647 Acc:  98.00% | Val Loss: 0.0492 Acc:  98.32% ✓ [Best: 98.32%]
Epoch  3/10 | Train Loss: 0.0468 Acc:  98.48% | Val Loss: 0.0436 Acc:  98.70% ✓ [Best: 98.70%]
Epoch  4/10 | Train Loss: 0.0456 Acc:  98.58% | Val Loss: 0.0303 Acc:  99.19% ✓ [Best: 99.19%]
Epoch  5/10 | Train Loss: 0.0428 Acc:  98.62% | Val Loss: 0.0383 Acc:  98.81%
Epoch  6/10 | Train Loss: 0.0406 Acc:  98.65% | Val Loss: 0.0325 Acc:  98.94%
Epoch  7/10 | Train Loss: 0.0345 Acc:  98.89% | Val Loss: 0.0240 Acc:  99.19%

Early stopping at epoch 7
Best validation accuracy: 99.19% (epoch 4)

Training complete! Best model saved as 'best_efficientnet_fold1.pth'
----------------------------------------------------------------------
  EfficientNetB0 Fold 1 - Val Acc: 99.19%

Training Custom CNN-20...

Starting training for cnn20_fold1...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 3.2092 Acc:  11.12% | Val Loss: 3.0176 Acc:  11.50% ✓ [Best: 11.50%]
Epoch  2/10 | Train Loss: 2.3989 Acc:  24.18% | Val Loss: 1.8638 Acc:  39.45% ✓ [Best: 39.45%]
Epoch  3/10 | Train Loss: 2.0900 Acc:  34.28% | Val Loss: 1.9213 Acc:  37.62%
Epoch  4/10 | Train Loss: 1.8850 Acc:  41.22% | Val Loss: 1.4643 Acc:  51.06% ✓ [Best: 51.06%]
Epoch  5/10 | Train Loss: 1.7225 Acc:  46.59% | Val Loss: 1.5573 Acc:  49.21%
Epoch  6/10 | Train Loss: 1.6314 Acc:  49.71% | Val Loss: 1.0901 Acc:  65.70% ✓ [Best: 65.70%]
Epoch  7/10 | Train Loss: 1.5610 Acc:  51.96% | Val Loss: 1.5910 Acc:  51.82%
Epoch  8/10 | Train Loss: 1.4881 Acc:  54.69% | Val Loss: 1.3813 Acc:  57.18%
Epoch  9/10 | Train Loss: 1.3919 Acc:  57.16% | Val Loss: 2.6830 Acc:  26.94%

Early stopping at epoch 9
Best validation accuracy: 65.70% (epoch 6)

Training complete! Best model saved as 'best_cnn20_fold1.pth'
----------------------------------------------------------------------
  Custom CNN-20 Fold 1 - Val Acc: 65.70%

======================== FOLD 2/5 ========================

Training ResNet50...

Starting training for resnet50_fold2...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.3863 Acc:  87.82% | Val Loss: 0.3037 Acc:  90.79% ✓ [Best: 90.79%]
```

```
Epoch  2/10 | Train Loss: 0.1577 Acc:  94.85% | Val Loss: 0.1903 Acc:  93.36% ✓ [Best: 93.36%]
Epoch  3/10 | Train Loss: 0.1208 Acc:  96.07% | Val Loss: 0.4315 Acc:  88.33%
Epoch  4/10 | Train Loss: 0.1151 Acc:  96.13% | Val Loss: 0.5025 Acc:  87.61%
Epoch  5/10 | Train Loss: 0.0963 Acc:  96.82% | Val Loss: 0.0951 Acc:  96.61% ✓ [Best: 96.61%]
Epoch  6/10 | Train Loss: 0.0956 Acc:  96.93% | Val Loss: 0.1687 Acc:  94.72%
Epoch  7/10 | Train Loss: 0.0980 Acc:  96.82% | Val Loss: 0.0753 Acc:  97.32% ✓ [Best: 97.32%]
Epoch  8/10 | Train Loss: 0.0758 Acc:  97.51% | Val Loss: 0.1053 Acc:  96.57%
Epoch  9/10 | Train Loss: 0.0836 Acc:  97.22% | Val Loss: 0.1344 Acc:  95.58%
Epoch 10/10 | Train Loss: 0.0786 Acc:  97.41% | Val Loss: 0.0484 Acc:  98.39% ✓ [Best: 98.39%]

Training complete! Best model saved as 'best_resnet50_fold2.pth'
----------------------------------------------------------------------
  ResNet50 Fold 2 - Val Acc: 98.39%

Training EfficientNetB0...

Starting training for efficientnet_fold2...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.2925 Acc:  92.41% | Val Loss: 0.0675 Acc:  97.58% ✓ [Best: 97.58%]
Epoch  2/10 | Train Loss: 0.0694 Acc:  97.77% | Val Loss: 0.0374 Acc:  98.66% ✓ [Best: 98.66%]
Epoch  3/10 | Train Loss: 0.0519 Acc:  98.28% | Val Loss: 0.0583 Acc:  97.99%
Epoch  4/10 | Train Loss: 0.0464 Acc:  98.49% | Val Loss: 0.0360 Acc:  98.80% ✓ [Best: 98.80%]
Epoch  5/10 | Train Loss: 0.0389 Acc:  98.71% | Val Loss: 0.0386 Acc:  98.91% ✓ [Best: 98.91%]
Epoch  6/10 | Train Loss: 0.0358 Acc:  98.83% | Val Loss: 0.0364 Acc:  98.98% ✓ [Best: 98.98%]
Epoch  7/10 | Train Loss: 0.0376 Acc:  98.80% | Val Loss: 0.0246 Acc:  99.21% ✓ [Best: 99.21%]
Epoch  8/10 | Train Loss: 0.0303 Acc:  99.01% | Val Loss: 0.0292 Acc:  99.03%
Epoch  9/10 | Train Loss: 0.0314 Acc:  98.94% | Val Loss: 0.0581 Acc:  98.16%
Epoch 10/10 | Train Loss: 0.0325 Acc:  98.98% | Val Loss: 0.0347 Acc:  98.86%

Early stopping at epoch 10
Best validation accuracy: 99.21% (epoch 7)

Training complete! Best model saved as 'best_efficientnet_fold2.pth'
----------------------------------------------------------------------
  EfficientNetB0 Fold 2 - Val Acc: 99.21%

Training Custom CNN-20...

Starting training for cnn20_fold2...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 3.1000 Acc:  11.95% | Val Loss: 2.2940 Acc:  27.37% ✓ [Best: 27.37%]
Epoch  2/10 | Train Loss: 2.4222 Acc:  24.87% | Val Loss: 1.9605 Acc:  37.39% ✓ [Best: 37.39%]
Epoch  3/10 | Train Loss: 2.1923 Acc:  32.43% | Val Loss: 2.0957 Acc:  32.08%
Epoch  4/10 | Train Loss: 1.9877 Acc:  37.79% | Val Loss: 1.6805 Acc:  48.71% ✓ [Best: 48.71%]
Epoch  5/10 | Train Loss: 1.8536 Acc:  42.53% | Val Loss: 1.8717 Acc:  38.63%
Epoch  6/10 | Train Loss: 1.6961 Acc:  47.39% | Val Loss: 1.6209 Acc:  55.73% ✓ [Best: 55.73%]
Epoch  7/10 | Train Loss: 1.5962 Acc:  50.95% | Val Loss: 1.1899 Acc:  62.84% ✓ [Best: 62.84%]
Epoch  8/10 | Train Loss: 1.4703 Acc:  54.51% | Val Loss: 1.1286 Acc:  64.66% ✓ [Best: 64.66%]
Epoch  9/10 | Train Loss: 1.2877 Acc:  59.57% | Val Loss: 0.9246 Acc:  69.59% ✓ [Best: 69.59%]
Epoch 10/10 | Train Loss: 1.3897 Acc:  57.95% | Val Loss: 1.1967 Acc:  62.84%

Training complete! Best model saved as 'best_cnn20_fold2.pth'
----------------------------------------------------------------------
  Custom CNN-20 Fold 2 - Val Acc: 69.59%

======================== FOLD 3/5 ========================

Training ResNet50...

Starting training for resnet50_fold3...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.3625 Acc:  88.51% | Val Loss: 0.2483 Acc:  92.16% ✓ [Best: 92.16%]
Epoch  2/10 | Train Loss: 0.1432 Acc:  95.17% | Val Loss: 0.1049 Acc:  96.37% ✓ [Best: 96.37%]
Epoch  3/10 | Train Loss: 0.1313 Acc:  95.80% | Val Loss: 0.1542 Acc:  95.28%
Epoch  4/10 | Train Loss: 0.1118 Acc:  96.23% | Val Loss: 0.2245 Acc:  92.98%
Epoch  5/10 | Train Loss: 0.0875 Acc:  97.08% | Val Loss: 0.1167 Acc:  96.18%

Early stopping at epoch 5
Best validation accuracy: 96.37% (epoch 2)
```

```
Training complete! Best model saved as 'best_resnet50_fold3.pth'
----------------------------------------------------------------------
  ResNet50 Fold 3 - Val Acc: 96.37%

Training EfficientNetB0...

Starting training for efficientnet_fold3...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.2970 Acc:  92.13% | Val Loss: 0.0530 Acc:  98.16% ✓ [Best: 98.16%]
Epoch  2/10 | Train Loss: 0.0626 Acc:  97.99% | Val Loss: 0.0348 Acc:  98.77% ✓ [Best: 98.77%]
Epoch  3/10 | Train Loss: 0.0519 Acc:  98.27% | Val Loss: 0.0353 Acc:  98.91% ✓ [Best: 98.91%]
Epoch  4/10 | Train Loss: 0.0413 Acc:  98.74% | Val Loss: 0.0470 Acc:  98.62%
Epoch  5/10 | Train Loss: 0.0364 Acc:  98.89% | Val Loss: 0.0224 Acc:  99.36% ✓ [Best: 99.36%]
Epoch  6/10 | Train Loss: 0.0414 Acc:  98.72% | Val Loss: 0.0444 Acc:  98.66%
Epoch  7/10 | Train Loss: 0.0403 Acc:  98.67% | Val Loss: 0.0537 Acc:  98.36%
Epoch  8/10 | Train Loss: 0.0316 Acc:  98.96% | Val Loss: 0.0367 Acc:  98.83%

Early stopping at epoch 8
Best validation accuracy: 99.36% (epoch 5)

Training complete! Best model saved as 'best_efficientnet_fold3.pth'
----------------------------------------------------------------------
  EfficientNetB0 Fold 3 - Val Acc: 99.36%

Training Custom CNN-20...

Starting training for cnn20_fold3...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 2.9670 Acc:  15.82% | Val Loss: 2.1956 Acc:  28.50% ✓ [Best: 28.50%]
Epoch  2/10 | Train Loss: 2.2901 Acc:  28.02% | Val Loss: 1.9587 Acc:  36.53% ✓ [Best: 36.53%]
Epoch  3/10 | Train Loss: 2.0758 Acc:  35.85% | Val Loss: 1.8240 Acc:  38.07% ✓ [Best: 38.07%]
Epoch  4/10 | Train Loss: 1.8196 Acc:  43.18% | Val Loss: 1.4889 Acc:  51.84% ✓ [Best: 51.84%]
Epoch  5/10 | Train Loss: 1.6845 Acc:  47.53% | Val Loss: 1.7030 Acc:  46.97%
Epoch  6/10 | Train Loss: 1.5633 Acc:  51.03% | Val Loss: 1.5887 Acc:  49.77%
Epoch  7/10 | Train Loss: 1.4292 Acc:  55.16% | Val Loss: 1.1187 Acc:  65.55% ✓ [Best: 65.55%]
Epoch  8/10 | Train Loss: 1.3090 Acc:  59.03% | Val Loss: 0.9815 Acc:  73.32% ✓ [Best: 73.32%]
Epoch  9/10 | Train Loss: 1.2141 Acc:  61.96% | Val Loss: 1.3590 Acc:  57.48%
Epoch 10/10 | Train Loss: 1.1310 Acc:  64.34% | Val Loss: 0.7174 Acc:  78.85% ✓ [Best: 78.85%]

Training complete! Best model saved as 'best_cnn20_fold3.pth'
----------------------------------------------------------------------
  Custom CNN-20 Fold 3 - Val Acc: 78.85%

======================== FOLD 4/5 ========================

Training ResNet50...

Starting training for resnet50_fold4...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.3755 Acc:  88.28% | Val Loss: 0.3898 Acc:  88.78% ✓ [Best: 88.78%]
Epoch  2/10 | Train Loss: 0.1537 Acc:  94.93% | Val Loss: 0.1935 Acc:  93.78% ✓ [Best: 93.78%]
Epoch  3/10 | Train Loss: 0.1201 Acc:  95.96% | Val Loss: 0.0841 Acc:  97.46% ✓ [Best: 97.46%]
Epoch  4/10 | Train Loss: 0.1064 Acc:  96.31% | Val Loss: 0.1268 Acc:  95.93%
Epoch  5/10 | Train Loss: 0.1024 Acc:  96.49% | Val Loss: 0.1147 Acc:  96.43%
Epoch  6/10 | Train Loss: 0.0866 Acc:  97.11% | Val Loss: 0.1198 Acc:  96.06%

Early stopping at epoch 6
Best validation accuracy: 97.46% (epoch 3)

Training complete! Best model saved as 'best_resnet50_fold4.pth'
----------------------------------------------------------------------
  ResNet50 Fold 4 - Val Acc: 97.46%

Training EfficientNetB0...

Starting training for efficientnet_fold4...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.2906 Acc:  92.35% | Val Loss: 0.0618 Acc:  97.94% ✓ [Best: 97.94%]
Epoch  2/10 | Train Loss: 0.0685 Acc:  97.69% | Val Loss: 0.0625 Acc:  97.75%
Epoch  3/10 | Train Loss: 0.0517 Acc:  98.34% | Val Loss: 0.0276 Acc:  99.11% ✓ [Best: 99.11%]
```

```
Epoch  4/10 | Train Loss: 0.0430 Acc:  98.60% | Val Loss: 0.0263 Acc:  99.18% ✓ [Best: 99.18%]
Epoch  5/10 | Train Loss: 0.0358 Acc:  98.78% | Val Loss: 0.0264 Acc:  99.18%
Epoch  6/10 | Train Loss: 0.0370 Acc:  98.79% | Val Loss: 0.0256 Acc:  99.22% ✓ [Best: 99.22%]
Epoch  7/10 | Train Loss: 0.0330 Acc:  98.96% | Val Loss: 0.0548 Acc:  98.32%
Epoch  8/10 | Train Loss: 0.0372 Acc:  98.80% | Val Loss: 0.0435 Acc:  98.69%
Epoch  9/10 | Train Loss: 0.0299 Acc:  99.05% | Val Loss: 0.0206 Acc:  99.45% ✓ [Best: 99.45%]
Epoch 10/10 | Train Loss: 0.0362 Acc:  98.88% | Val Loss: 0.0447 Acc:  98.54%

Training complete! Best model saved as 'best_efficientnet_fold4.pth'
----------------------------------------------------------------------
  EfficientNetB0 Fold 4 - Val Acc: 99.45%

Training Custom CNN-20...

Starting training for cnn20_fold4...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 3.2357 Acc:  10.06% | Val Loss: 2.7072 Acc:  19.88% ✓ [Best: 19.88%]
Epoch  2/10 | Train Loss: 2.5274 Acc:  21.99% | Val Loss: 2.0291 Acc:  36.00% ✓ [Best: 36.00%]
Epoch  3/10 | Train Loss: 2.1830 Acc:  31.65% | Val Loss: 1.9458 Acc:  35.65%
Epoch  4/10 | Train Loss: 2.0420 Acc:  35.99% | Val Loss: 2.3747 Acc:  25.66%
Epoch  5/10 | Train Loss: 1.9299 Acc:  39.30% | Val Loss: 1.7605 Acc:  44.47% ✓ [Best: 44.47%]
Epoch  6/10 | Train Loss: 1.8030 Acc:  43.93% | Val Loss: 1.6777 Acc:  46.77% ✓ [Best: 46.77%]
Epoch  7/10 | Train Loss: 1.6497 Acc:  49.10% | Val Loss: 1.3533 Acc:  57.09% ✓ [Best: 57.09%]
Epoch  8/10 | Train Loss: 1.5840 Acc:  51.68% | Val Loss: 1.6904 Acc:  47.39%
Epoch  9/10 | Train Loss: 1.4373 Acc:  55.69% | Val Loss: 1.5041 Acc:  53.29%
Epoch 10/10 | Train Loss: 1.3406 Acc:  58.59% | Val Loss: 1.4013 Acc:  54.03%

Early stopping at epoch 10
Best validation accuracy: 57.09% (epoch 7)

Training complete! Best model saved as 'best_cnn20_fold4.pth'
----------------------------------------------------------------------
  Custom CNN-20 Fold 4 - Val Acc: 57.09%

======================== FOLD 5/5 ========================

Training ResNet50...

Starting training for resnet50_fold5...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.3689 Acc:  88.40% | Val Loss: 0.3263 Acc:  89.36% ✓ [Best: 89.36%]
Epoch  2/10 | Train Loss: 0.1638 Acc:  94.64% | Val Loss: 0.0933 Acc:  96.91% ✓ [Best: 96.91%]
Epoch  3/10 | Train Loss: 0.1218 Acc:  95.84% | Val Loss: 0.1781 Acc:  94.23%
Epoch  4/10 | Train Loss: 0.1087 Acc:  96.42% | Val Loss: 0.0877 Acc:  97.20% ✓ [Best: 97.20%]
Epoch  5/10 | Train Loss: 0.0941 Acc:  96.89% | Val Loss: 0.3811 Acc:  91.20%
Epoch  6/10 | Train Loss: 0.1033 Acc:  96.56% | Val Loss: 0.1116 Acc:  96.13%
Epoch  7/10 | Train Loss: 0.0895 Acc:  97.00% | Val Loss: 0.0874 Acc:  97.12%

Early stopping at epoch 7
Best validation accuracy: 97.20% (epoch 4)

Training complete! Best model saved as 'best_resnet50_fold5.pth'
----------------------------------------------------------------------
  ResNet50 Fold 5 - Val Acc: 97.20%

Training EfficientNetB0...

Starting training for efficientnet_fold5...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 0.2927 Acc:  92.22% | Val Loss: 0.0693 Acc:  97.54% ✓ [Best: 97.54%]
Epoch  2/10 | Train Loss: 0.0686 Acc:  97.72% | Val Loss: 0.0603 Acc:  98.04% ✓ [Best: 98.04%]
Epoch  3/10 | Train Loss: 0.0472 Acc:  98.49% | Val Loss: 0.0484 Acc:  98.28% ✓ [Best: 98.28%]
Epoch  4/10 | Train Loss: 0.0492 Acc:  98.32% | Val Loss: 0.0510 Acc:  98.09%
Epoch  5/10 | Train Loss: 0.0366 Acc:  98.80% | Val Loss: 0.0241 Acc:  99.14% ✓ [Best: 99.14%]
Epoch  6/10 | Train Loss: 0.0360 Acc:  98.85% | Val Loss: 0.0464 Acc:  98.35%
Epoch  7/10 | Train Loss: 0.0382 Acc:  98.71% | Val Loss: 0.0186 Acc:  99.35% ✓ [Best: 99.35%]
Epoch  8/10 | Train Loss: 0.0285 Acc:  99.13% | Val Loss: 0.0243 Acc:  99.15%
Epoch  9/10 | Train Loss: 0.0354 Acc:  98.83% | Val Loss: 0.0583 Acc:  98.26%
Epoch 10/10 | Train Loss: 0.0336 Acc:  98.89% | Val Loss: 0.0304 Acc:  99.04%
```

```
Early stopping at epoch 10
Best validation accuracy: 99.35% (epoch 7)

Training complete! Best model saved as 'best_efficientnet_fold5.pth'
----------------------------------------------------------------------
  EfficientNetB0 Fold 5 - Val Acc: 99.35%

Training Custom CNN-20...

Starting training for cnn20_fold5...
----------------------------------------------------------------------
Epoch  1/10 | Train Loss: 3.2762 Acc:  11.65% | Val Loss: 2.7224 Acc:  16.65% ✓ [Best: 16.65%]
Epoch  2/10 | Train Loss: 2.6640 Acc:  18.52% | Val Loss: 2.4405 Acc:  21.76% ✓ [Best: 21.76%]
Epoch  3/10 | Train Loss: 2.4074 Acc:  24.94% | Val Loss: 2.0362 Acc:  37.88% ✓ [Best: 37.88%]
Epoch  4/10 | Train Loss: 2.1822 Acc:  31.90% | Val Loss: 1.9245 Acc:  36.16%
Epoch  5/10 | Train Loss: 1.9779 Acc:  37.23% | Val Loss: 2.2643 Acc:  27.41%
Epoch  6/10 | Train Loss: 1.8696 Acc:  40.90% | Val Loss: 1.6262 Acc:  46.62% ✓ [Best: 46.62%]
Epoch  7/10 | Train Loss: 1.7770 Acc:  43.48% | Val Loss: 1.3079 Acc:  59.29% ✓ [Best: 59.29%]
Epoch  8/10 | Train Loss: 1.6038 Acc:  48.90% | Val Loss: 1.1331 Acc:  63.77% ✓ [Best: 63.77%]
Epoch  9/10 | Train Loss: 1.5210 Acc:  52.02% | Val Loss: 4.1284 Acc:  30.27%
Epoch 10/10 | Train Loss: 1.4680 Acc:  53.61% | Val Loss: 1.7152 Acc:  47.22%

Training complete! Best model saved as 'best_cnn20_fold5.pth'
----------------------------------------------------------------------
  Custom CNN-20 Fold 5 - Val Acc: 63.77%
```

Per-Fold Results:

	Fold	ResNet50 Acc (%)	EfficientNetB0 Acc (%)	CNN-20 Acc (%)	ResNet50 Loss	EfficientNetB0 Loss	CNN-20 Loss	ResNet50 Top-3 Acc (%)	EfficientNetB0 Top-3 Acc (%)	CNN-20 Top-3 Acc (%)
0	Fold 1	96.88	99.19	65.70	0.1007	0.0303	1.0901	99.93	99.99	87.69
1	Fold 2	98.39	99.21	69.59	0.0484	0.0246	0.9246	99.96	99.97	89.36
2	Fold 3	96.37	99.36	78.85	0.1049	0.0224	0.7174	99.84	99.97	94.67
3	Fold 4	97.46	99.45	57.09	0.0841	0.0206	1.3533	99.87	99.96	80.90
4	Fold 5	97.20	99.35	63.77	0.0877	0.0186	1.1331	99.82	99.97	88.00

Average Across All Folds:

Model	Avg Accuracy (%)	Std Accuracy	Avg Loss	Avg Top-3 Acc (%)
ResNet50	97.26	0.67	0.0852	99.88
EfficientNetB0	99.31	0.10	0.0233	99.97
Custom CNN-20	67.00	7.18	1.0437	88.13

7. Export Notebook to HTML

```
✓ Notebook successfully exported to FirstDraft_Output_20251207_071542.html
```