

CHAPTER 8

RESULTS AND DISCUSSION

Plant identification based on leaf image classification is an area of research which has proved to be challenging during the past few decades and is gaining more and more attention due to the increase in environmental awareness from the public, especially botanists. In this research work, an image classification and recognition system, called CAP-LR, was developed for the purpose of plant identification through leaf recognition. The study proposed three categories of classification models, namely, BPNN-based models, SVM-based models and WNN-based CAP-LR models. All the CAP-LR models were built using the leaf image enhancement algorithm (WEC algorithm), segmentation algorithm (WCF algorithm) and feature selection algorithm (GA \cap KPCA) before leaf image classification for plant identification. The techniques used are summarized in Table 8.1.

Performance evaluation of the enhanced classification models is the most important step in any research. Different researchers use different parameters for analysis. In this study, the performance of the proposed leaf image recognition models are tested using two datasets, namely, standard dataset and real dataset (Chapter 3). This chapter presents the experimental results of the recognition phase of CAP-LR and analyzes the performance of nine proposed CL-CL models (Chapter 7).

The main aim here is to identify the combination of level 1 and level 2 classifiers that best suit the leaf recognition and plant identification process. Three performance metrics (Chapter 3), namely, recognition rate (%), error rate (%) and speed of classification (seconds) were used during the analysis of the proposed algorithms. During experiments, a 10-fold cross-validation method was used. The average results were taken as the final outcome of the classifier.

TABLE 8.1
TECHNIQUES USED IN CAP-LR

Phases	Technique Used
Leaf Image Enhancement	Enhanced Wavelet based Denoising with inbuilt Edge Enhancement and Automatic Contrast Adjustment Algorithm (WEC Method)
Leaf Segmentation	Enhanced Wavelet based Segmentation using Clustering and Texture based Color Features (WCF Method)
Features Extracted	<ul style="list-style-type: none"> (i) Geometric Features (Eccentricity, Extent, Orientation) (ii) Color (Mean, Standard Deviation, Skew, Kurtosis) (iii) Texture (Energy, Entropy, Homogeneity, Variance) (iv) Fractal Features (Average Fractal Dimension, Standard Deviation FD, Lacunarity) (v) Leaf Specialized Features (Diameter, Physiological Length, Physiological Width, Area, Perimeter, Smooth Factor, Aspect Ratio, Form Factor, Rectangularity, Narrow factor, Perimeter ratio of diameter, Perimeter ratio of Physiological Length and Physiological Width, Vein feature, Ripple)
Feature Selection	Genetic Algorithm combined with KPCA using Shared Operator (GA \cap KPCA)
Leaf Recognition	<ul style="list-style-type: none"> (i) BPNN-Based CL-CL Models (BPNN-BPNN, SVM-BPNN, WNN-BPNN models) (ii) SVM-Based CL-CL Models (BPNN-SVM, SVM-SVM, WNN-SVM models) (iii) WNN-Based CL-CL Models (BPNN-WNN, SVM-WNN, WNN -WNN models)

All the results presented in this chapter, performs WEC, WCF and GA \cap KPCA algorithms described in Chapters 4, 5, and 6 respectively, before performing leaf image recognition for plant identification.

8.1. BPNN-BASED CL-CL MODELS

This section presents the performance of BPNN-based CL-CL models that use BPNN classifier in level 1 and BPNN, WNN and SVM classifiers used in level 2 to produce the optimized training set. All the tables indicate the results produced only by the level 2 classifiers. The results, apart from comparing the three proposed BPNN-based CL-CL models, are also compared with the conventional BPNN classifier.

8.1.1. Experimental Results of BPNN-Based CL-CL Models using Standard Dataset

The recognition rate, error rate and speed of classification obtained by the proposed and BPNN models while using Standard dataset are presented in this section.

- **Recognition Rate**

Table 8.2 shows the recognition rate obtained by the BPNN-based CL-CL models while using the single and fused feature sets for Standard dataset.

From the results, it is evident that all the proposed BPNN-based CL-CL models produce improved results when compared with the conventional BPNN model. Comparison between the proposed models revealed that the model that used WNN in level 1 produced the best recognition rate when compared with the other two proposed models (BPNN-BPNN and BPNN-SVM).

Among the five single feature sets, the leaf feature set followed by fractal feature set produces high recognition rate when compared with color, texture and geometric feature sets. On the other hand, in fusion feature set, the combination of leaf and fractals produces the best result when compared to other three fusion feature sets.

All the fused feature sets produce better recognition rate when compared with single feature set proving that the inclusion of fusion algorithm in CAP-LR is successful.

Usage of color feature set results in lower recognition rate. This is because, by nature, the leaves consist of varying colors and usage of color features alone will not produce enough distinction in feature vector. This when combined with leaf feature vector, improves the recognition rate, proving that the leaf feature is important for leaf recognition and plant identification.

TABLE 8.2
RECOGNITION RATE (%) OF BPNN-BASED CL-CL
MODELS (STANDARD)

FEATURES	BPNN-BPNN	SVM-BPNN	WNN-BPNN	BPNN
SINGLE FEATURE SETS				
Geometric	86.43	90.12	91.30	83.90
Color	84.87	88.69	88.79	82.89
Texture	86.41	89.85	90.34	83.52
Fractals	87.16	91.07	92.69	85.35
Leaf	87.76	91.72	92.91	86.05
FUSED FEATURE SETS				
Leaf + Geometric	90.38	94.70	95.88	87.98
Leaf + Color	88.62	92.75	94.26	87.40
Leaf + Texture	89.46	94.12	95.44	87.82
Leaf + Fractals	91.80	96.83	97.13	89.62

From the results of BPNN-based CL-CL models, the winning algorithm is identified as the WNN-BPNN model using the single feature set, leaf (92.91%) and WNN-BPNN model using the fused feature set, leaf + fractals (97.13%). The

efficiency gain of this model over other proposed models and conventional model is shown in Figure 8.1.

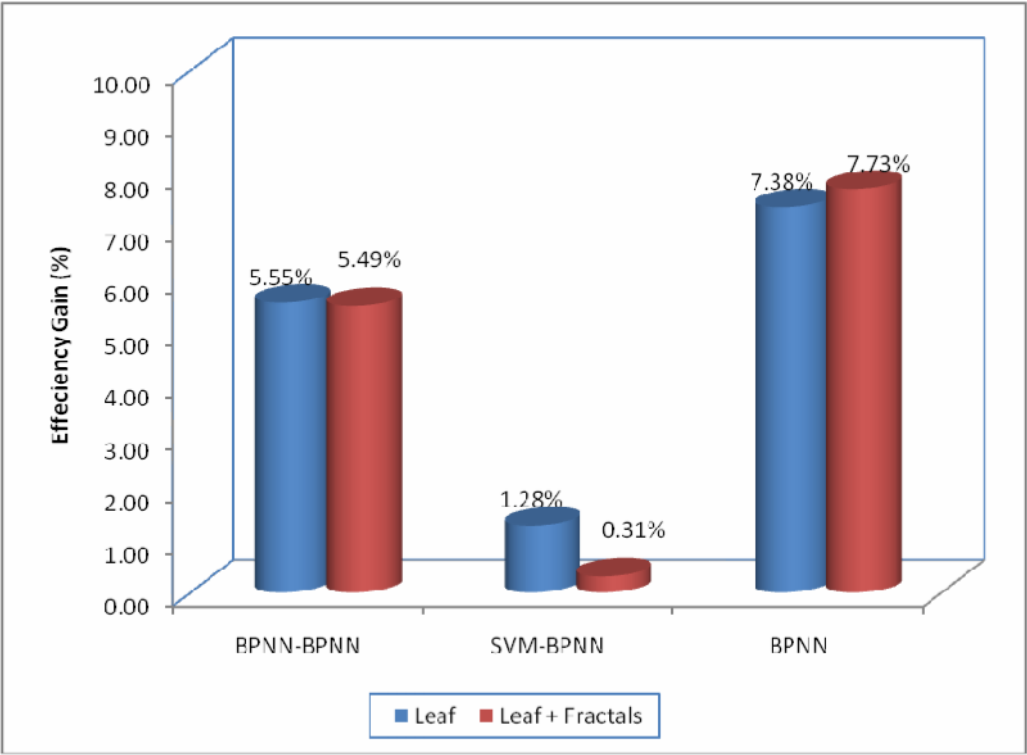


Figure 8.1 : Efficiency Gain of WNN-BPNN Model using Standard Dataset over Recognition Rate

From the figure, it could be seen that the winning leaf classification model produces 5.55%, 1.28% and 7.38% efficiency gain with respect to recognition rate over BPNN-BPNN, SVM-BPNN and conventional BPNN model while using leaf feature set. The same model, produced 5.49%, 0.31% and 7.73% efficiency gain while using leaf + fractal feature set.

- Error Rate**

Table 8.3 produces the error rate of BPNN-BPNN, SVM- BPNN and WNN- BPNN leaf image classifiers along with the conventional BPNN classifier.

TABLE 8.3**ERROR RATE (%) OF BPNN-BASED CL-CL MODELS (STANDARD)**

FEATURES	BPNN-BPNN	SVM-BPNN	WNN-BPNN	BPNN
SINGLE FEATURE SETS				
Geometric	9.13	6.91	6.13	13.14
Color	10.19	8.20	7.37	14.15
Texture	9.45	7.49	6.50	13.57
Fractals	8.71	6.41	5.72	12.74
Leaf	8.40	6.00	5.21	12.37
FUSED FEATURE SETS				
Leaf + Geometric	6.58	4.19	3.74	10.34
Leaf + Color	7.89	5.37	4.64	11.58
Leaf + Texture	7.40	4.93	4.31	11.16
Leaf + Fractals	6.15	3.80	3.34	9.97

The error rate results show that all the proposed BPNN-based models produce low error rate when compared to the conventional model. Further, the results also show that the WNN-BPNN model produces least errors when compared with the other two proposed models. Again, considering the single feature sets, the leaf feature set produced least errors and leaf + fractals performed well by producing minimum errors when compared with the results of other fused feature sets.

Thus, again the winning combination is WNN-BPNN model with leaf (single feature set) and leaf + fractals (fused feature set) with respect to error rate also. To analyze the increased performance obtained by the WNN-BPNN model while using leaf and leaf + fractals feature sets, efficiency gain with respect to error rate was calculated.

The WNN-BPNN model showed 37.92%, 13.18% and 57.85% an efficiency gain while using leaf feature set and 45.69%, 12.11% and 66.50% while using leaf + fractals feature set. This shows that the 2 level leaf recognition algorithm is efficient in terms of error rate also.

- **Speed**

Speed of classification is another important factor that affects the performance of leaf recognition and plant classification. The time taken by the BPNN-based CL-CL models, measured in seconds, for single and fused feature sets is shown in Figures 8.2 and 8.3 respectively.

The results analyzing the speed of the classifiers also show that the WNN-BPNN model results in higher speed when compared with BPNN-BPNN and SVM-BPNN models. All the proposed models are faster than the conventional BPNN model, indicating that the feature selection process reduces the training feature set, which in turn speeds up the classification process.

However, while analyzing single feature sets, the results vary from the results of recognition and error rates. Maximum speed was obtained by the fractal and geometric features, which are closely followed by texture and color feature. Leaf feature requires more time to classify the leaf images. This is because of the number of feature dimensions, which is high with leaf features.

Fusion of leaf features with other features still increases the number of feature dimensions and hence are still slower. However, the inclusion of $GA \cap KPCA$ dimensionality reduction makes sure that the speed difference is not maximum between feature sets. While considering fused feature sets, Leaf + Fractals results in faster recognition followed by leaf +Geometric feature set.

Thus, the winning combination with respect to speed is WNN + BPNN model with fractal features for single feature set and Leaf + Fractals for fusion based feature set.

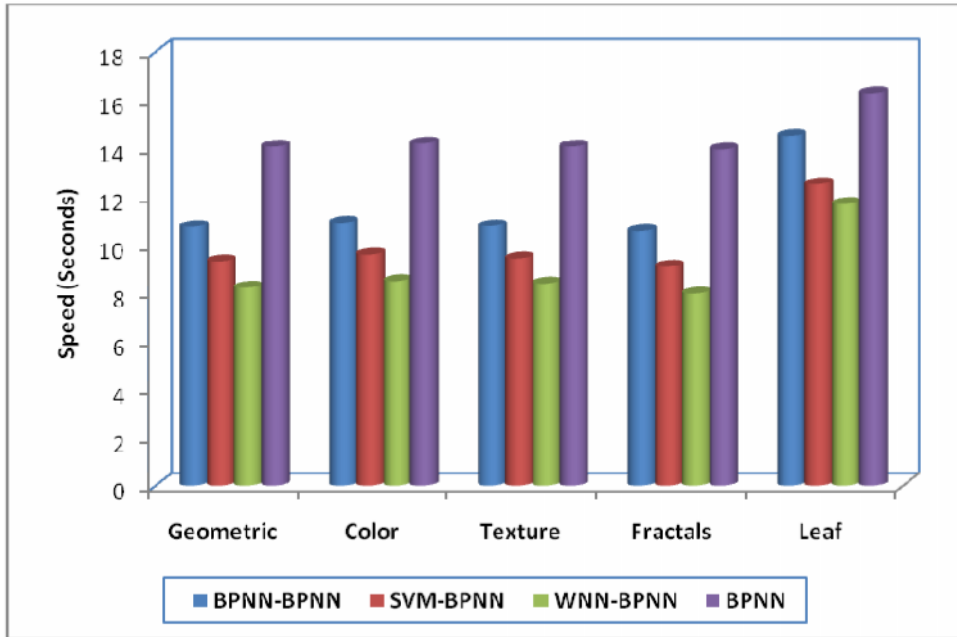


Figure 8.2: Speed of BPNN-based CL-CL Models (Single Feature Sets)

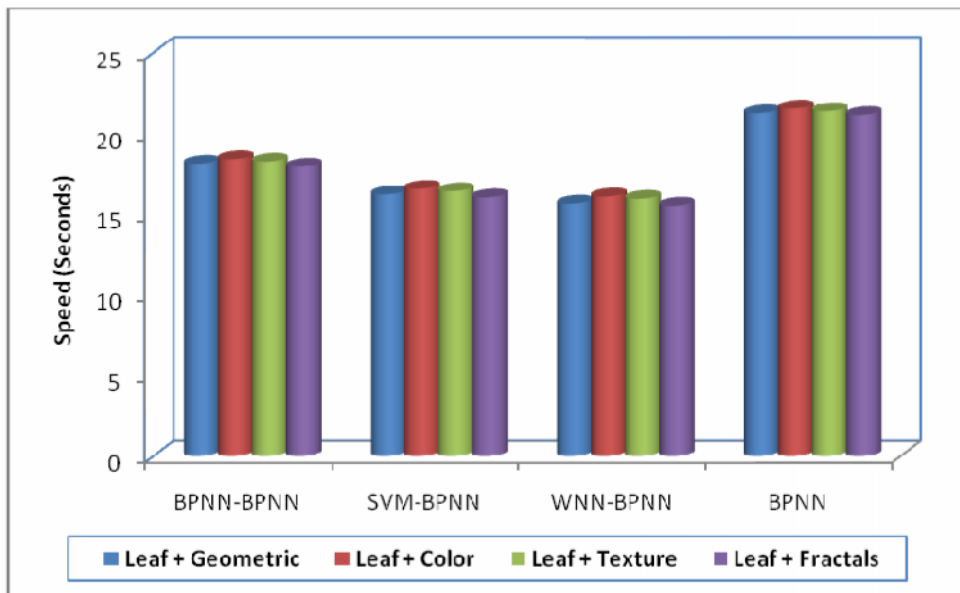


Figure 8.3: Speed of BPNN-based CL-CL Models (Fused Feature Sets)

8.1.2. Experimental Results of BPNN-Based CL-CL Models using Real Dataset

This section presents the recognition rate, error rate and speed of recognition while using the real dataset.

- **Recognition Rate**

Table 8.4 presents recognition rate of the BPNN-based CL-CL classifiers while using the single and fusion feature sets.

TABLE 8.4
RECOGNITION RATE OF BPNN-BASED CL-CL MODELS (REAL)

FEATURES	BPNN-BPNN	SVM-BPNN	WNN-BPNN	BPNN
SINGLE FEATURE SETS				
Geometric	85.52	89.47	90.78	82.91
Color	84.67	88.00	88.45	82.63
Texture	86.29	89.41	90.08	83.17
Fractals	87.16	90.91	92.67	84.76
Leaf	87.33	91.28	92.73	85.42
FUSED FEATURE SETS				
Leaf + Geometric	90.16	94.52	95.20	87.29
Leaf + Color	88.11	92.31	93.78	87.35
Leaf + Texture	89.15	93.62	95.14	86.90
Leaf + Fractals	91.39	96.15	96.94	89.38

The results obtained with real dataset are similar to that of the Standard dataset while using recognition rate as performance metric. Here also, the WNN-BPNN model with leaf features (single features) and leaf + fractals (fused features) produce maximum recognition rate. Figure 8.4 presents the efficiency gain of the winning model over BPNN-BPNN and SVM-BPNN models for both leaf and leaf + fractals feature sets.

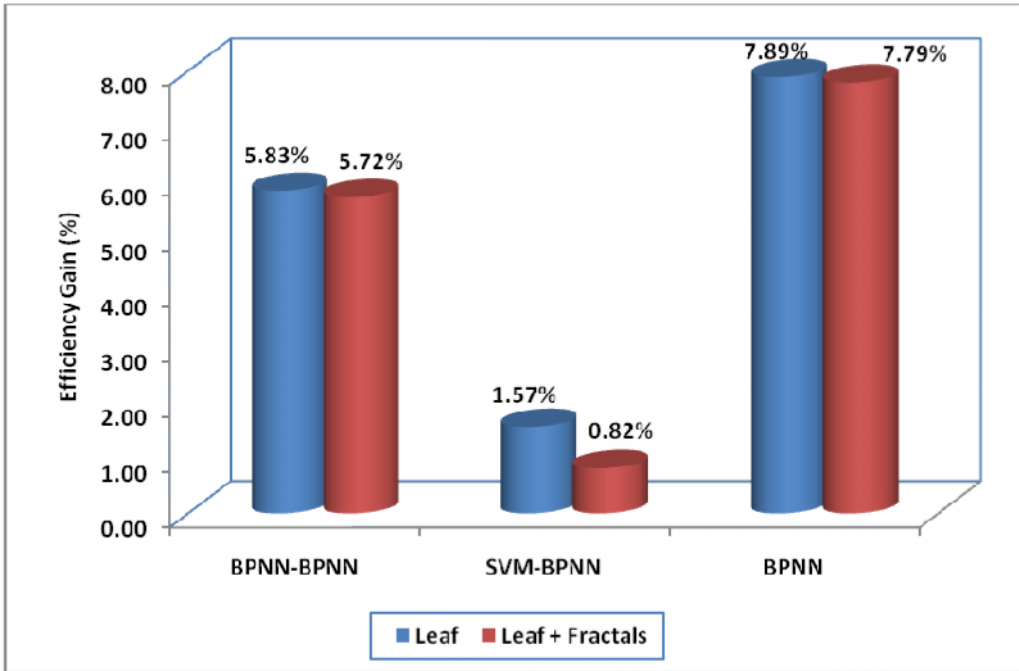


Figure 8.4 : Efficiency Gain of WNN-BPNN Model using Real Dataset over Recognition Rate

From the result, it can be seen that the usage of WNN to optimize the operations of BPNN classifier is successful and produces positive gain irrespective of the feature set used. A maximum efficiency gain of 7.89% and 7.79% was achieved by WNN-BPNN over conventional BPNN while using leaf and leaf + fractals feature sets.

- **Error Rate**

Figures 8.5 and 8.6 present the error rate of BPNN-based CL-CL models when applied with the five single feature sets (geometric, color, texture, fractals and leaf) and four fusion feature sets (Geometric+leaf, color+leaf, texture +leaf and Fractals+leaf) respectively.

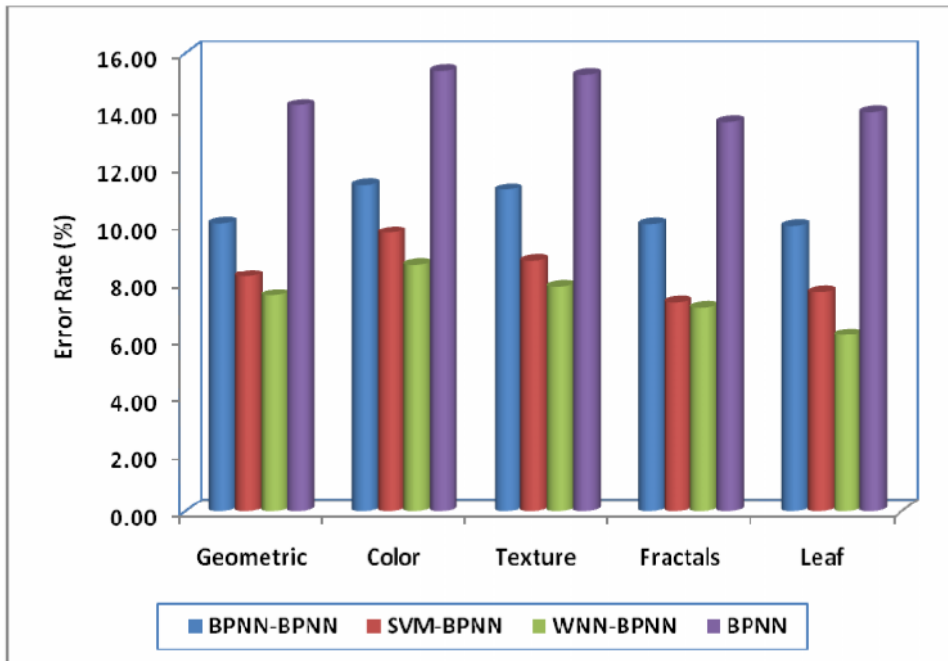


Figure 8.5 : Error Rate of BPNN-based CL-CL Models (Single Features)

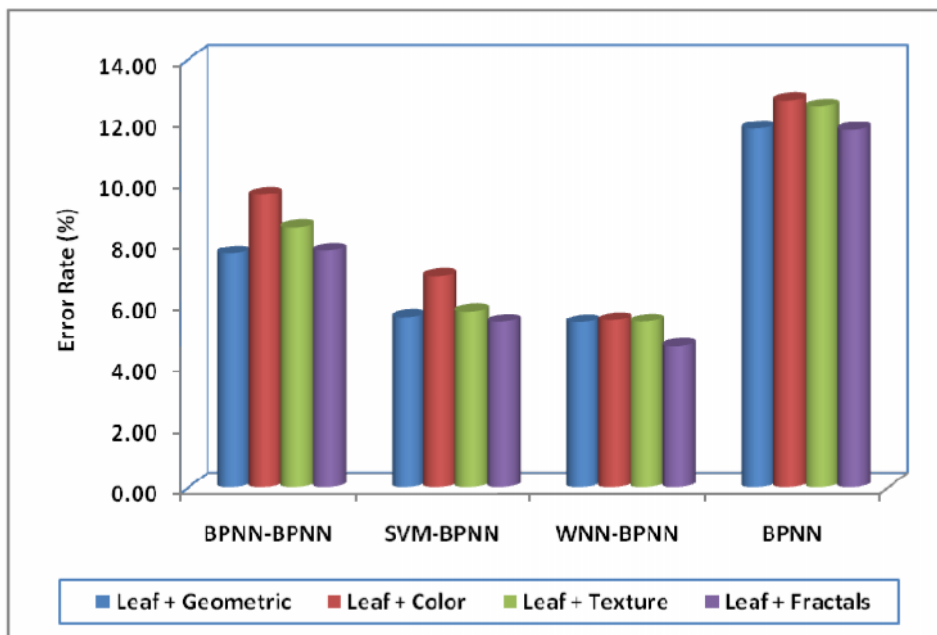


Figure 8.6 : Error Rate of BPNN-based CL-CL Models (Fused Features)

The results from the figures also indicate that the WNN-BPNN model reduces the classification errors while using both single and fused feature sets. The leaf feature set and the feature set, combining leaf and fractal feature set, improves the classifier performance with respect to error rate.

TABLE 8.5**EFFICIENCY GAIN (%) OF WNN-BPNN MODEL FOR LEAF AND LEAF+FRACTAL FEATURE SETS (REAL DATASET)**

Feature Set	BPNN-BPNN	SVM-BPNN	BPNN
Leaf	38.33	19.73	55.85
Leaf + Fractals	40.36	14.69	60.53

The WNN-BPNN model with leaf feature set produced an error rate of 6.15% and leaf + fractal feature set produced 4.61% error rate which has produced maximum efficiency gain when compared with other two proposed models and BPNN models as shown in the above table. The efficiency gain obtained by the WNN-BPNN model with respect to error rate is shown in Table 8.5.

- **Speed**

Table 8.6 shows the speed of the BPNN-based CL-CL models for both single and fused feature sets. The results are again compared with the traditional BPNN model.

TABLE 8.6**SPEED OF BPNN-BASED CL-CL MODELS (REAL)**

FEATURES	BPNN-BPNN	SVM-BPNN	WNN-BPNN	BPNN
SINGLE FEATURE SETS				
Geometric	11.76	10.40	9.05	15.01
Color	12.32	11.54	11.08	14.83
Texture	11.91	10.52	9.18	15.19
Fractals	11.60	10.37	8.82	14.71
Leaf	15.25	13.34	13.26	17.70
FUSED FEATURE SETS				
Leaf + Geometric	19.32	17.30	16.64	22.27
Leaf + Color	20.06	18.05	17.50	23.00
Leaf + Texture	19.62	17.58	16.97	22.76
Leaf + Fractals	18.92	17.31	16.54	21.99

The results shows that the speed with regard to real dataset is similar to that of standard dataset and the WNN-BPNN model with fractals feature set and WNN-BPNN model with leaf + fractals feature set are the models with high speed.

8.2. SVM-BASED CL-CL MODELS

This section presents the results of CL-CL models which use the results of BPNN, SVM and WNN classifiers (level 1) to improve the results of SVM classifier in level 2. The results compare the effect of using the selected single and fusion based feature sets. Further, as the operation of SVM is enhanced, the results are also compared with the conventional SVM classifier.

8.2.1. Experimental Results of SVM-Based CL-CL Models using Standard Dataset

This section presents the recognition rate of the proposed enhanced SVM-based CL-CL models.

- Recognition Rate**

Figures 8.7 and 8.8 present the recognition rate of the SVM-based CL-CL models.

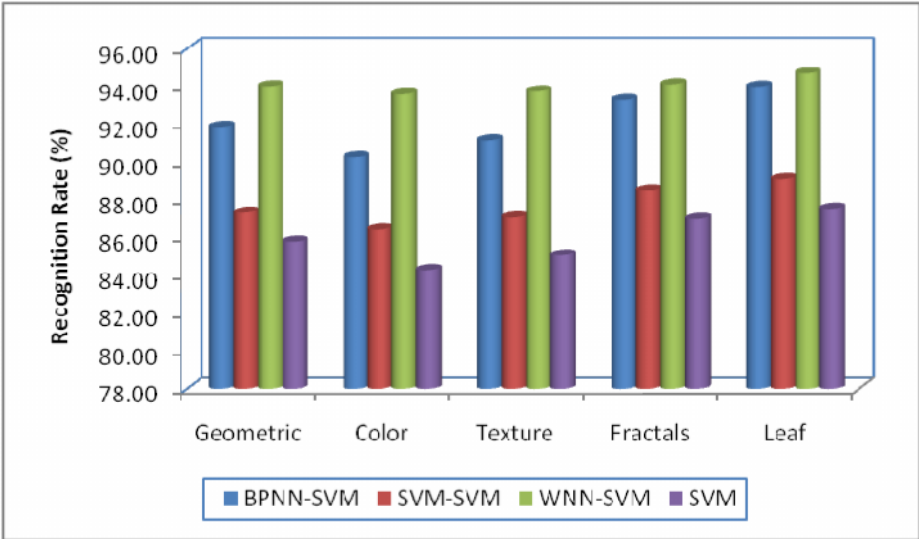
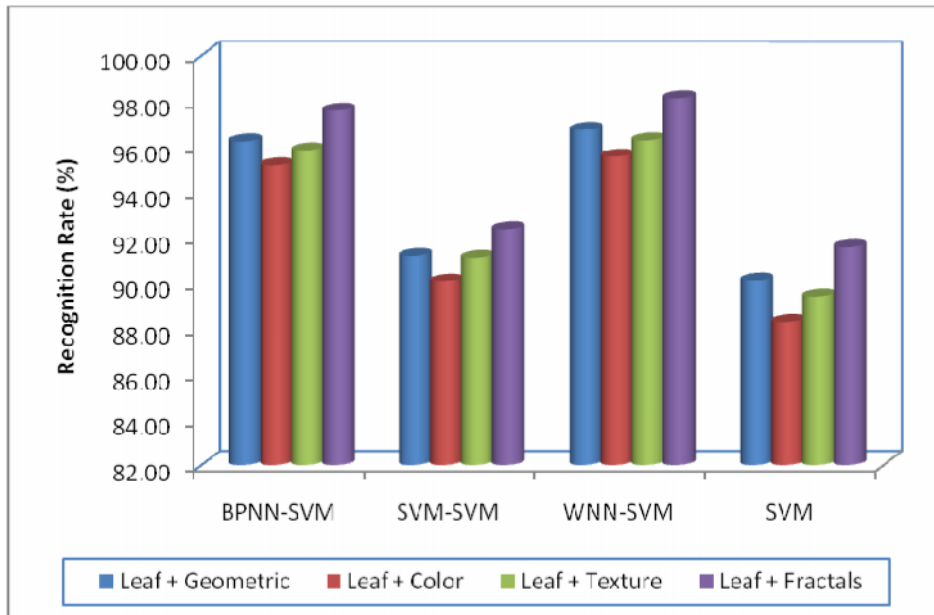


Figure 8.7 : Recognition Rate of SVM-based CL-CL Models (Single Feature Sets – Standard Dataset)



**Figure 8.8 : Recognition Rate of SVM-based CL-CL Models
(Fused Feature Sets – Standard Dataset)**

The results related to recognition rate indicate that all the proposed SVM-based CL-CL models produce better results than the traditional SVM classifier. Further, the results also show that the SVM classifier that was enhanced using WNN algorithm is more accurate than other classifiers.

While analyzing the performance of the classifiers with respect to the feature set used, the leaf feature set and fractal feature set shows promising results. All the fused feature set produce better results than single feature sets. The combination of leaf and fractal feature set produce high recognition accuracy. A maximum of 98.11% percentage was achieved by the WNN-SVM model while using leaf + fractal fusion feature set from Standard dataset.

The efficiency gain of the winning models with respect to recognition rate over the other classifiers is shown in Table 8.7.

TABLE 8.7**EFFICIENCY GAIN (%) OF RECOGNITION RATE FOR STANDARD LEAF DATASET**

Features	BPNN-SVM	SVM-SVM	SVM
Leaf	0.75	5.93	7.58
Leaf + Fractals	0.54	5.86	6.66

From the result it can be seen that the WNN classifier has improved the accuracy of leaf recognition for plant classification and proves that the methodology of using 2 level classification process is successful and advantageous.

- **Error Rate**

Table 8.8 presents the error rates of SVM-based CL-CL models.

TABLE 8.8**ERROR RATE OF SVM-BASED CL-CL MODELS (STANDARD)**

FEATURES	BPNN-SVM	SVM-SVM	WNN-SVM	SVM
SINGLE FEATURE SETS				
Geometric	5.61	7.78	5.38	10.93
Color	6.82	8.64	6.37	12.18
Texture	6.15	8.10	5.77	11.44
Fractals	5.15	7.29	4.84	10.57
Leaf	4.69	6.95	4.52	10.14
FUSED FEATURE SETS				
Leaf + Geometric	3.13	4.79	2.62	8.43
Leaf + Color	4.14	6.26	3.84	9.52
Leaf + Texture	3.76	5.69	3.48	9.19
Leaf + Fractals	2.66	4.49	2.10	7.94

The results obtained again show the WNN-SVM model as the winning CL-CL classifier to recognize leaves for plant identification. The dataset shows low error rate while comparing the five selected single features. In a similar fashion, the leaf +

fractals produces low error rates while comparing the usage of other three fusion feature sets.

- **Speed**

Figures 8.9 and 8.10 show the speed of the SVM-based CL-CL classifiers using single and fused feature sets for Standard dataset.

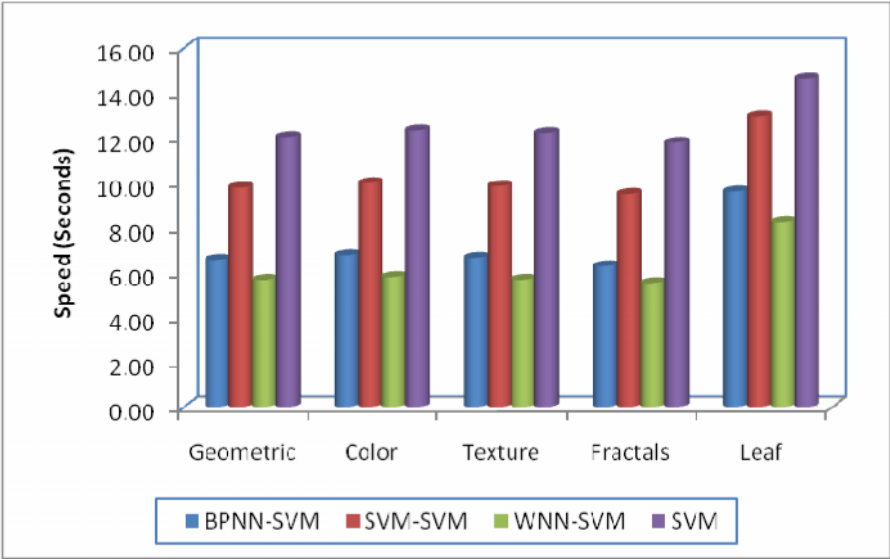


Figure 8.9 : Speed of SVM-based CL-CL Models (Single Feature Sets – Standard Dataset)

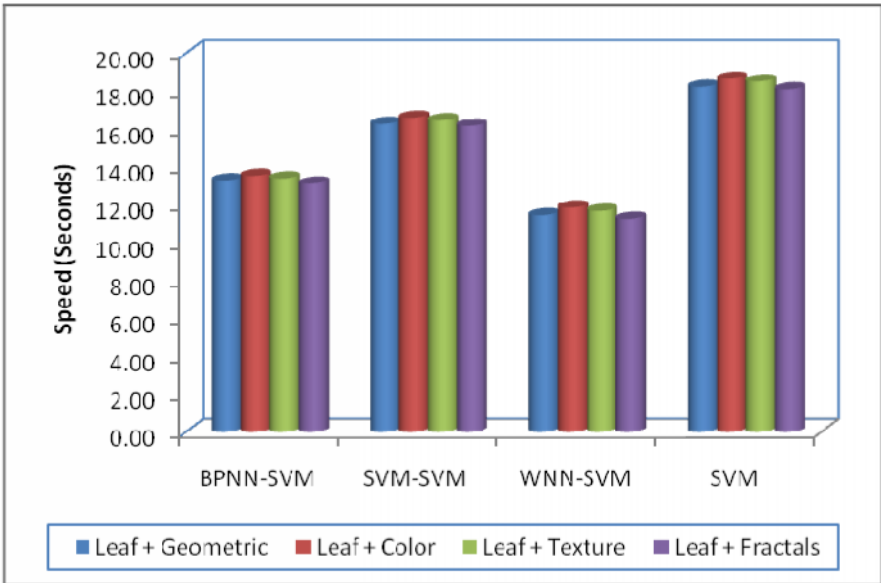


Figure 8.10 : Speed of SVM-based CL-CL Models (Fused Feature Sets – Standard Dataset)

While considering the speed as a performance estimator, again the WNN-SVM model proved to be quick in recognizing the leaf image. However, while considering the single feature sets, the fractal feature set proved to be efficient when compared with others. The leaf + fractal were efficient while considering the fusion feature set.

Thus, taking into consideration all the metrics, the SVM-WNN model with leaf + fractal feature set is considered to be the winner among the SVM-based CL-CL models while using the standard dataset of leaf images.

8.2.2. Experimental Results of SVM-Based CL-CL Models using Real Dataset

This section presents the recognition rate, error rate and speed of the SVM-based CL-CL models for real dataset.

- **Recognition Rate**

Tables 8.9 shows the recognition rate of the SVM-based CL-CL models for both the selected single features and fused features for real dataset.

The results show that the CL-CL model that used WNN for optimizing the training feature set (level 1) and whose result is used by SVM (level 2) to classify leaf images for plant identification produces better quality recognition rate than BPNN-SVM and SVM-SVM CL-CL models. The efficiency gain obtained by WNN-SVM model with respect to recognition rate is presented in Table 8.10.

From the table results, it is evident that the usage of WNN to optimize the working of SVM classifier is successful with both leaf and leaf + fractals feature sets obtained from real dataset. Similarly, the leaf + fractals feature set showed an efficiency gain of 0.50% when compared with leaf feature set for WNN-SVM classifier. This shows that the usage of feature fusion technique along with the GA \cap KPCA feature selection algorithm have improved the leaf recognition process.

TABLE 8.9**RECOGNITION RATE OF SVM-BASED CL-CL MODELS (REAL)**

FEATURES	BPNN-SVM	SVM-SVM	WNN-SVM	SVM
SINGLE FEATURE SETS				
Geometric	91.70	87.14	93.11	84.86
Color	89.55	86.36	93.15	84.12
Texture	90.67	86.92	93.58	84.09
Fractals	92.98	87.81	93.21	86.16
Leaf	93.97	88.11	94.68	87.44
FUSED FEATURE SETS				
Leaf + Geometric	95.77	90.71	96.51	89.62
Leaf + Color	94.19	89.89	94.68	87.41
Leaf + Texture	95.61	90.44	95.50	88.87
Leaf + Fractals	97.44	91.69	97.92	91.52

TABLE 8.10**EFFICIENCY GAIN (%) OF RECOGNITION RATE FOR STANDARD LEAF DATASET**

Features	BPNN-SVM	SVM-SVM	SVM
Leaf	0.75	6.93	7.64
Leaf + Fractals	0.50	6.37	6.54

- **Error Rate**

The error rate obtained by the various SVM-based CL-CL models is tabulated in Table 8.11.

TABLE 8.11**ERROR RATE OF SVM-BASED CL-CL MODELS (REAL)**

FEATURES	BPNN-SVM	SVM-SVM	WNN-SVM	SVM
SINGLE FEATURE SETS				
Geometric	6.70	9.16	6.92	12.63
Color	7.78	10.19	7.72	13.53
Texture	7.21	9.00	7.15	13.21
Fractals	6.27	9.00	6.18	12.18
Leaf	5.68	8.48	5.46	11.63
FUSED FEATURE SETS				
Leaf + Geometric	4.85	5.78	4.07	10.08
Leaf + Color	5.08	7.52	5.44	11.17
Leaf + Texture	5.46	6.65	4.73	10.01
Leaf + Fractals	3.81	5.33	3.38	8.85

The results concerned with error rate performance metric also demonstrate a similar relationship as that of Standard dataset. Here also the WNN-SVM using leaf (single feature) and leaf + fractal (fused feature) shows a reduction in error rate when compared to the other models.

- **Speed**

Figures 8.11 and 8.12 show the efficiency of the classifiers used for recognizing the leaf images in terms of speed.

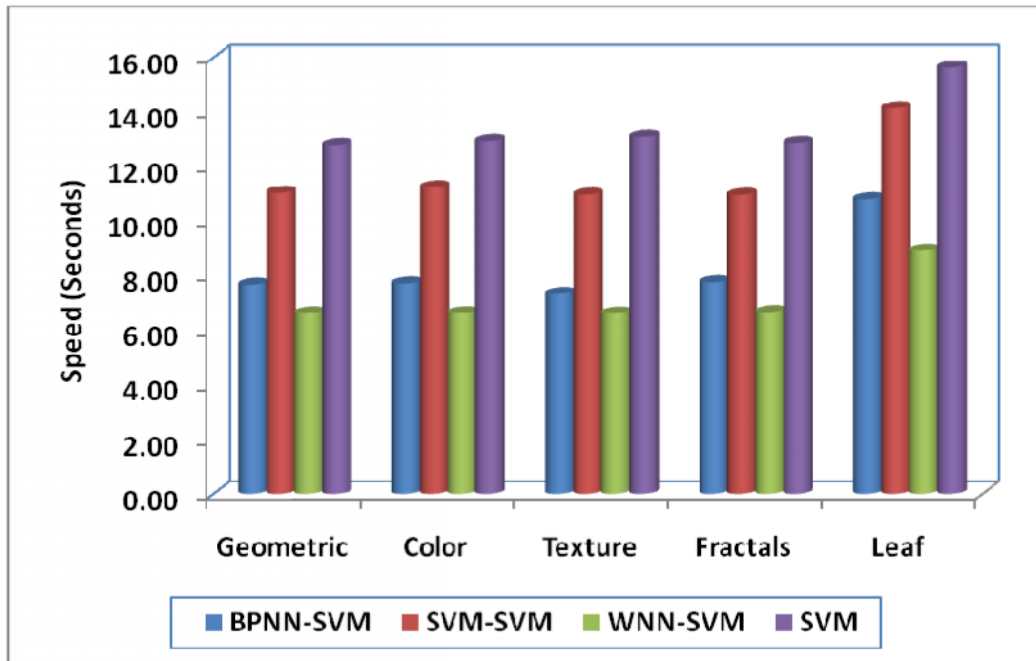


Figure 8.11: Speed of SVM-based CL-CL Models (Single Feature Sets – Real Dataset)

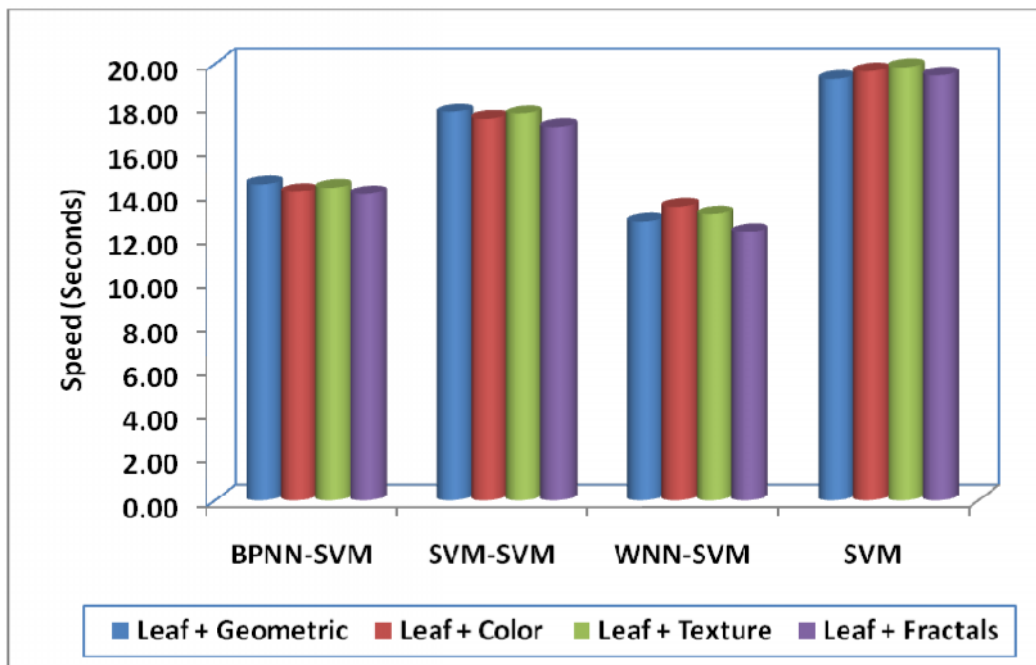


Figure 8.12: Speed of SVM-based CL-CL Models (Fused Feature Sets – Real Dataset)

From the results, it is evident that the WNN-SVM model using leaf + fractal feature set is the quickest to produce recognition results when compared with all other SVM-based CL-CL models.

From the various results presented in this section, it is clear that the WNN-SVM model using leaf + fractal feature produces maximum gain with respect to recognition rate, error rate and speed of classification.

8.3. WNN-BASED CL-CL MODELS

This section presents the results of the WNN-based CL-CL models while using the five selected single feature sets and four fusion feature sets extracted from standard and real datasets.

8.3.1. Experimental Results of WNN-Based CL-CL Models using Standard Dataset

The results obtained by the various selected performance metrics by the WNN-based CL-CL models using standard dataset are presented in this section.

- **Recognition Rate**

Figures 8.13 and 8.14 present the recognition rate of WNN-based CL-CL models using single and fused feature sets respectively.

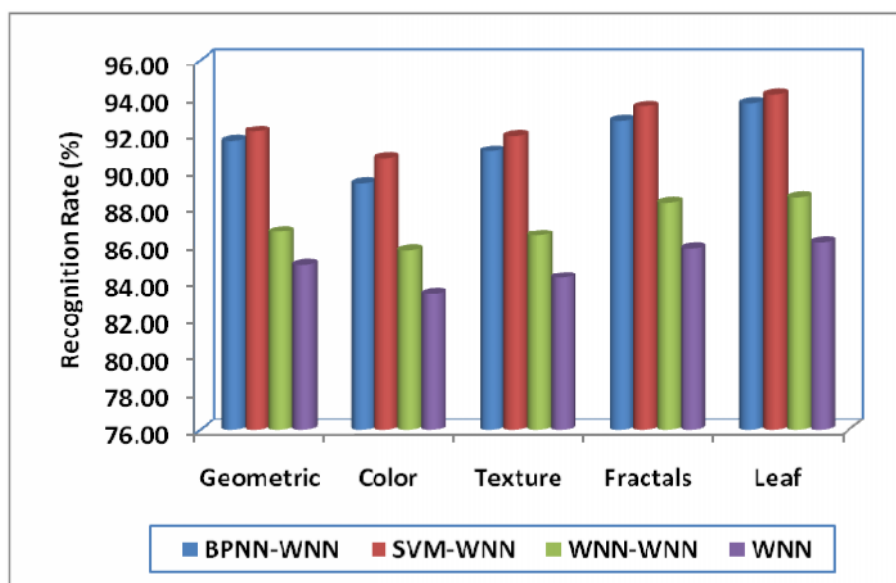


Figure 8.13 : Recognition Rate of SVM-based CL-CL Models (Single Feature Sets – Standard Dataset)

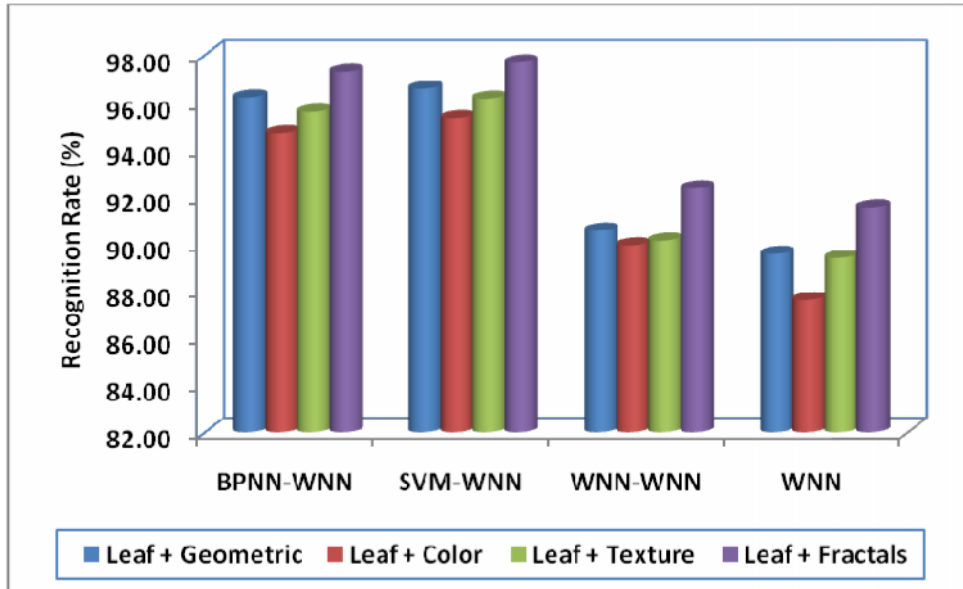


Figure 8.14 : Recognition Rate of SVM-based CL-CL Models (Fused Feature Sets – Standard Dataset)

While considering the results of recognition rates, all the proposed WNN-based CL-CL models, namely, BPNN-WNN, SVM-WNN and WNN-WNN, showed increased performance compared with the conventional WNN model. Comparing the performance of the proposed classifiers revealed that the SVM classifier used in level 2 produced high accuracy on classifying leaf images. As with other CL-CL models, the leaf and leaf + fractals feature set maximized the performance of the classifiers ability to correctly recognize the leaf images.

The SVM-WNN model produced an efficiency gain of 0.47% and 0.41% over BPNN-SVM model while using leaf and leaf + fractal feature sets respectively. The same over WNN-WNN model was 5.92% and 5.47% respectively and WNN model was 8.49% and 6.29% respectively. This clearly proves that the WNN model using the optimized training results of SVM model while using leaf and leaf + fractal feature set produces maximum advantage while considering leaf recognition rate.

- **Error Rate**

Table 8.12 show the error rate of the WNN-based CL-CL models for standard dataset.

TABLE 8.12

ERROR RATE OF WNN-BASED CL-CL MODELS (STANDARD)

FEATURES	BPNN-WNN	SVM-WNN	WNN-WNN	WNN
SINGLE FEATURE SETS				
Geometric	5.64	5.42	8.24	11.39
Color	6.96	6.63	9.26	12.69
Texture	6.20	5.78	8.61	11.80
Fractals	5.20	5.04	7.89	10.96
Leaf	4.80	4.64	7.50	10.49
FUSED FEATURE SETS				
Leaf + Geometric	3.24	2.92	5.70	8.56
Leaf + Color	4.23	3.86	6.70	9.78
Leaf + Texture	3.78	3.49	6.39	9.23
Leaf + Fractals	2.93	2.51	5.22	8.14

The results in the above table also prove that the SVM-WNN model using leaf and leaf + fractal feature sets produces lower error rates thus confirming the high efficiency of the model.

- **Speed**

Table 8.13 presents the time taken by the WNN-based CL-CL models in seconds for recognizing a leaf image from standard dataset.

TABLE 8.13**SPEED OF WNN-BASED CL-CL MODELS (STANDARD)**

FEATURES	BPNN-WNN	SVM-WNN	WNN-WNN	WNN
SINGLE FEATURE SETS				
Geometric	7.15	6.18	10.16	13.02
Color	7.31	6.32	10.35	13.31
Texture	7.21	6.19	10.16	13.11
Fractals	7.01	5.97	9.94	12.76
Leaf	10.26	9.07	13.32	16.27
FUSED FEATURE SETS				
Leaf + Geometric	13.44	12.34	17.27	19.07
Leaf + Color	13.75	12.75	17.63	19.50
Leaf + Texture	13.56	12.63	17.44	19.32
Leaf + Fractals	13.24	12.15	17.15	18.90

Considering single feature set, the fractals feature followed by geometric feature produced fast recognition results. Similarly, while considering feature sets produced by GA \cap KPCA algorithm, the leaf + fractals produce good results with high speed. All the classifiers were quick in producing recognition results when compared to the conventional WNN model. Comparison between WNN-based models reveals SVM-WNN model as the classifier with high speed.

8.3.2. Experimental Results of WNN-Based CL-CL models using Real Dataset

The recognition rate, error rate and speed of the WNN-based CL-CL model when presented with real dataset are presented in this section.

- **Recognition Rate**

Table 8.14 shows the recognition rate of the WNN-based CL-CL models.

TABLE 8.14**RECOGNITION RATE OF WNN-BASED CL-CL MODELS (REAL)**

FEATURES	BPNN-WNN	SVM-WNN	WNN-WNN	WNN
SINGLE FEATURE SETS				
Geometric	91.16	91.26	85.76	84.72
Color	89.02	90.67	85.24	83.27
Texture	90.88	91.62	86.45	83.28
Fractals	91.88	92.97	87.81	85.74
Leaf	93.21	93.51	87.99	86.10
FUSED FEATURE SETS				
Leaf + Geometric	96.05	96.03	89.60	89.08
Leaf + Color	94.54	94.69	89.73	86.71
Leaf + Texture	94.91	95.73	89.46	89.27
Leaf + Fractals	96.91	97.40	92.17	91.29

The trend obtained here is the same as that of Standard dataset and shows that WNN classifier when used with SVM for level 2 classification produces the best result. The importance of leaf feature in recognition is again stressed by the high recognition rate obtained while using leaf feature and leaf + fractals feature sets with WNN-based CL-CL models. The efficiency of the winning model SVM + WNN showed an efficiency increase of 3.99% while using the fused feature set over single feature set. This shows that the performance of the model can be increased by using feature fusion technique.

- **Error Rate**

Table 8.15 presents the error rate of the proposed WNN-based CL-CL model while using the nine features extracted from real dataset.

TABLE 8.15**ERROR RATE OF WNN-BASED CL-CL MODELS (REAL)**

FEATURES	BPNN-WNN	SVM-WNN	WNN-WNN	WNN
SINGLE FEATURE SETS				
Geometric	7.04	6.86	9.15	12.33
Color	8.38	7.78	10.09	13.93
Texture	7.76	7.04	10.05	13.08
Fractals	6.37	6.45	9.56	12.21
Leaf	6.23	5.62	8.94	11.51
FUSED FEATURE SETS				
Leaf + Geometric	4.43	4.47	7.01	9.42
Leaf + Color	5.37	5.52	7.93	11.07
Leaf + Texture	5.36	5.02	7.64	10.95
Leaf + Fractals	4.15	3.93	6.42	9.11

The results obtained while using real dataset is the same as the results obtained from Standard dataset and shows that the SVM-WNN model using leaf feature set in single feature category and leaf + fractals feature set in fusion based feature category produces improved error rate when compared with the other models.

- **Speed**

The speed of the various WNN-based CL-CL models is shown in Figures 8.15 and 8.16.

The results show that the usage of fractal feature set and geometric feature set produces a fast result when compared with color and texture feature set. In contrast to the other parameters, leaf feature set takes longer time to produce recognition results. But this trend changed with fused feature sets, where again the leaf + fractals feature set produce fast results.

Comparison between classifiers reveals a trend that is similar to that of standard dataset. Further, among the four classifiers, the conventional WNN model is the slowest. This shows that the feature selection algorithm combining the results of Genetic Algorithm (GA) and Kernel Principal Component Analysis (KPCA) using shared (\cap) operator is a positive part of CAP-LR system.

Table 8.16 presents the details of the CL-CL models for the three selected parameters for both standard and real datasets. The ranking order of the various feature sets used is presented in Table 8.17. The ranking order of the various CL-CL models proposed with respect to recognition rate, error rate and speed, is presented in Table 8.18.

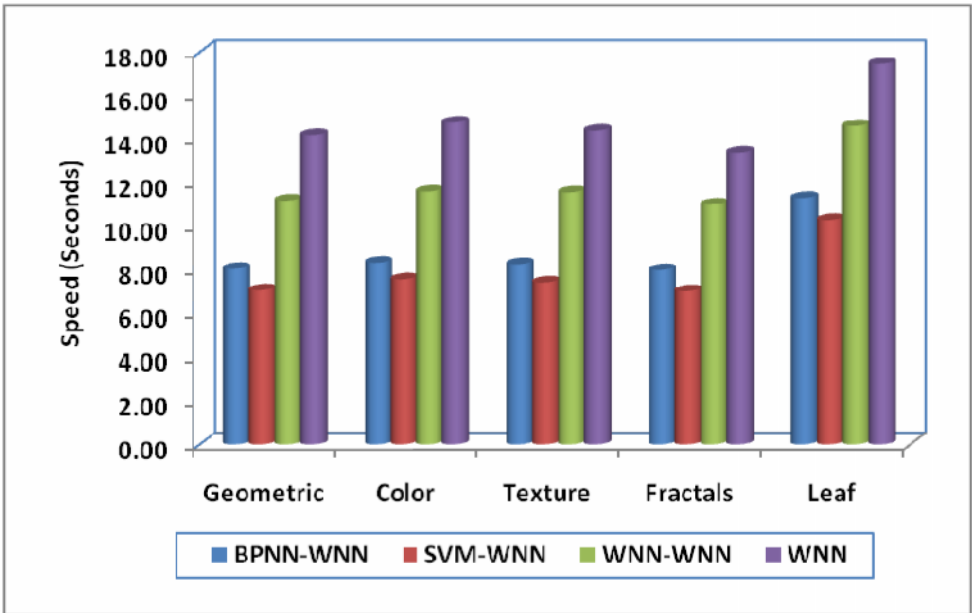


Figure 8.15 : Speed of WNN-based CL-CL Models (Single Feature Sets – Real Dataset)

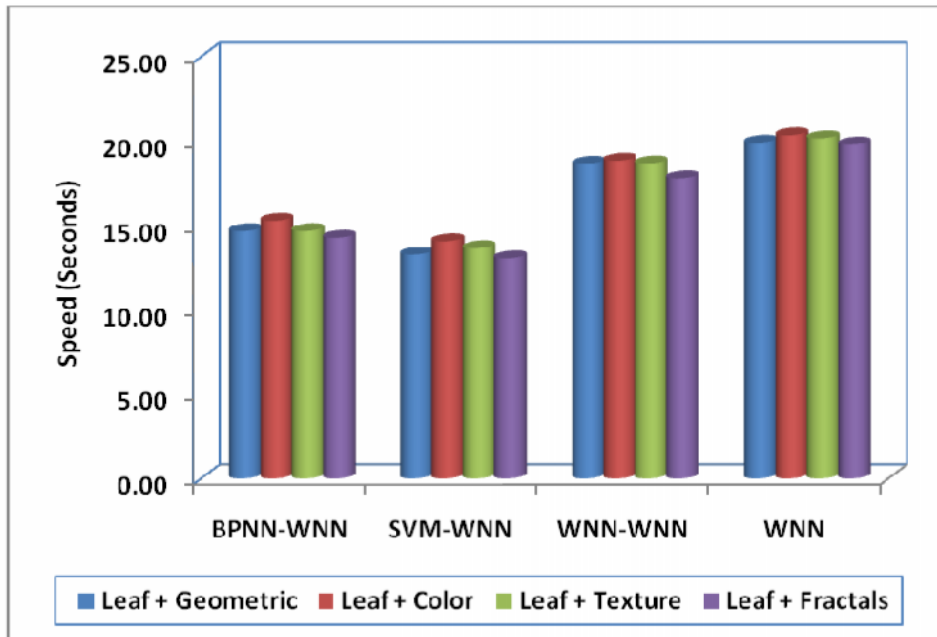


Figure 8.16 : Speed of WNN-based CL-CL Models (Fused Feature Sets – Real Dataset)

TABLE 8.16

DETAILS OF WINNING MODELS

Feature Sets	BPNN-Based CL-CL Models		SVM-Based CL-CL Models		WNN-Based CL-CL Models	
	Standard	Real	Standard	Real	Standard	Real
Recognition Rate (%)						
Winning Model	WNN-BPNN		WNN-SVM		SVM-WNN	
Leaf	92.91	92.73	94.71	94.68	94.13	93.51
Leaf + Fractals	97.13	96.94	98.11	97.92	97.68	97.40
Error Rate (%)						
Leaf	5.21	6.15	4.52	5.46	4.64	5.62
Leaf + Fractals	3.34	4.61	2.10	3.38	2.51	3.93
Speed (Seconds)						
Fractals	7.96	8.82	5.52	6.66	5.97	7.43
Leaf + Fractals	15.53	16.64	11.27	12.29	12.15	13.27

TABLE 8.17**PERFORMANCE RANKING ORDER OF THE FEATURE SETS**

Feature Sets	Ranking Order	
	Recognition and Error Rates	Speed
Single Feature Sets		
Geometric	4	2
Color	5	4
Texture	3	3
Fractals	2	1
Leaf	1	5
Fused Feature Sets		
Leaf + Geometric	2	2
Leaf + Color	4	4
Leaf + Texture	3	3
Leaf + Fractals	1	1

TABLE 8.18**PERFORMANCE RANKING ORDER OF THE PROPOSED CL-CL MODELS**

Model	Ranking Order
BPNN-BPNN	9
SVM-BPNN	6
WNN-BPNN	5
BPNN-SVM	3
SVM-SVM	7
WNN-SVM	1
BPNN-WNN	4
SVM-WNN	2
WNN-WNN	8
SVM	10
WNN	11
BPNN	12

Thus, from the various experiments it was found that the WNN-SVM model with fused feature set, leaf + fractal is best suited to recognize leaf images for plant identification.

The winning algorithm WNN-SVM algorithm showed a maximum of 98.11% and 97.92% accuracy while using leaf features with fractal features. As mentioned previously in chapter 3, the work was motivated by Wu *et al.* (2007) system, where an average accuracy of 90.31% was achieved. This shows that the proposed amalgamation of algorithms have improved the performance of leaf recognition and thus, plant identification tasks and the efficiency gain achieved by the WNN-SVM model when compared to Wu *et al.* model showed 7.95% and 7.77% while using standard and real leaf image dataset with respect to accuracy.

8.4. CHAPTER SUMMARY

This chapter presented the results pertaining to the various proposed CL-CL models. The three performance metrics, namely, recognition rate, error rate and speed was used for this purpose. The proposed CL-CL model was grouped into three categories based on the classifier used in level 2. The results showed WNN-BPNN, WNN-SVM and SVM-WNN models as the efficient classifiers to identify plants. The work is summarized along with future research directions in the next chapter, **Summary and Conclusion**.