Quantitative Analysis of Sucrose, Raffinose and Moisture Content in Sugarbeets Utilizing Hyperspectral Imaging and Advanced Machine Learning Techniques

by

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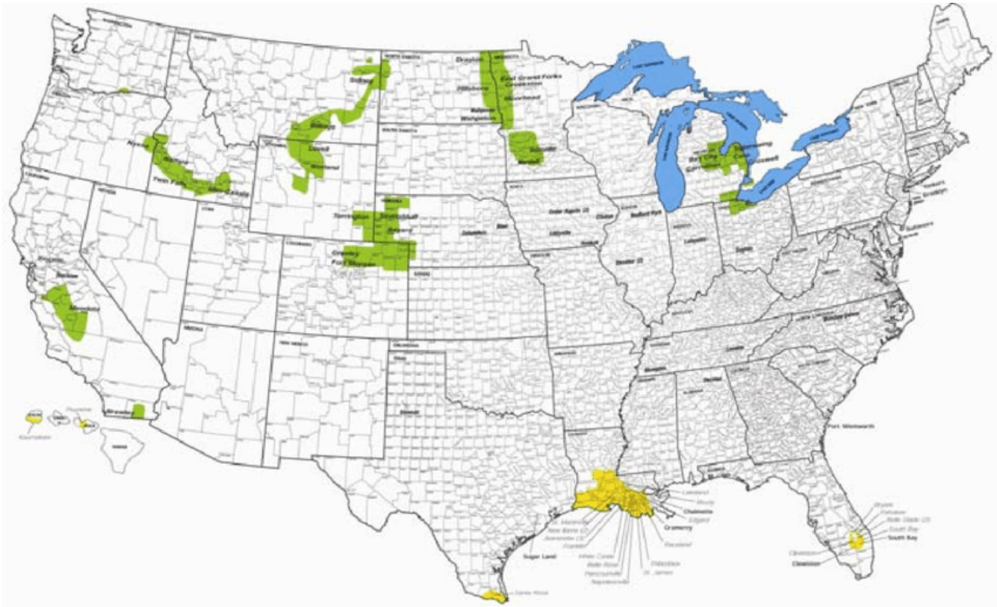
Sugar Beet Industry Overview

1 Global Importance

20-25% of sugar worldwide is produced from sugarbeets. The other 75-80% comes from sugarcane.

2 U.S. Production

9-12% to the global 20%. This is about 9 million tons of sugar annually.



3 Sugar

Sucrose = Glucose and Fructose.

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Composition of Sugarbeets

Component	Concentration %
Moisture	75 - 86
Sucrose	15 - 20
Non-sucrose	2 - 3
Pulp	~ 5

Raffinose = Galactose + Glucose + fructose

Sucrose

Moisture content

Need for Rapid Analysis

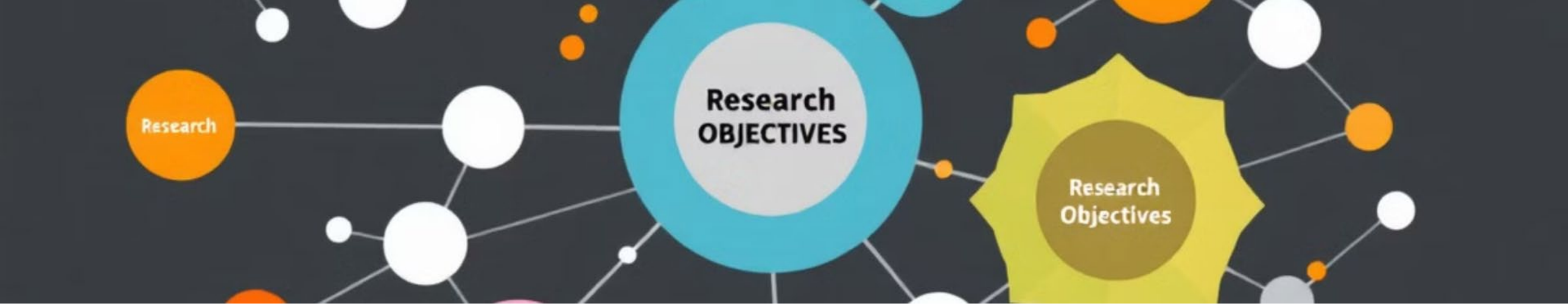
- Farmers get paid based on recoverable sugar per acre.
- Processors want beets with high sucrose content for more profits.
- Factories to adjust extraction and purification processes.
- Monitoring roots while in storage

Sucrose

Moisture content

Need for Rapid Analysis

- High moisture dilutes sucrose content.
- Excess moisture promotes microbial growth.
- Affects slicing, diffusion, and drying processes.



Objective

Develop models to accurately measure sucrose, raffinose and moisture content in sugar beets.

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Sample Acquisition and Preparation

To increase variability, Sugar beet samples were collected from three locations; Moorhead, MN, Renville, MN, and Wahpeton, ND

To further increase variability, they were sliced (15mm) and cored (15mm).

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Hyperspectral Image Acquisition

Camera

Specim SWIR camera in the spectral region of 1,000-2,500 nm.

Lighting

Images will be captured in a dark room to prevent interference.

Processing

Image analysis and modeling were done using Python 3.10.11.

Measuring Moisture Content

Ermis & Özkan, (2021)

- Wet weight (WW) of samples recorded with scale balance.
- Samples were dried in oven at 65˚C until constant weight.
- Dried weight (DW) of samples recorded.
- Samples crushed using coffee grinder.
- Moisture content (%) = $(WW - DW)/WW * 100$.

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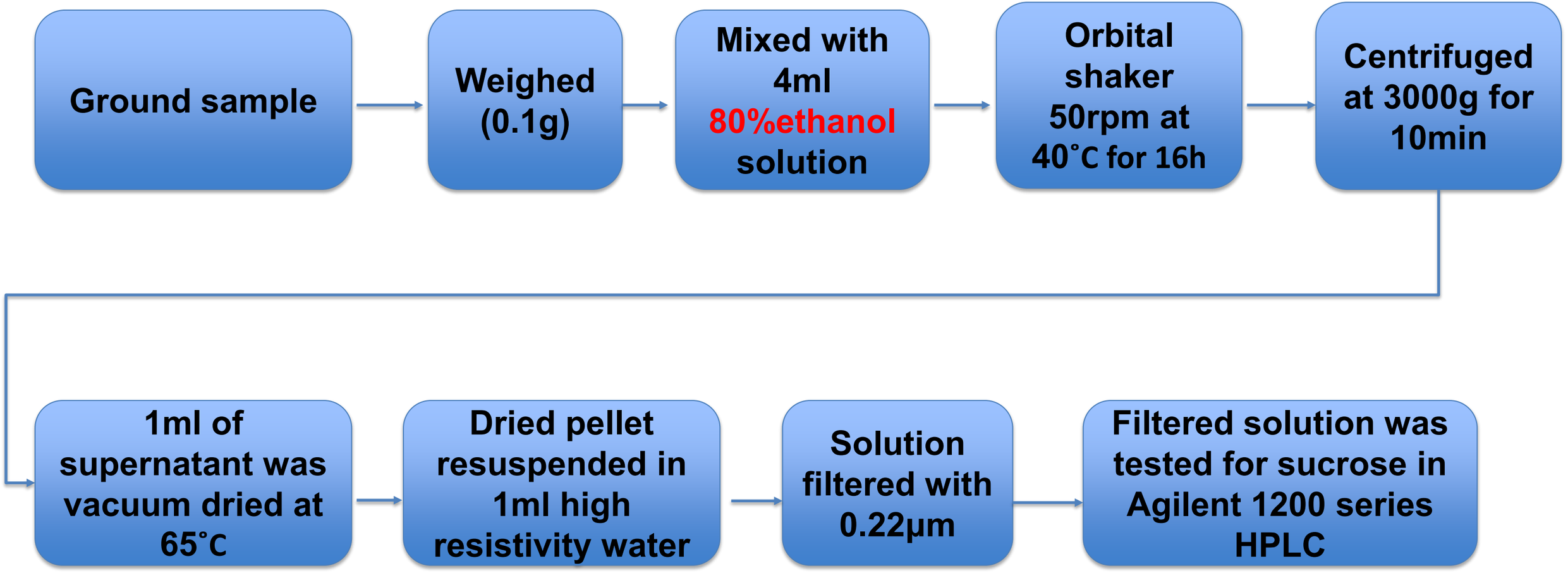
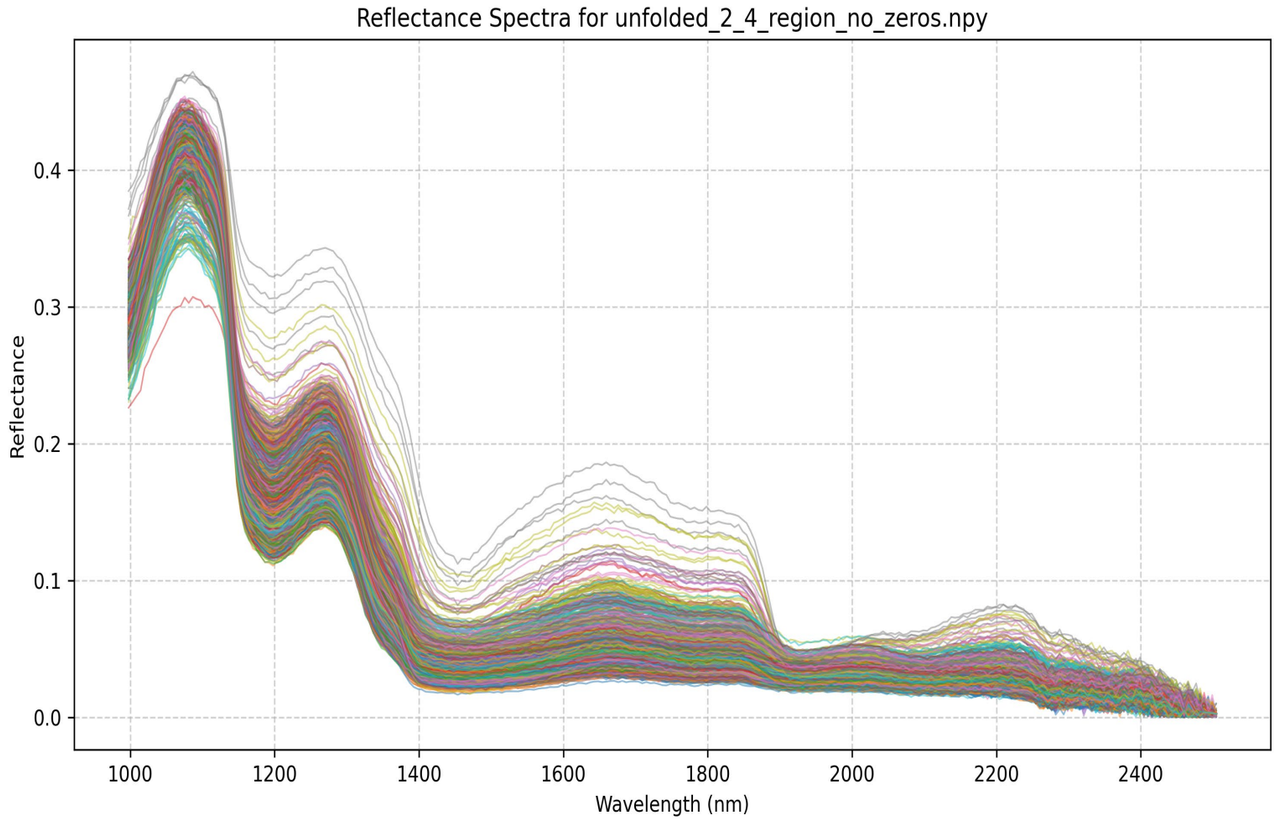
Measuring Sucrose Content

Trebbi & McGrath, 2004



Hyperspectral Image Preprocessing

- Calibration using dark and white reference images.
- Cropping the region of interest.
- Unfolding the hypercube.



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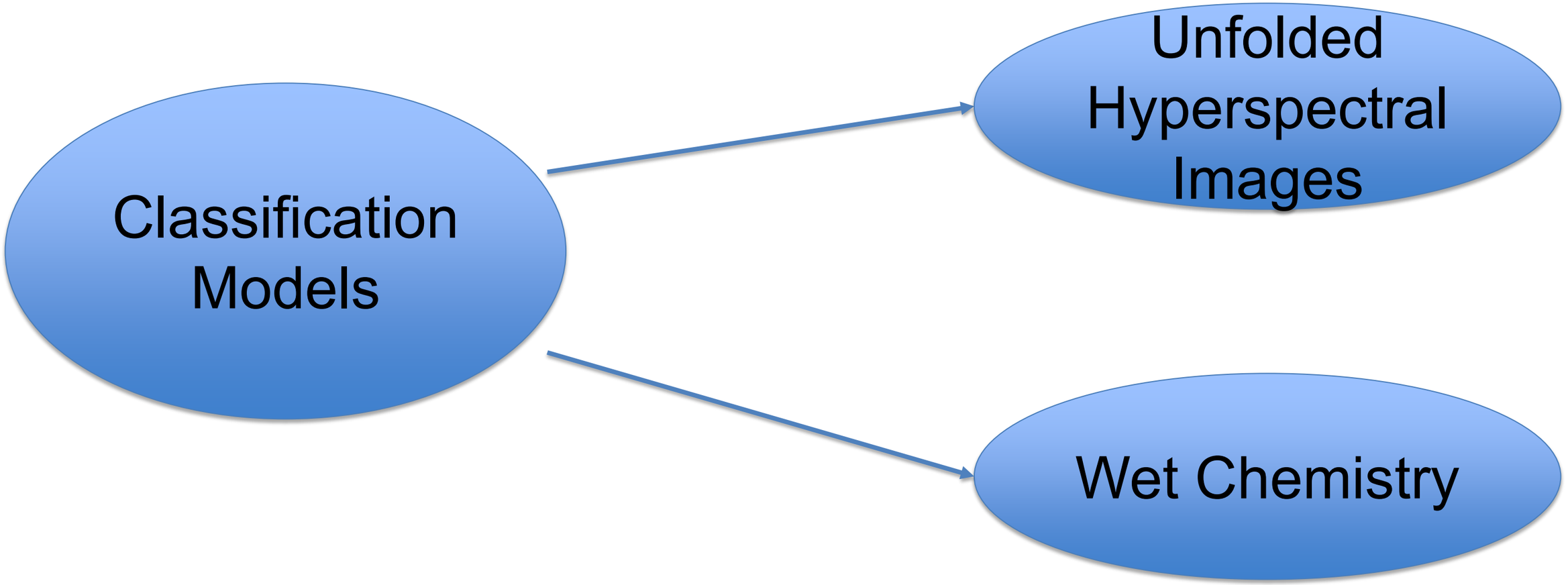
Model Development



Model Selection

- Artificial Neural Networks (ANN), Support Vector Machine (SVM), Random Forest (RF), and Linear Discriminate Analysis (LDA) for classifying both moisture and sucrose content.

- Selection of these models was based on their proven effectiveness in similar agricultural classification tasks.

Model	Accuracy %	References
ANN	>85	Pantazi et al. (2019)
SVM	93.45	Shao and Lunetta (2012)
RF	98.4	Geetharamani and Arun Pandian (2019)
LDA	98.3	Lu et al. (2018)
SVM	98	Lu and Lu (2019)

Model Development

1. 3 Classes were assigned to the wet chemistry data.

- Moisture Content: Low (0) = < 75, Medium (1) = 76 – 78, High (2) = > 78

- Sucrose Content: Low (0) = < 5, Medium (1) = 6 – 11, High (2) = > 11

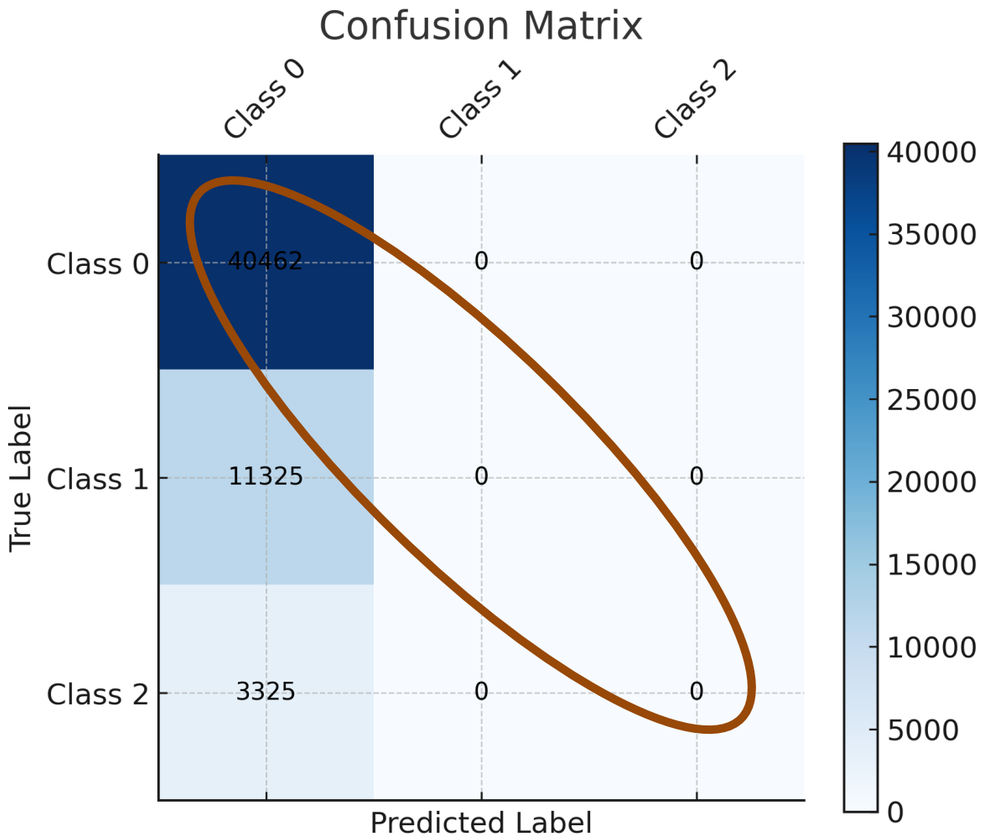
2. All unfolded data for samples were combined into one dataset.

3. Dataset was split into 60%, 20% and 20% for training, validation and testing.

Basic Statistics

Feature	Mean	Standard Deviation	Max Value	Min Value
Moisture	72.12	3.78	80.01	63.75
Sucrose	8.82	4.37	16.54	0.0018

Moisture Content: ANN




```
Accuracy: 0.7342
F1 Score: 0.6216

Classification Report:
                precision    recall  f1-score   support

             0       0.73      1.00      0.85     40462
             1       0.00      0.00      0.00     11325
             2       0.00      0.00      0.00      3325

      accuracy                           0.73     55112
     macro avg       0.24      0.33      0.28     55112
  weighted avg       0.54      0.73      0.62     55112
```

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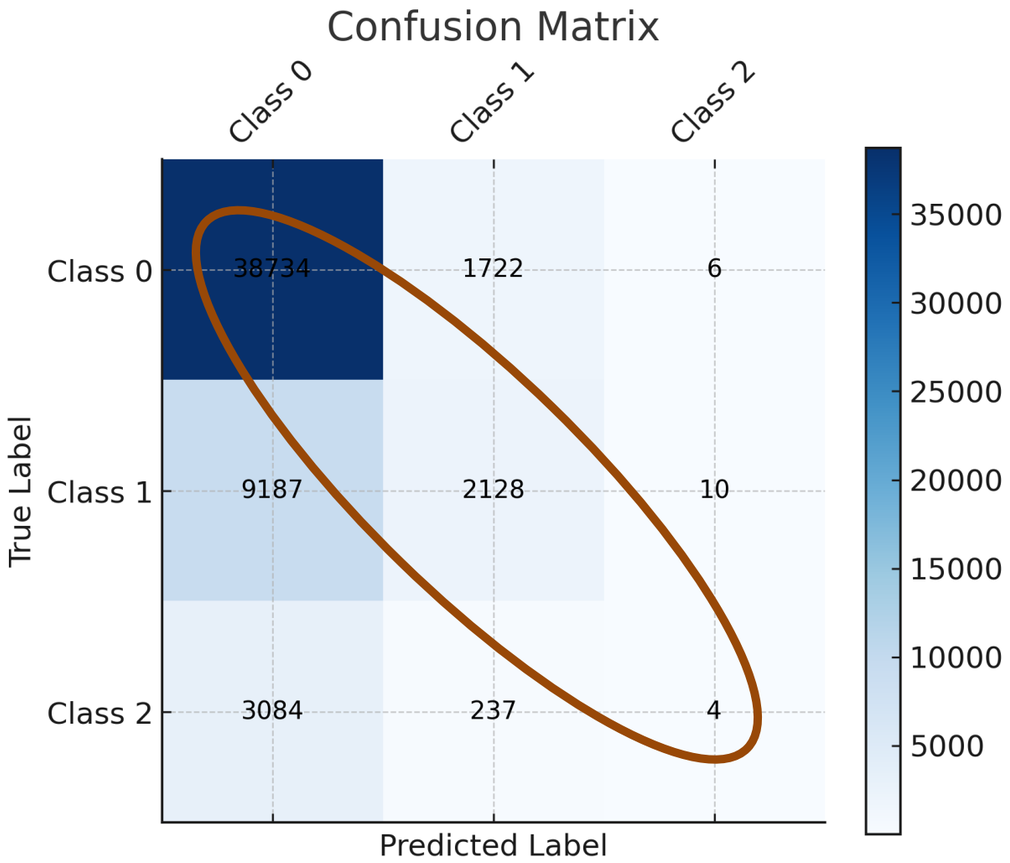
Moisture Content: LDA



Accuracy: 0.7415
F1 Score: 0.6787

Classification Report:

	precision	recall	f1-score	support
0	0.76	0.96	0.85	40462
1	0.52	0.19	0.28	11325
2	0.20	0.00	0.00	3325
accuracy			0.74	55112
macro avg	0.49	0.38	0.38	55112
weighted avg	0.68	0.74	0.68	55112

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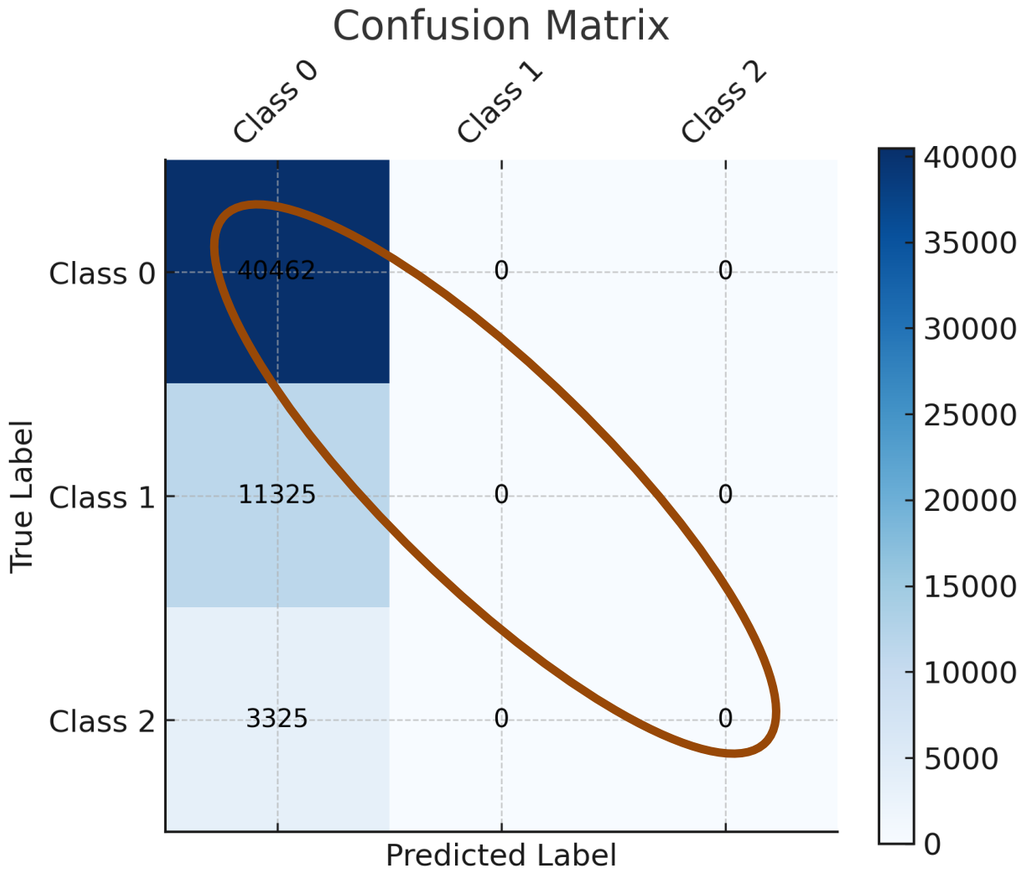
Moisture Content: SVM




```
Accuracy: 0.7342
F1 Score: 0.6216

Classification Report:
              precision    recall  f1-score   support

           0       0.73      1.00      0.85     40462
           1       0.00      0.00      0.00     11325
           2       0.00      0.00      0.00      3325

    accuracy                           0.73     55112
   macro avg       0.24      0.33      0.28     55112
weighted avg       0.54      0.73      0.62     55112
```

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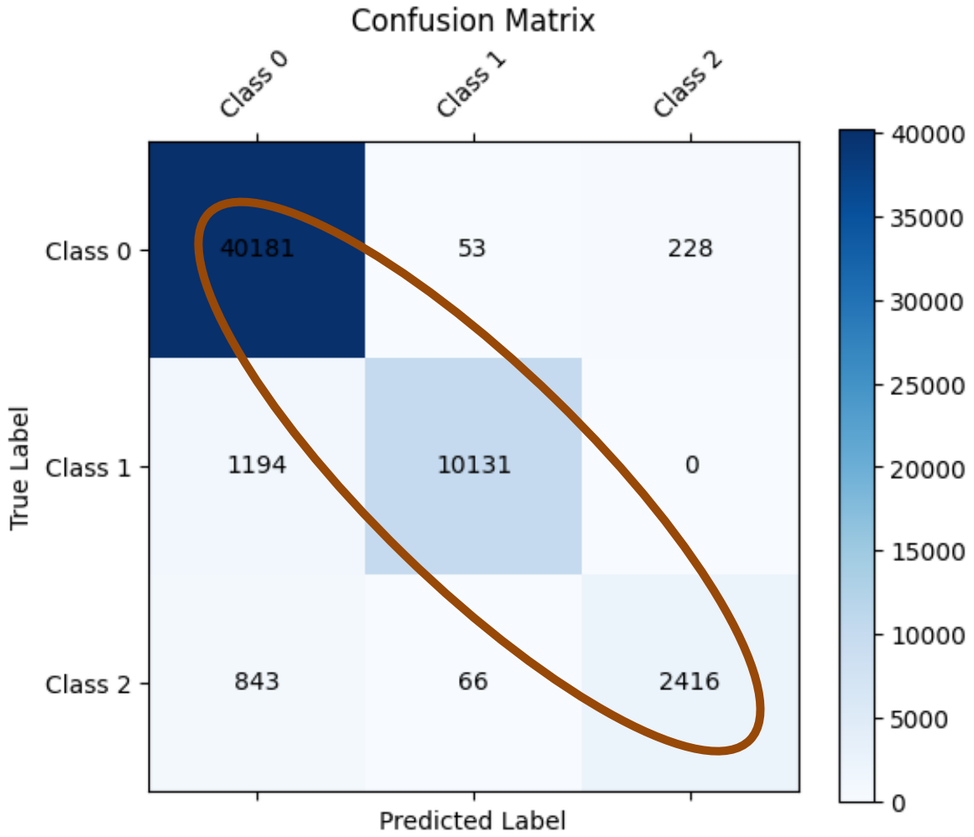
Moisture Content: RF




```
Accuracy: 0.9567
F1 Score: 0.9554

Classification Report:
              precision    recall  f1-score   support

           0       0.95      0.99      0.97     40462
           1       0.99      0.89      0.94     11325
           2       0.91      0.73      0.81      3325

    accuracy                           0.96     55112
   macro avg       0.95      0.87      0.91     55112
weighted avg       0.96      0.96      0.96     55112
```

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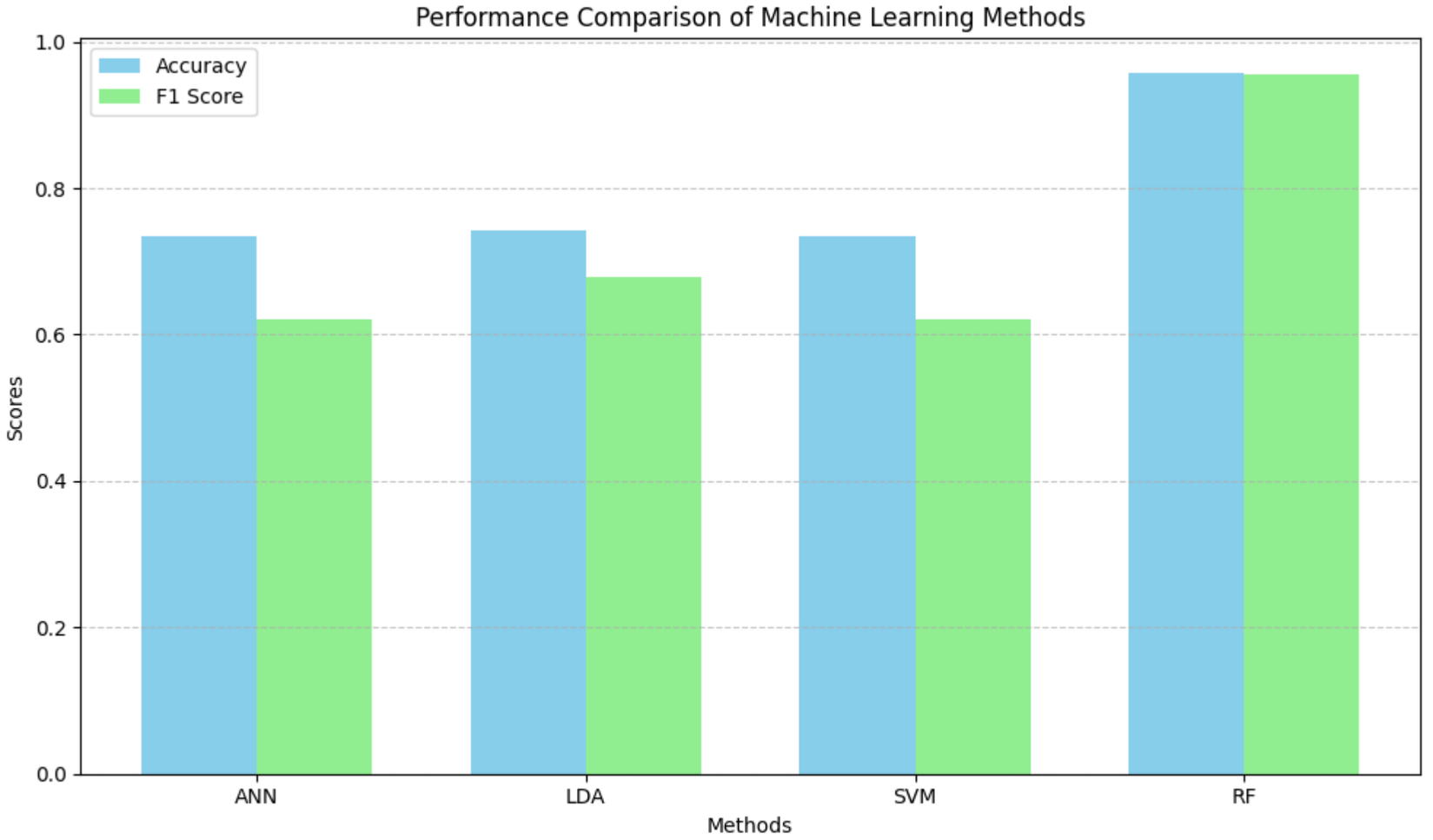

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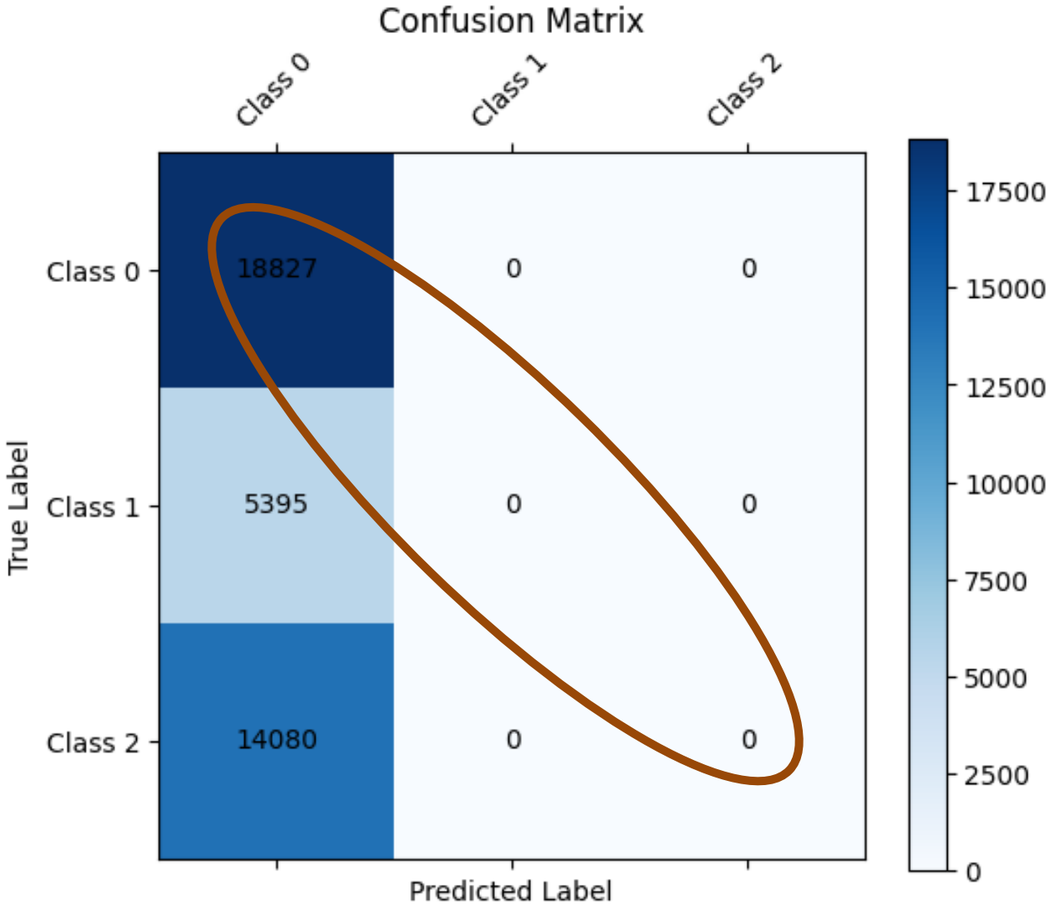
Sucrose: ANN




```
Accuracy: 0.4915
F1 Score: 0.324

Classification Report:
              precision    recall  f1-score   support

           0     0.4915         1    0.6591     18827
           1     0.0000         0    0.0000      5395
           2     0.0000         0    0.0000     14080

    accuracy                         0.4915     38302
   macro avg     0.1638    0.3333    0.2197     38302
weighted avg     0.2416    0.4915    0.3240     38302
```

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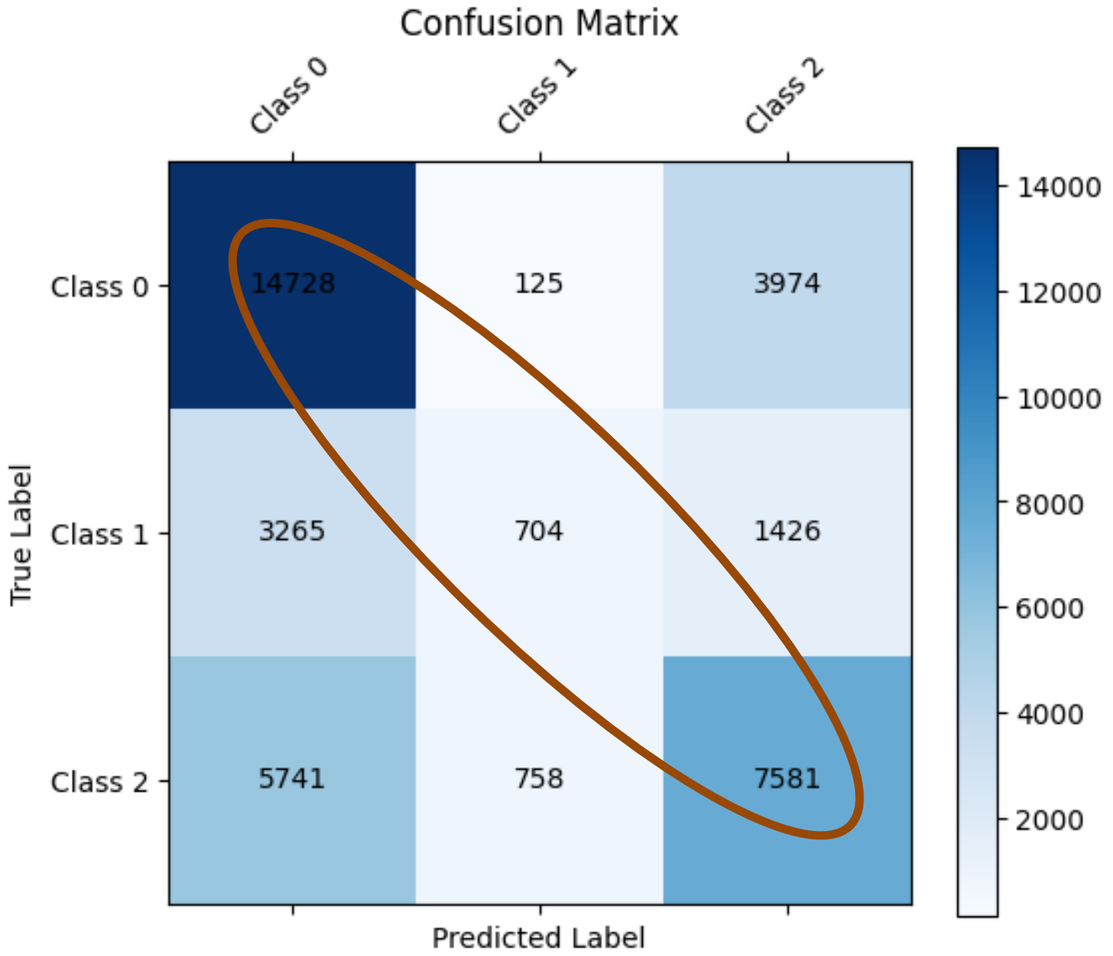
Sucrose: LDA

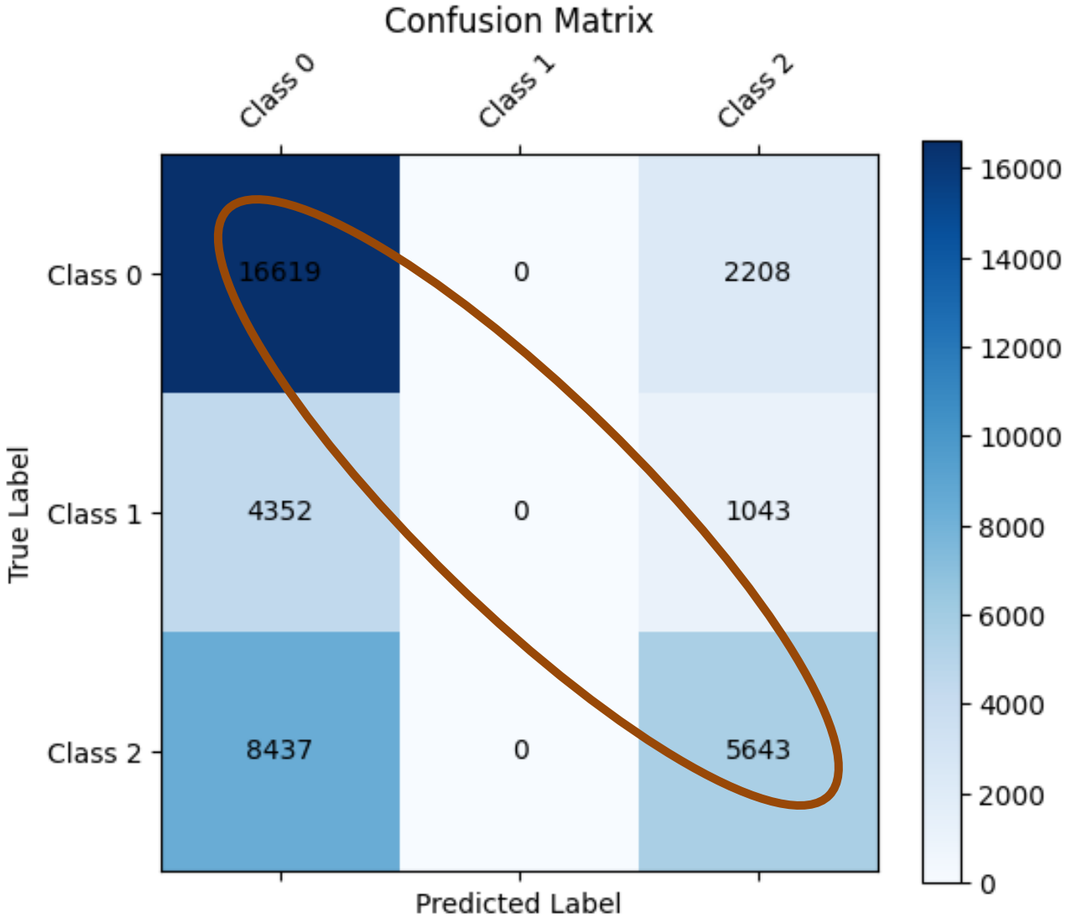


Accuracy: 0.6008
F1 Score: 0.5746

Classification Report:

	precision	recall	f1-score	support
0	0.62	0.78	0.69	18827
1	0.44	0.13	0.20	5395
2	0.58	0.54	0.56	14080
accuracy			0.60	38302
macro avg	0.55	0.48	0.48	38302
weighted avg	0.58	0.60	0.57	38302

Sucrose: SVM

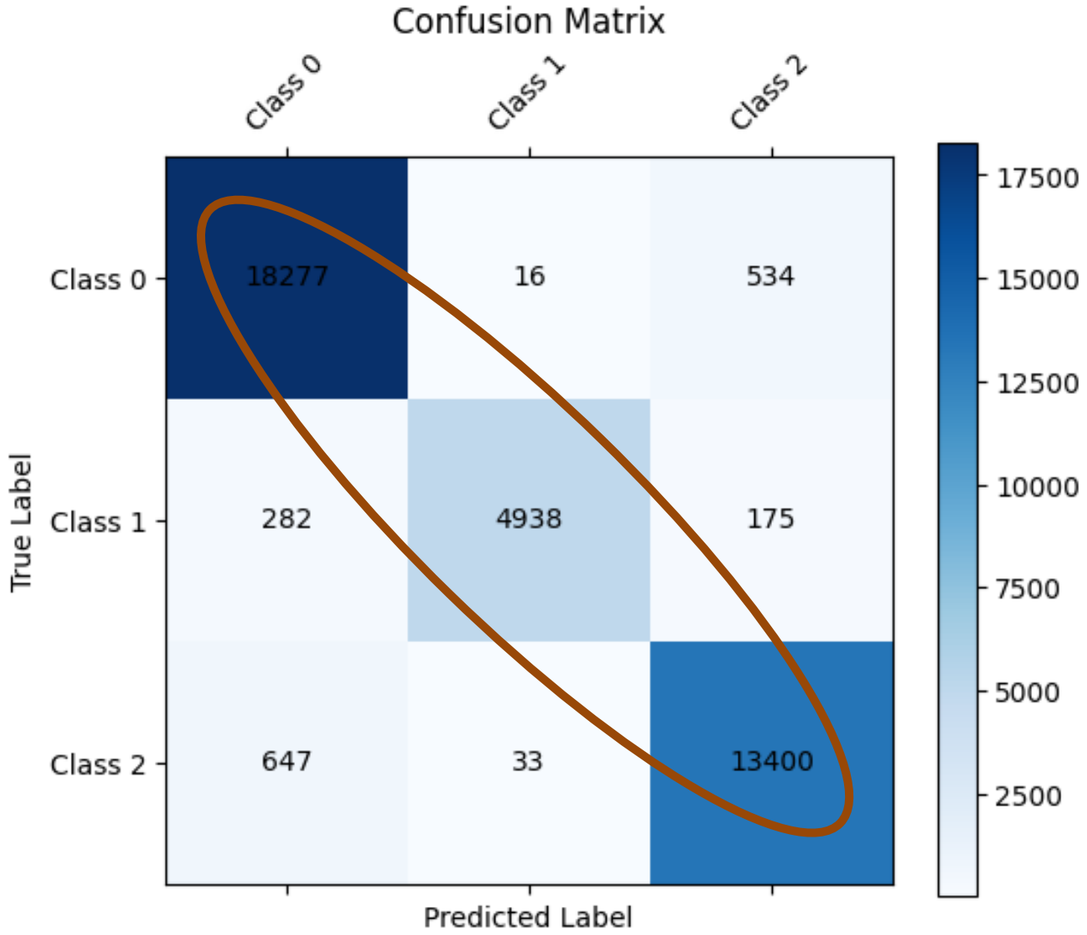


Accuracy: 0.5812
F1 Score: 0.5193

Classification Report:

	precision	recall	f1-score	support
0	0.57	0.88	0.69	18827
1	0.00	0.00	0.00	5395
2	0.63	0.40	0.49	14080
accuracy			0.58	38302
macro avg	0.40	0.43	0.39	38302
weighted avg	0.51	0.58	0.52	38302

Sucrose: RF




```
Accuracy: 0.9560
F1 Score: 0.9559

Classification Report:
              precision    recall  f1-score   support

           0       0.95      0.97      0.96     18827
           1       0.99      0.92      0.95      5395
           2       0.95      0.95      0.95     14080

    accuracy                           0.96     38302
   macro avg       0.96      0.95      0.95     38302
weighted avg       0.96      0.96      0.96     38302
```

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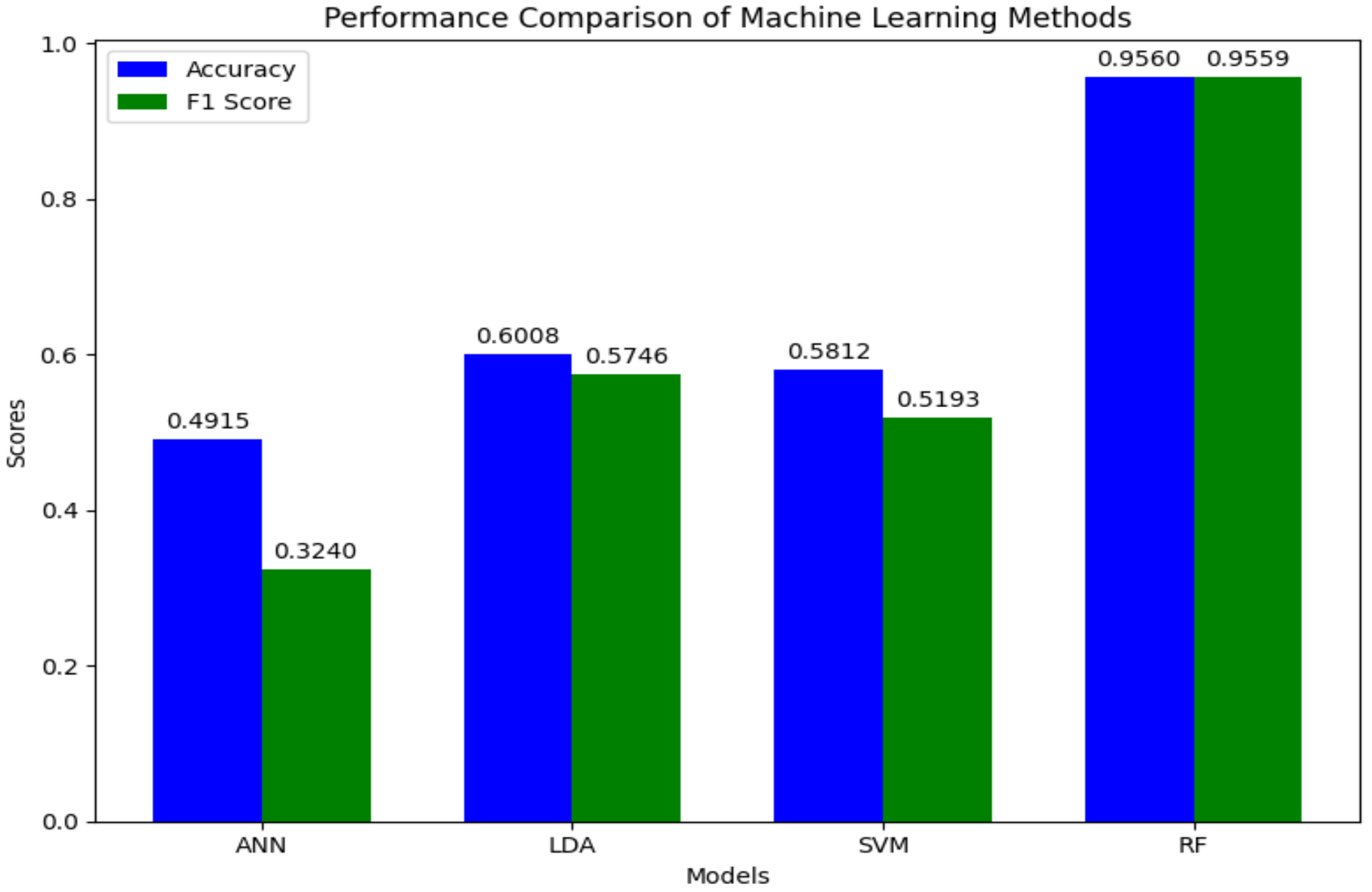

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Conclusion

Models did not perform badly considering;

- Small sample sizes were used.
- No preprocessing techniques like Standard Normal Variate, Savitzky-Golay Filtering were used.
- No feature extraction was done to select most significant features, representative of sucrose, and moisture content.

Conclusion

Hyperspectral Imaging technology combined with Machine Learning techniques are accurate for predicting moisture content and sucrose content in sugar beets.

Acknowledgments

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American Association of Sugarbeet Technologists

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Thank You!

Questions?

Happy to answer any questions you might have.

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