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AUTOMATED QUALITY DETERMINATION OF BROCCOLI AND CAULIFLOWER USING DEEP LEARNING

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ABSTRACT

Broccoli and cauliflower have a narrow harvesting window, making accurate quality assessment essential for determining optimal harvest timing. This study developed specific grading models to automatically determine the quality of broccoli and cauliflower by three phenotypic indicators: color, shape, and maturity, using deep learning methods. About 600 top-view field images of broccoli and cauliflower were collected under natural conditions, and all annotations were cross-checked and verified by experts. Three separate YOLOv11-based models were developed to classify samples into normal or abnormal categories. The color model, shape model, and maturity model achieved mAP50 scores of 0.863, 0.936, and 0.832, respectively. These results demonstrate that the proposed models provide an objective and practical approach for field-level crop quality determination, supporting farmers in making informed harvest decisions and improving crop management efficiency.

Keywords: Deep Learning, Image Segmentation, Crop Quality, Auto Grading

INTRODUCTION

Automated cruciferous vegetables quality assessment addresses labor-intensive manual inspection and subjective evaluation challenges in commercial agriculture. Broccoli and cauliflower stand out as particularly important economic crops. In Taiwan, the annual production of broccoli and cauliflower in 2024 was about 35,000 metric tons each (Ministry of Agriculture, Taiwan, 2025). Because broccoli and cauliflower have a narrow harvesting window, accurate quality assessment is essential for determining optimal harvest timing and ensuring market value. Key criteria include the smoothness of the curd surface and the compactness of the head. However, recording these phenotypic features is labor-intensive, and harvest decisions and market value assessments based on them are susceptible to subjective bias. Therefore, this study aims to develop an automated process to determine the quality of broccoli and cauliflower, addressing the need to both reduce the labor required for recording and minimize the influence of subjective judgment in harvest evaluation and market value assessment.

MATERIALS AND METHODS

BROCCOLI AND CAULIFLOWER DATASET

This study established an image dataset of broccoli and cauliflower, comprising about 600 top-view field images collected under natural conditions. The images were annotated for three quality-related traits of color, shape, and maturity, each classified as normal or abnormal (Fig. 1), and all annotations were cross-checked and verified by experts.

Traits Crops	Color	Shape	Maturity
Broccoli	<p>Normal</p> <ul style="list-style-type: none"> Uniform color Without obvious yellow-green areas 160 instances 	<p>Normal</p> <ul style="list-style-type: none"> Round shape Compact curd 232 instances 	<p>Normal</p> <ul style="list-style-type: none"> Fine buds, not oversized No withered buds or yellow flowers 110 instances 
	<p>Abnormal</p> <ul style="list-style-type: none"> Non-uniform color Yellow-green areas Purplish-black spot Withered buds 168 instances 	<p>Abnormal</p> <ul style="list-style-type: none"> Obvious missing corner Incomplete curd 95 instances 	<p>Abnormal</p> <ul style="list-style-type: none"> Withered buds and yellow flowers Uneven growth 218 instances 
Cauliflower	<p>Normal</p> <ul style="list-style-type: none"> Uniform color Different varieties exhibit different color, like white, yellow 155 instances 	<p>Normal</p> <ul style="list-style-type: none"> Round shape Compact curd 196 instances 	<p>Normal</p> <ul style="list-style-type: none"> Fine buds, not oversized No withered buds or flowers 162 instances 
	<p>Abnormal</p> <ul style="list-style-type: none"> Non-uniform color Purplish spots Withered buds 105 instances 	<p>Abnormal</p> <ul style="list-style-type: none"> Obvious missing corner Incomplete curd 64 instances 	<p>Abnormal</p> <ul style="list-style-type: none"> Withered buds and yellow flowers Uneven growth 98 instances 

Fig.1 Dataset composition of broccoli and cauliflower with an overview of all classes.

AUTOMATED QUALITY DETERMINATION MODEL

Three separate YOLOv11-based models (Khanam et al.,2024) were developed to optimize trait-specific performance and enable independent deployment. The model performance was evaluated using precision, recall, and mean average precision at IoU = 0.5 (mAP50). Training used stratified data splitting (80% training, 20% validation) with standard augmentation techniques for improved robustness. During inference, the pipeline generates two types of outputs: (i) annotated prediction images containing bounding boxes and segmentation masks with class labels, and (ii) a structured tabular report (Excel/CSV) that documents, for each image, the predicted normal/abnormal status of each trait along with the associated confidence scores.

RESULTS & DISCUSSION

Overall, the three models achieved high performance metrics (Table 1). Among them, the shape model demonstrated superior performance with precision, recall, and mAP50 values of 0.932, 0.938, and 0.936, respectively, exceeding those of the color and maturity models. The color and maturity models showed acceptable results, with mAP50 values of 0.863 and 0.832, respectively. However, the color model showed weaker performance in cauliflower_abnormal, while the maturity model exhibited relatively lower results in broccoli_normal and cauliflower_abnormal.

Detailed error analysis revealed systematic patterns. For the color model, a common source of misclassification arose from cultivar variation in cauliflower. While some cultivars have white curds, others exhibit a yellowish hue. In the current dataset. Only 21 yellow-curd instances were available within the color-normal class (155 instances in total). Due to this imbalance, the model tended to misclassify yellow-curd samples (Fig.2). For the maturity model, the precision of the broccoli_normal class was markedly lower than that of broccoli_abnormal. Analysis of common errors suggests that misclassifications were attributed to variations in lighting conditions and differences in shooting distance. When the object occupied a smaller proportion of the image due to greater shooting distance, the cues for judging maturity in broccoli such as buds enlargement became less clear, leading to incorrect predictions (Fig.3).

Table 1 Performances of all models for each class.

Class	Broccoli normal	Broccoli abnormal	Cauliflower normal	Cauliflower abnormal	All
Color					
Precision	0.857	0.994	0.900	0.704	0.864
Recall	0.909	0.868	0.844	0.794	0.854
mAP50	0.891	0.930	0.895	0.735	0.863
Shape					
Precision	0.996	0.886	1.000	0.845	0.932
Recall	0.923	0.974	0.927	0.929	0.938
mAP50	0.973	0.898	0.969	0.902	0.936
Maturity					
Precision	0.630	0.898	0.970	0.778	0.819
Recall	0.859	0.795	0.889	0.933	0.867
mAP50	0.746	0.875	0.942	0.764	0.832

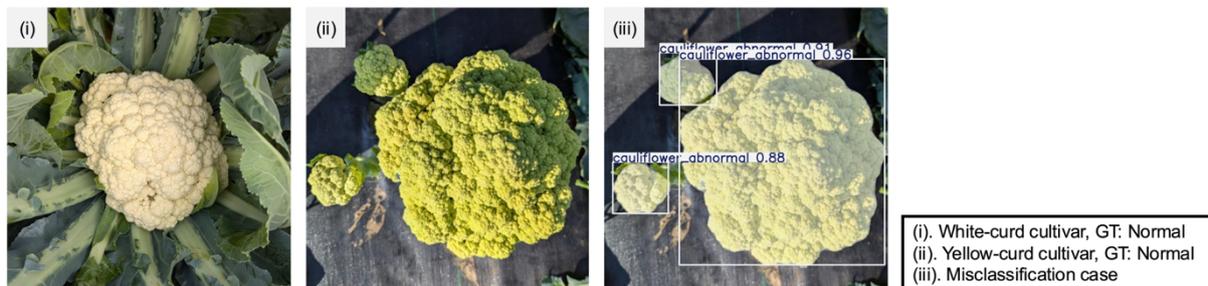


Fig.2 Representative misclassification of the color model due to cultivar variation.

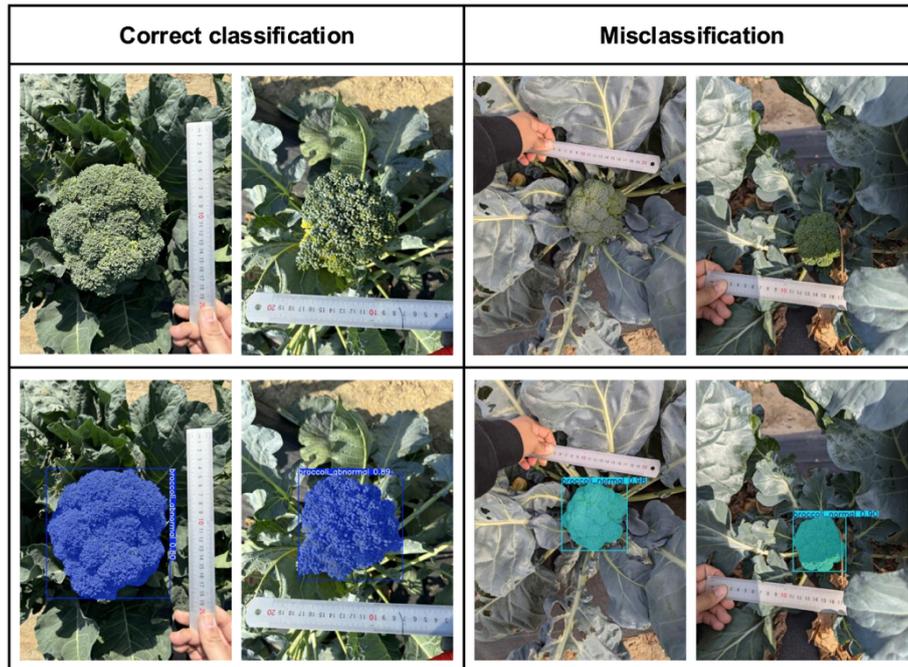


Fig.3 Representative examples of correct and incorrect classifications.

CONCLUSIONS

This study developed an automated grading models for broccoli and cauliflower quality assessment. Using YOLOv11 model, the color model, shape model, and maturity model achieved mAP50 of 0.863, 0.936, and 0.832, respectively. By reducing subjective bias and labor demand in traditional grading, the proposed approach has the potential to assist farmers in making timely harvest decisions and to enhance crop management efficiency. Future work should address dataset imbalances, particularly for cauliflower cultivar diversity, and develop standardized imaging protocols to improve model robustness across different field conditions. Additionally, expanding the dataset and balancing class distributions may further enhance the model's performance, and providing a user-friendly interface will facilitate its adoption in practical field applications.

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