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Development of robust UAV-based phenotyping solutions for field-growing rapeseed plants to accelerate yield improvement in rapeseed breeding

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Background:

Accurate, intelligentised and high-throughput phenotyping has arisen to be one of the biggest bottlenecks of crop breeding. Rapeseed yield constitutes of several silique parameters at its maturing period - actually it is systematically and dynamically decided by the whole plant developing period, which includes the vegetative growth period, flowering period and fruit developing period.

Objective:

Providing means for the accurate identification and quantification of yield-related traits at the corresponding key developing periods can accelerate the dissection of yield shaping and extensively promote higher-yield breeding. Based on our experimental understanding of yield shaping, three major elements: leaf area index, flower richness and silique pod area index are chosen to monitor and evaluate the growth performances and yield potential at vegetative, reproductive, and fruiting stages, respectively.

Methods:

Taking flower richness as a case study, counting them in-field is a time-consuming, labour-intensive and meanwhile destructive for subsequent plant growth. The main and branch inflorescence status (numbers and vigour) decide flower richness. Here, we presented a non-destructive, high-throughput, accurate phenotyping solution to measure the rapeseed inflorescence numbers during its whole flowering period. To count the inflorescences automatically, we transferred the counting problem to a deep learning task. A low-cost inflorescence counting approach using Convolutional Neural Networks (CNN) based on Unmanned Aerial Vehicle (UAV) Red-Green-Blue (RGB) imagery of consecutive rapeseed plots at flowering period were developed.

Results:

The crucial step is to train a deep neural network that maps from an input image to the corresponding annotated density map or manual labelling box. Moreover, we constructed a Rapeseed Inflorescence Benchmark (RIB) to verify the effectiveness of our model. Experimental results showed that indicators R2 for counting and mAP for location were over 0.96 and 92%, respectively. Compared with Faster R-CNN, YOLOv4, CenterNet and TasselNetV2+, the proposed method achieved state-of-the-art counting performance on RIB and had advantages in location accuracy. The counting result revealed a quantitative dynamic change of the number of rapeseed inflorescences in time dimension. Furthermore, a significant positive correlation between the actual plot yield and the automatically obtained rapeseed inflorescence total number was identified.

Conclusions:

Thus, a set of UAV assisted methods for better determination of the flower richness was developed, which can greatly support the breeding of higher-yield rapeseed varieties. By employing the combination of deep learning and unmanned aerial vehicle (UAV) images captured by RGB, multispectral and other (e.g. laser) cameras, we also developed a low-cost freezing-tolerant rapeseed material recognition approach to support breeder choose elite freezing-tolerant germplasms. The development of several high-through phenotyping approaches, separately for lodging state, silique pod area index and leaf area index of rapeseed plants at the field (mostly plot) level are ongoing or nearly completed.

By systematically combining and integrating the high-through phenotyping information of stress (abiotic and biotic) tolerance, lodging index, leaf area (vegetative vigour), flower richness (branch state) and canopy index (pod area index), the dissection of rapeseed yield shaping can be extensively promoted. The corresponding fast, intelligent breeding solutions and approaches will be developed or improved subsequently.