Holistic and Component-based Automated Plant Phenotyping Analysis using Visible-Light Images

Presented by

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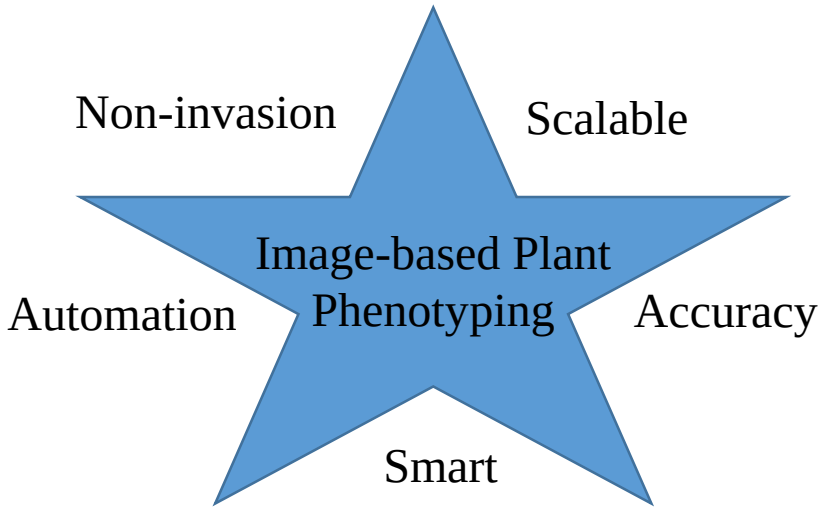
Image-based Plant Phenotyping

Definition:

- ❖Monitoring and quantification of phenotyping traits by analyzing plant images
- ❖Using different camera modalities: visible light, fluorescent, infrared, hyperspectral
- ❖Images are often captured at regular intervals
- ❖The plants are monitored in a controlled environment

Advantages:



Plant Phenotyping Analysis

Holistic Analysis

(Considers the whole plant as a single object to measure attributes)

Primary/Basic

1. Height of the minimum bounding rectangle
2. Diameter of minimum enclosing circle
3. Perimeter of convex hull
4. Area of convex hull
5. Caliper length
6. Centroid of plant
7. Principal axis of rotation

Derived/Advanced

1. Bi-angular convex-hull area ratio
2. Plant aspect ratio

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Component Analysis

(Analyzes individual parts of a plant, e.g., leaves and stems)

Leaf

1. Number of leaves
2. Size of leaves
3. Angle between leaf and stem

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Stem

1. Stem height
2. Internode distance
3. Stem angle

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•
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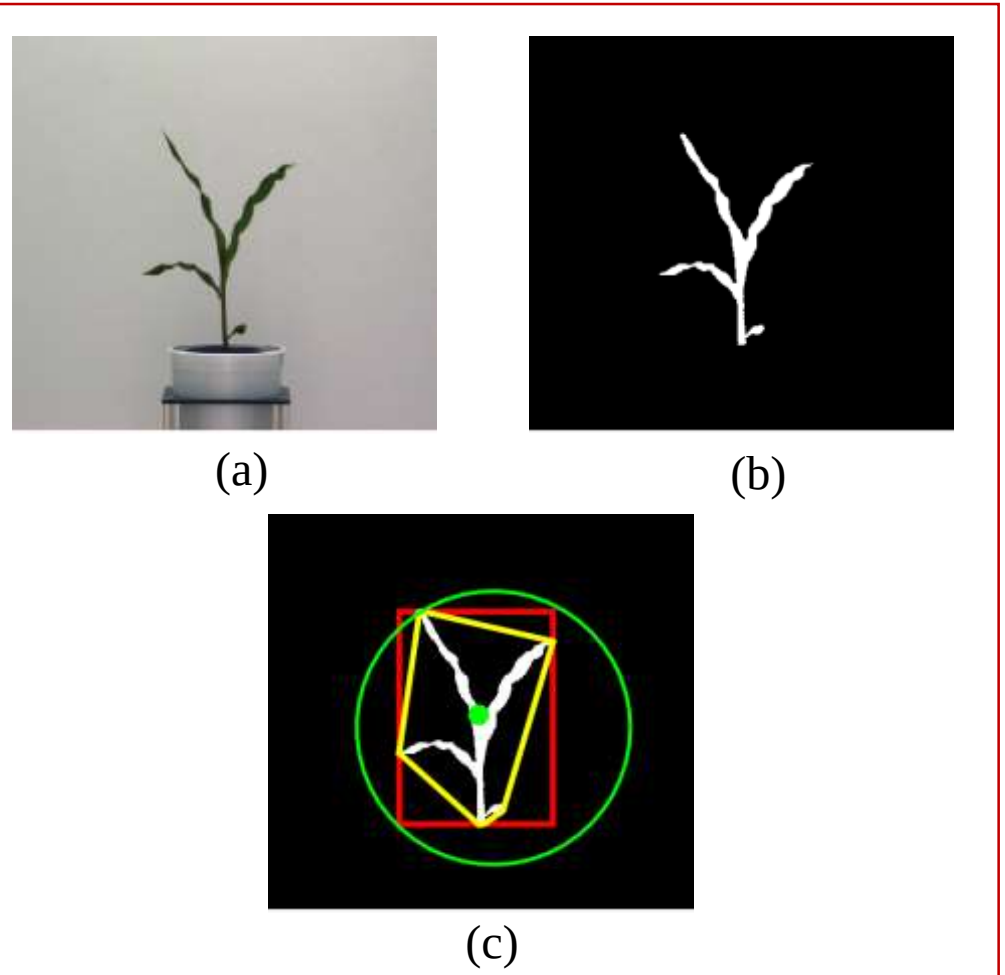
Holistic Phenotypes

- Primary holistic phenotyping analysis measures the individual attributes of the basic geometric shape.

  e.g., height of the bounding rectangle of a plant to quantify plant height, area of the convex-hull to quantify plant size.

- Derived holistic parameters combine two or more primary phenotypes for advanced plant phenotyping analysis.

  e.g., Bi-angular convex-hull area ratio, Plant aspect ratio.



Primary Holistic Phenotypes

Derived Holistic Phenotypes

1. Bi-angular Convex-hull Area Ratio

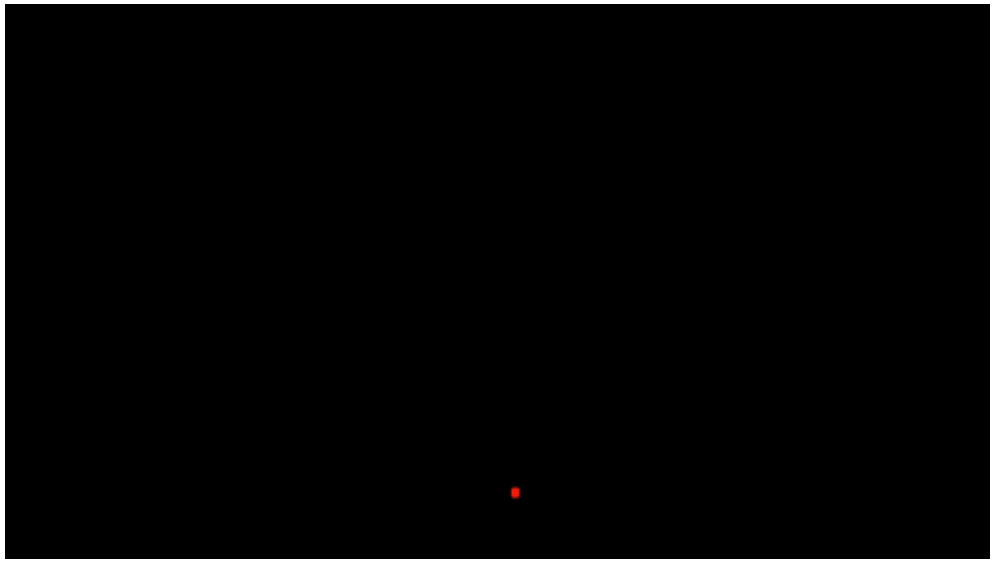
$$\text{B-A}_{\text{CH}}\text{R} = \frac{\text{Area}_{\text{CH}} \text{ at side view } 0^\circ}{\text{Area}_{\text{CH}} \text{ at side view } 90^\circ}$$

Derived Holistic Phenotypes

2. Plant Aspect Ratio

$$\text{P - AR} = \frac{\text{Height of the BR at Side Vew}}{\text{Diameter of the MEC at Top View}}$$

BR = Bounding rectangle
MEC = Minimum enclosing circle



Significance of the Phenotypes

Holistic

Bi-angular convex-hull area ratio:

Phyllotaxy-the arrangement of leaves around the stem in response to light signals perceived through the photochromic pathway in order to optimize light interception.

Plant aspect ratio:

It provides information of canopy architecture

Component-Based

Total number and size of leaves:

Plants are not static, but changing organisms with consistently increasing complexity in shape and appearance over time. The growth of a plant is best interpreted by the number of leaves and the size of each leaf.

Stem angle:

The stem-angle, i.e., the angle between the stem and the horizontal axis, away from vertical can be an early signal that a given plant is going to be susceptible to lodging.

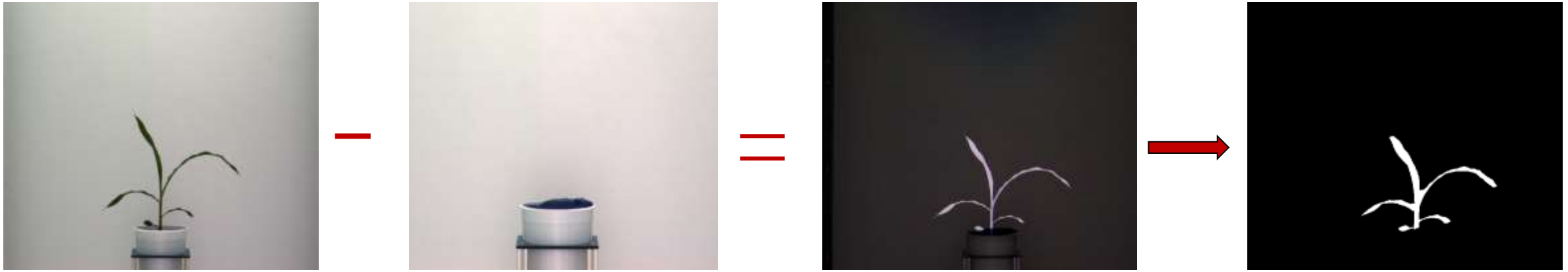
Leaf Detection and Leaf-Size Measurement

(a) Original image

(b) Background image

(c) Gray image
(frame differencing)

(d) Binary image

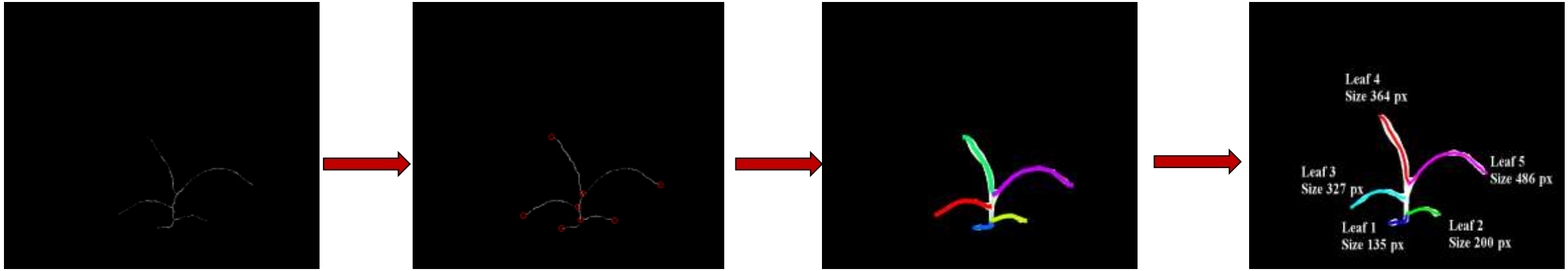


(e) Skeleton image

(f) Skeleton with
detected leaf-tips

(g) Skeleton with
detected leaves

(h) Display of leaf-
size



Component Phenotypes

Node-Tip Distance (ND) (1):

$$ND = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

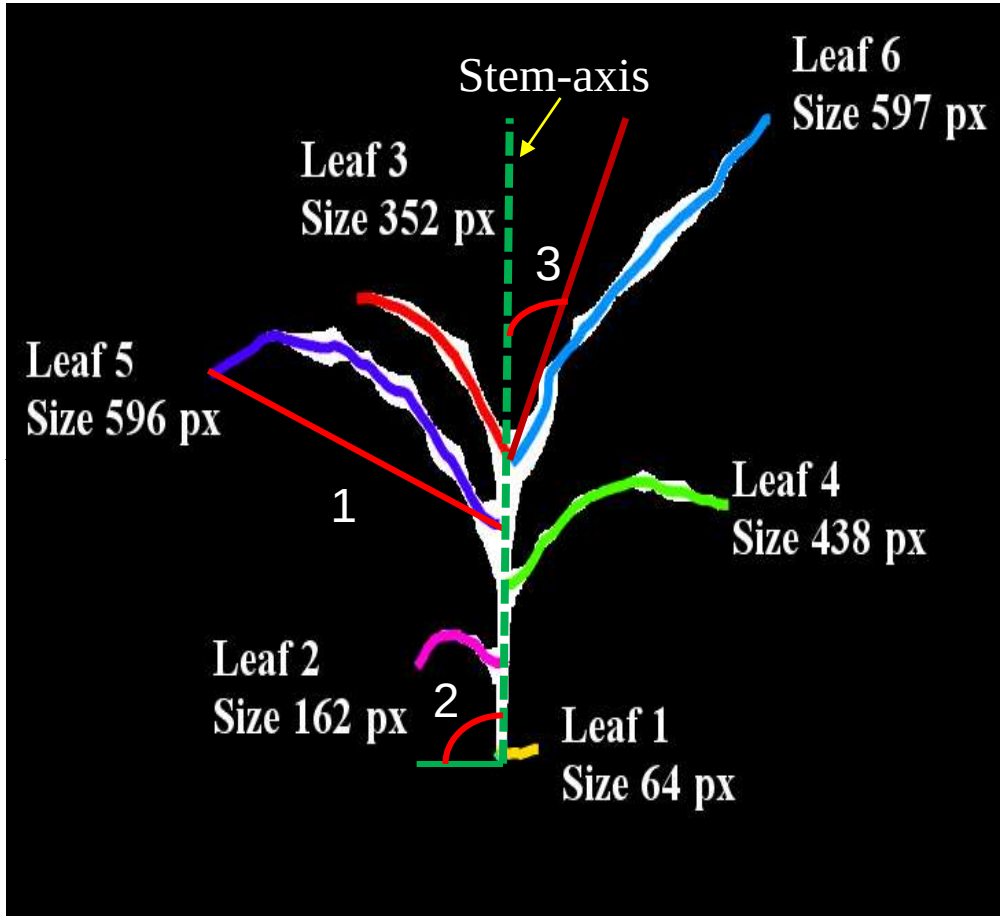
Where, (x_1, y_1) and (x_2, y_2) respectively denote the co-ordinates of the leaf-node and leaf-tip.

Stem Angle (2):

It is measured as the angle between the stem-axis and the horizontal axis. Stem-axis is drawn by linear regression curve fitting of all the nodes of a stem.

Leaf Angle (3):

It is measured as the angle between the stem-axis and the tangent drawn at the leaf-node.



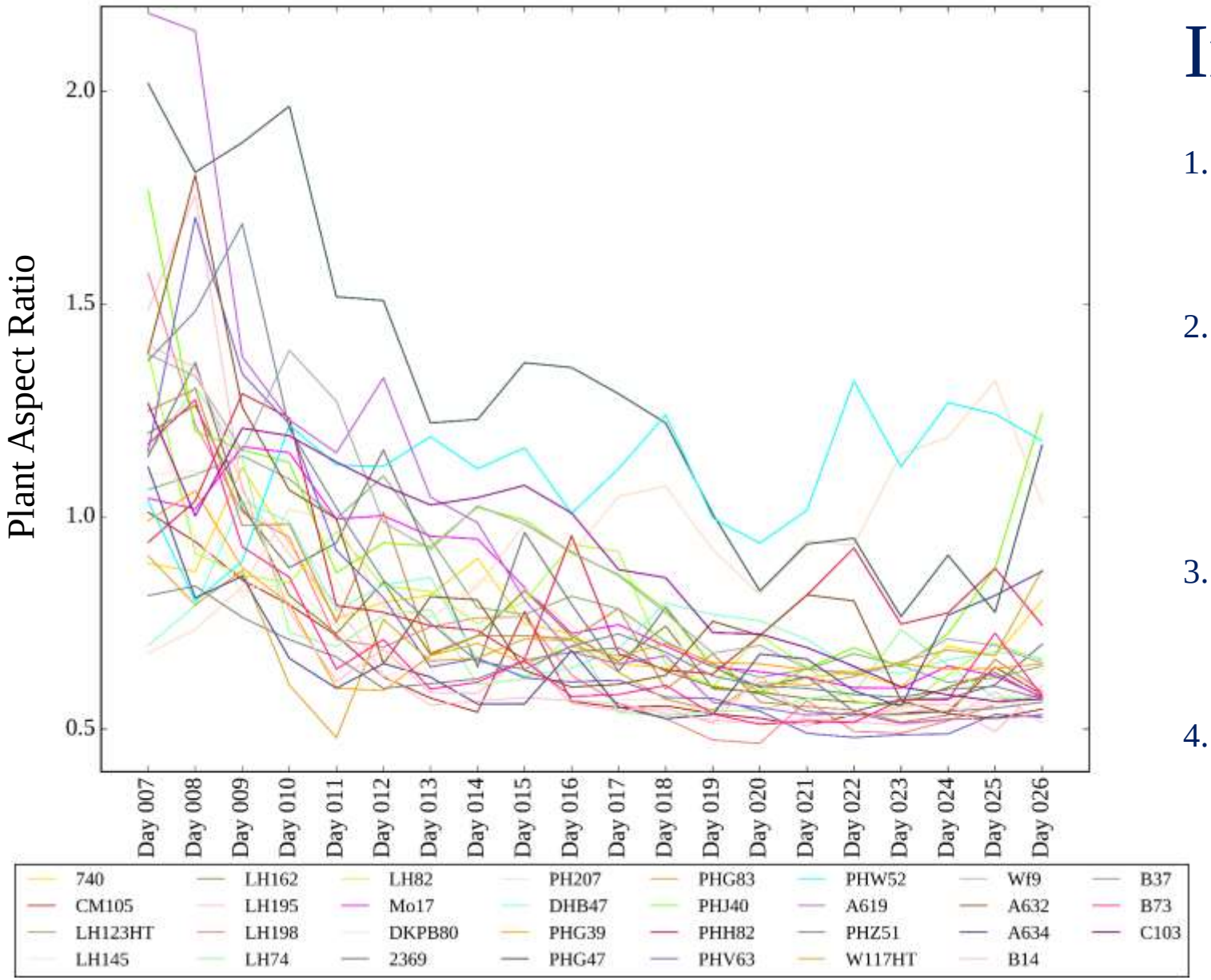
Lemnatec Scanalyzer 3D High-throughput Plant Phenotyping System at the UNL, USA

1. 672 plant capacity for plants up to 2.5 meters
2. 3 Watering stations
3. Rotating lifters for up to 360 side view images
4. 5 camera types- visible light, fluorescent, infrared, near infrared, hyperspectral

Panicoid Phenomap-1 Dataset

- Consists of images of maize plants of 40 genotypes including at least one representative accession from five panicoid grain crops: maize, sorghum, pearl millet, proso millet, foxtail millet
- The images are captured using visible light camera of the Lemnatec Scanalyzer 3D high-throughput plant phenotyping system for 3 views: side view 0 °, side view 90 ° and top view, for 26 days.
- It contains 13728 total number of images of 176 total number of plants.
- The dataset is freely available from: http://plantvision.unl.edu/

Data capturing system-Lemnatec Scanalyzer 3D high throughput plant phenotyping facility at the University of Nebraska-Lincoln, USA



Inferences

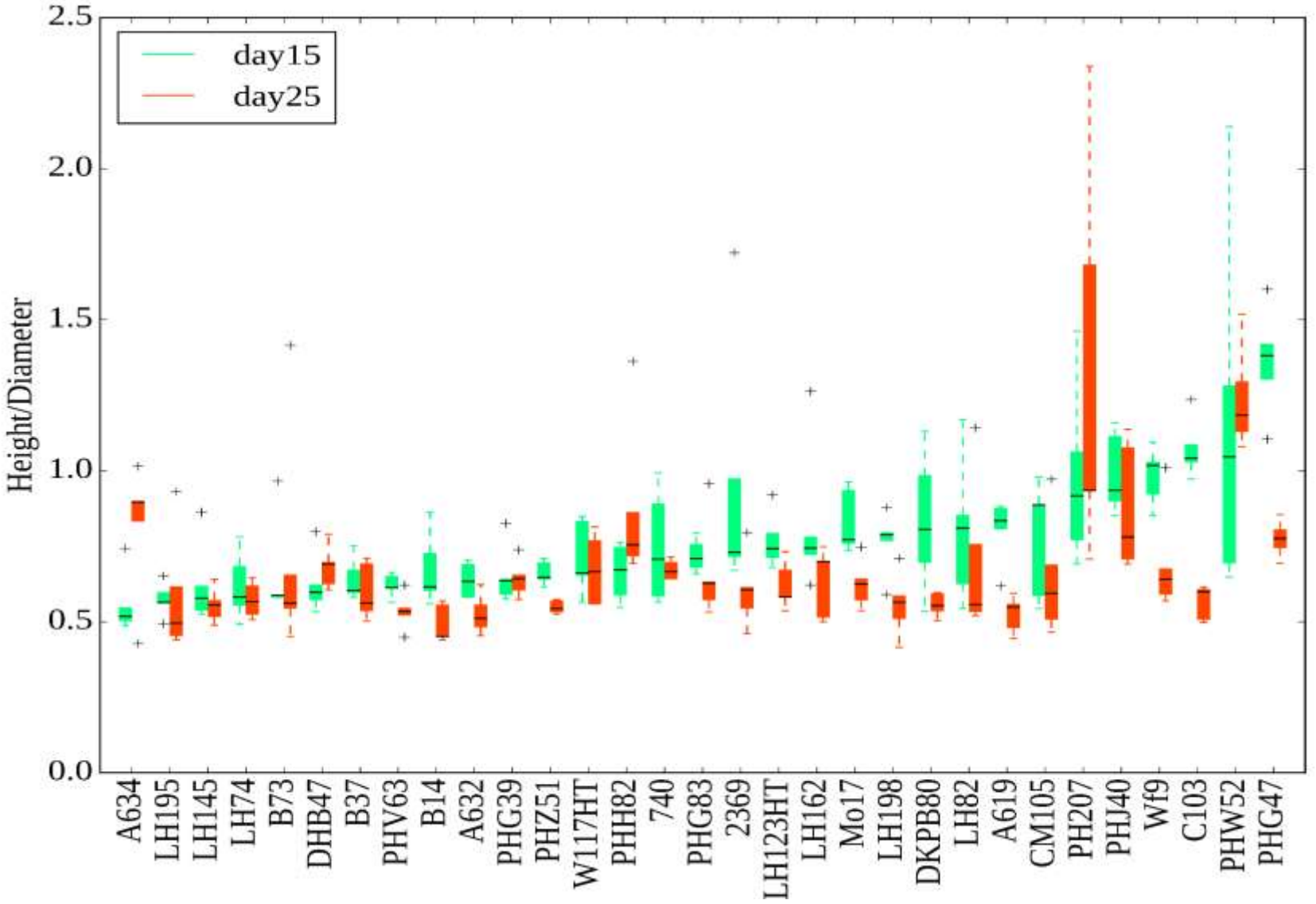
1. Plant aspect ratio decreases with time, i.e., rate of increase in plant width is more compared to the plant height.

2. For some genotypes (e.g., 2369 and C103) plant aspect ratio decreases significantly with time, but for some others (e.g., PHW52 and PHG39) it fluctuates between fairly similar values.

3. Some genotypes have higher plant aspect ratios (e.g., PHG47) compared to the others (e.g., B73).

4. These inferences demonstrate the potential of plant aspect ratio to be an effective phenotype regulated by genetic variation.

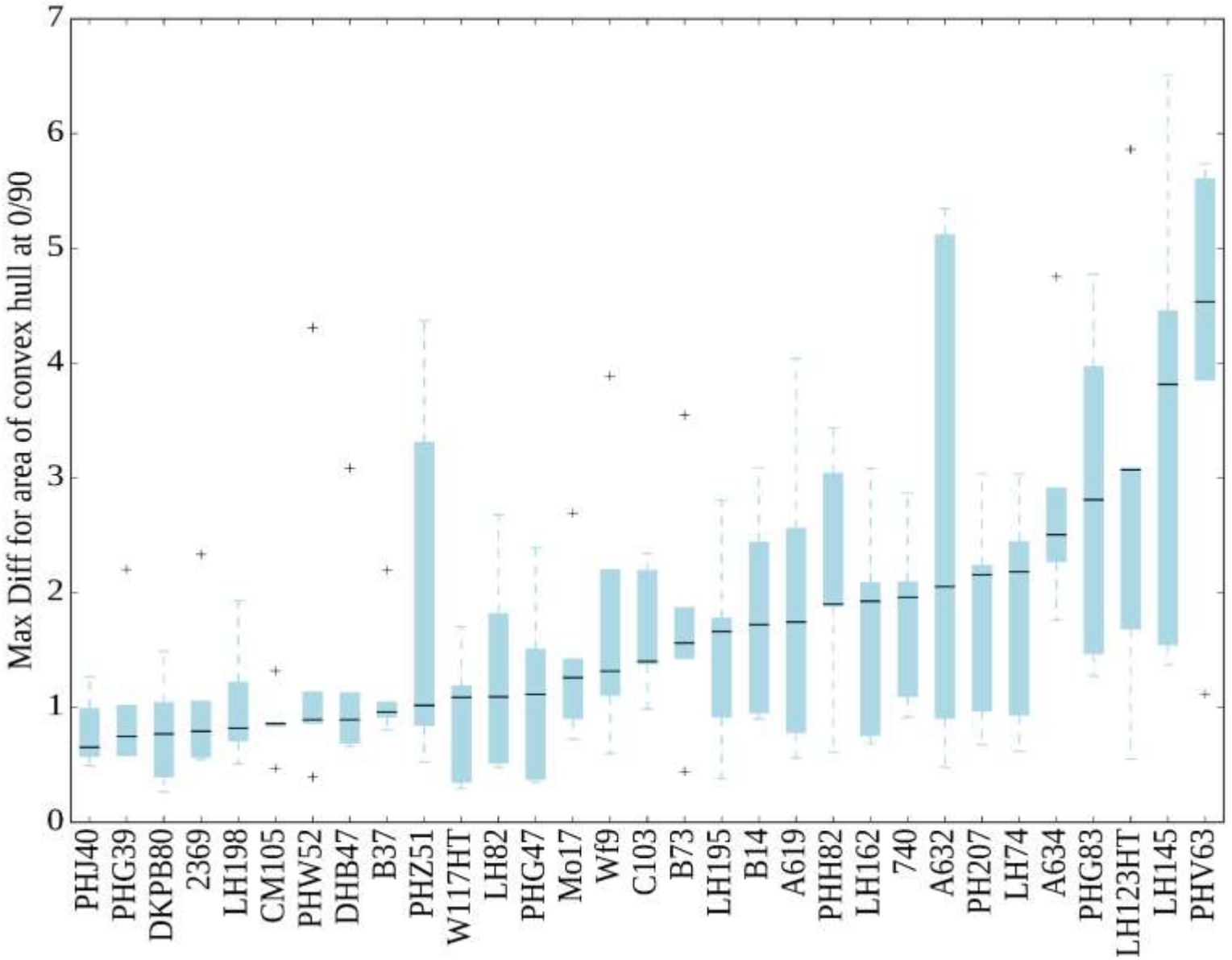
Heritability Test using Boxplot: Plant Aspect Ratio



Inferences:

1. Most genotypes exhibited higher plant aspect ratios on Day 15 than on Day 25.
2. Heritability on Day 15 is 23.23% which is significantly higher than on Day 25, i.e., 14.00%.
3. PHG47 has the highest ratio on day 15 followed by PHW52, while PHW52 has the highest ratio on Day 25.

Heritability Test: Bi-angular Convex-hull Area Ratio



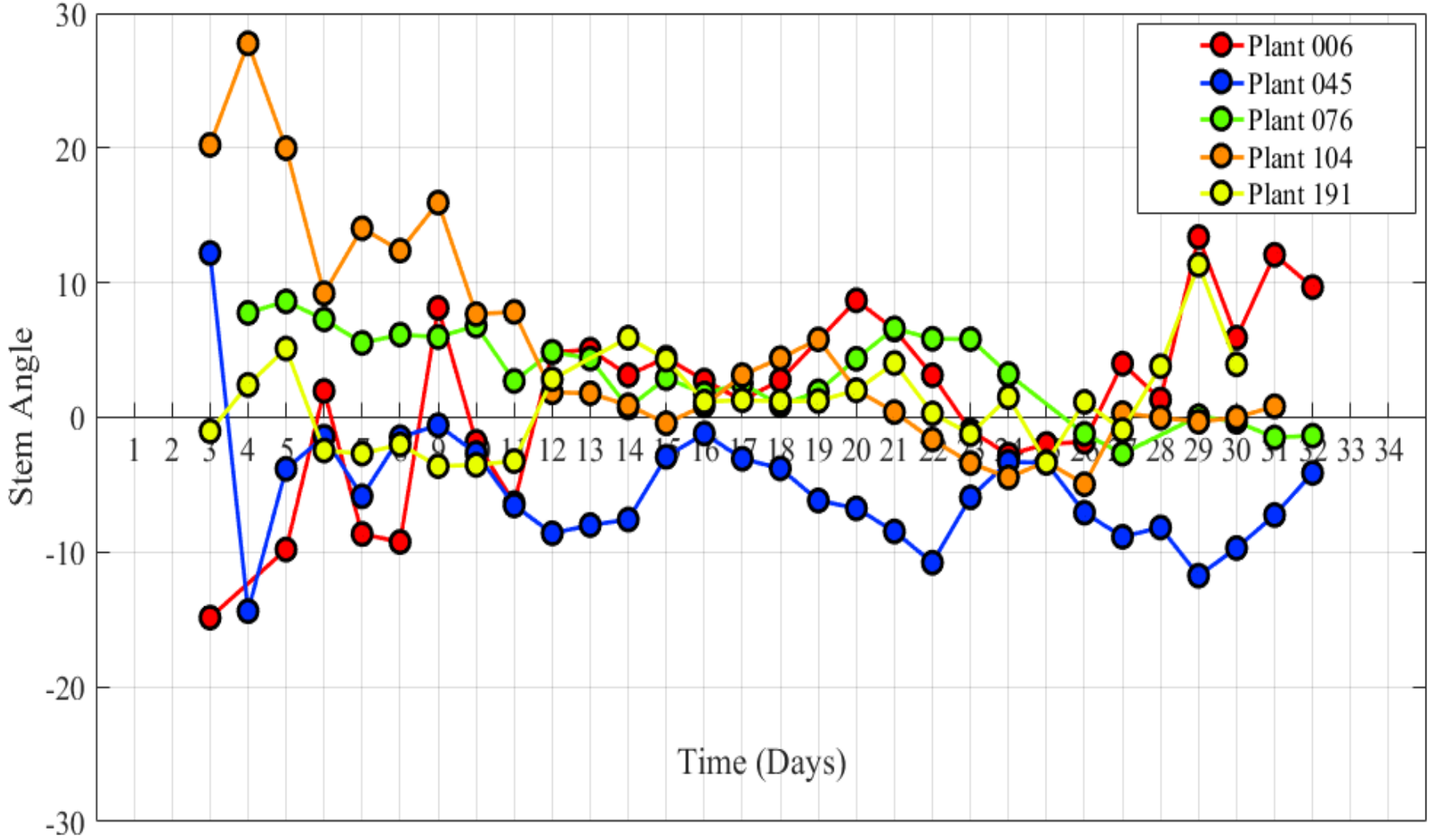
Inferences:

1. The median value for all corn lines lies within 0.5-5 (value for PHV63 is 4.54 (highest), value for common genotype B73 is 1.56).

2. Estimated heritability- proportion of total variation which can be explained by genetic variation- was calculated to be 24.85%.

3. Partially controlled by genetics, likely to be also regulated by environmental factors, i.e., influenced by phytochrome signaling differences between plants in the edges and central of the greenhouse.

Component Phenotype-Stem Angle



Conclusion

- Image-based plant phenotyping: non-destructive analysis with little manual intervention in high throughput fashion with accuracy and speed.
- The image-based plant phenotyping analysis is classified into two types: holistic and component-based.
- Introduced two new holistic phenotypes: bi-angular convex-hull ratio and plant aspect ratio to respectively analyze genetic regulation of phyllotaxy and canopy architecture.
- An algorithm is provided for leaf-count, inter-node distance and leaf-size measurement.
- Computed component based phenotypes: node-tip distance, stem angle and leaf angle.
- Released a benchmark dataset called Panicoid Phenomap-1.
- Experimental analyses demonstrate the effectiveness of these phenotypes regulated by genetic variation in maize plant.

Thank You!