Summary of Doctoral Thesis

Enrollment year: March 2023
UGAS Specialty: Bioproduction science
Name Hassan Md Rakibul

Title	**Impact of elevated temperature and CO_2 on photosynthesis, phenology, fruit quality and growth of apple tree**

Introduction and purpose

The global atmospheric environment has changed dramatically since the era of the industrial revolution. Mean global temperature has raised by ~0.85 ^{0}C since 1880, and will rise further by 1.4- 4.4 ^{0}C by the end of this century. Moreover, the CO_2 concentration ([CO_2]) of the atmosphere will be doubled by the end of this century from the current 410 ppm.

Crop production, including apple, is receiving both positive and negative influences from the climate change. In general, short-term elevated [CO_2] substantially accelerates photosynthesis in C_3 plants since the current [CO_2] is insufficient to make rubisco activity saturate, and also rising [CO_2] competitively depresses the oxygenase activity of rubisco and in turn photorespiration. However, this photosynthesis acceleration is hardly fully realized due to the down-regulation of photosynthesis when plants are grown under long-term elevated [CO_2].

In addition, the elevated temperature has also caused the phenological changes of apple trees. Generally, high temperature advances the spring phenology whereas delays the autumn phenology, resulting in the extension of the growing period. This phenological changes may further influence the carbon cycle within the apple orchard ecosystem. Moreover, fruit quality of apple is greatly influenced by air temperature during the growing season. If the temperature at the growth stage raises higher than optimum, it will damage fruit quality in terms of soluble solid content, firmness and skin color.

This study was conducted to clarify the actual influence of future climate on apple production in Japan through the long-term experiment using field-grown trees. The whole experiment was conducted in Aomori prefecture which produces 61% apple in Japan. Special attention was paid on down-regulation of leaf photosynthesis, dry matter production, phenology, and fruit quality changes.

Materials and methods

Three environmentally controlled greenhouses (GH-A, GH-T, and GH-C) were used in this study. In GH-A, the atmospheric condition was kept the same as outside. In GH-T, the temperature was controlled to be always higher by 3 ^{0}C. In GH-C, air temperature was kept the same as in GH-T, while [CO_2] was kept higher by 150 ppm than ambient. Both GH-T and GH-C were controlled from March 15 to December 5, and during the remaining period they were subjected to snowfall. Six trees of 'Tsugaru' and 'Fuji', which are the representative early- and late-matured cultivar, 7-years-old in 2022, planted in each greenhouse with the spacing of 2×3 m, were used for experiment.

Results and discussion

(1) Chapter II

Down-regulation of leaf photosynthesis under elevated CO_2 in apple trees with different fruit load

In Chapter II, I examined whether, to what extent, and why long-term elevated [CO_2] in GH-C down-regulates the photosynthesis efficiency of apple leaves. Photosynthesis down-regulation is routinely attributed to insufficient sink capacity. The apple tree is generally extremely sink-limited because more than 80% of fruits are thinned off for achieving commercial quality. Therefore, I conducted the measurement under different fruit load of 50 and 100 fruits tree^{-1} (8.3 and 16.7 m^{-2}) in two consecutive growing years of 2020 and 2021, respectively. Photosynthetic light- or CO_2-response curves, along with photosynthesis parameters in GH-T and GH-C, were measured in June, August, and October in both years.

The result revealed that photosynthesis down-regulation in GH-C occurred clearly only under low fruit load conditions. This down-regulation was not associated with stomatal limitation; however, it was a consequence of the reduction in Rubisco carboxylation activity and RuBP regeneration efficiency. In high fruit load conditions, the reduction in photosynthetic rate in GH-C was less pronounced, without showing significant differences in the biochemical parameters of photosynthesis. As a whole, photosynthesis down-regulation was not clearly detected in high fruit load condition. In spite of the down-regulation, the leaf photosynthetic rate measured under the prospected future climate condition in GH-C increased by 25% and 33% under low and high fruit load respectively, compared with the current condition.

(2) Chapter III

Change in fruit quality during harvest and preservation period under elevated CO_2 and high temperature

In chapter III, I compared the fruit quality of 'Tsugaru' and 'Fuji' in three greenhouses during the harvest season in 2021 and 2022. Although the fruit quality during the fruit maturation period is important for growers to decide the harvesting date, most of the studies regarding fruit quality have been conducted using the tree grown under present climate condition. Harvesting schedule for GH-A was followed by the harvesting calendar of Aomori Prefecture, while the schedule for GH-T and GH-C was decided by the observation. The firmness and acid concentration of 'Tsugaru' in GH-T and GH-C decreased from earlier and faster than those in GH-A, whereas soluble solid and color rating increased with time later. Therefore, fruits of 'Tsugaru' in GH-T and GH-C seemed better to be harvested around 10 days earlier than those in GH-A. As the starch rating of 'Fuji' in GH-T and GH-C was minimum from the fruit sampling time, they could also harvest earlier than that in GH-A. However, considering that firmness maintained and color rating continued to increase till late, 'Fuji' in GH-T and GH-C seemed better to be harvested around 5 days later than those in GH-A.

I also compared the fruit quality of 'Fuji' in three greenhouses during the preservation period in 2021-22. For the fruits cultivated under high temperature in GH-T, firmness and acid concentration were inferior to those in GH-A at the beginning, but were not inferior after 150 days of preservation. In contrast, for the fruit cultivated under high [CO_2] in GH-C, firmness was always inferior and acid concentration decreased more rapidly, when compared with those in GH-T.

(3) Chapter IV

The effect of elevated CO_2 and high temperature on phenology, dry matter production, and partitioning

In Chapter IV, I examined the dates of various phenological events in three greenhouses in 2020 and 2021. Result reveled that high temperature in GH-T accelerated bud sprouting and leaf emergence by 3-6 and 6-12 days, respectively when compared with the ambient temperature in GH-A. Similarly, the flowering and full-bloom dates in GH-T became earlier by more than 10 days. Defoliation in GH-T delayed compared to GH-A, thereby the growing season was extended conspicuously. High [CO_2] in GH-C trended to delay all phenological events slightly.

I also examined above-ground dry matter production and its distribution in three greenhouses in 2020 and 2021. High temperature in GH-T considerably increased the dry matter production in 2020, although a less increasing tendency was observed in 2021. The effect of elevated [CO_2] on dry matter production in GH-C was around 20 % when averaged over years and varieties. In this study, under low fruit load conditions in 2020, the largest part of the total dry matter was partitioned into shoots whereas it considerably reduced under high fruit load conditions in 2021. High temperature in GH-T conspicuously decreased the dry matter partitioning to fruit, and this partitioning ratio was hardly improved by high [CO_2] in GH-C. It's obvious from this study that a higher accumulation of total dry matter in GH-C may not be distributed to fruit. Dry matter partitioning to the leaf and trunk shows a declining tendency by increasing crop load and it tends to increase in high temperature and/or elevated CO_2.

Concluding remarks

According to this research, apple leaf photosynthesis, fruit quality, phenology and growth will be influenced variously by the changing climate condition. These knowledges will be valuable for apple grower for speculating the apple tree response to future environment and for making the strategy of cultivation.

Note 1 The summary will be published online. Please confirm that UGAS has your permission to do so.

Note 2 In the summary, please do not include any content beyond your control (e.g. patents or intellectual assets) which will make online publication impossible.

Note 3 The summary should be four or five pages in total.