PHOTOVOLTAIC TEA PLANTATION IN CHINA

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Abstract

Photovoltaic (PV) agriculture is a new type of agriculture that widely applies solar power generation to modern agricultural planting, breeding, irrigation, pest control and power supply of agricultural machinery. PV-agriculture system meets the requirements of biological chain relationship and biologically optimal production of raw material-energy system, follows the production rules of agricultural products and innovates material and energy conversion technology so as to achieve the purpose of intelligent light, water and temperature regulation. The agricultural products produced by PV-agriculture system is safer, more nutritious and more productive than the products produced by the traditional way. Tea (Camellia sinensis) is a typical weak light tolerant plant and the best crop for building PV-agriculture system. The advances in PV-tea plantation system studies, including effects of PV on yield, quality, abiotic stress and economic efficiency of tea production are discussed in the present paper.

Keywords: *Camellia sinensis, tea yield, tea quality, abiotic stress, economic efficiency*

1. INTRODUCTION

With the accelerated process of economy, environmental issues and energy issues have become the focus of attention of world, along with the energy crisis and environmental pollution. As a result of the environmental protection consciousness enhancing, many countries starts to advocate the sustainable development, encourage investment in the development of environment-friendly product and expanding the clean energy generation.

Solar energy is one of the most important renewable energy, has long been the attention of people. The photovoltaic(PV) is developing rapidly in China. Apart from market demand, it is mostly due to the strong policy for PV energy incentivisation, for example, "The Twelfth Five-Year Plan of PV Industry", in which PV power generation is promoted with subsidies, with combination of rural poverty alleviation not only were in [1]. Due to the policy encouragement, The capacity of installed PV in China have shown a rapid increase in the last few years (Figure 1). The total capacity of installed PV in China in 2018 was increased to 174 GW, up 34% from the previous year (National Energy Administration (NEA). Statistics of photovoltaic power generation in 2018. http://www.nea.gov.cn/2019-03/19/c_137907428.htm). However, the PV panels have potential conflicts of interest between daylighting and energy efficient. The desertification of land where solar panels are deployed is one of the major problems in the PV industry.

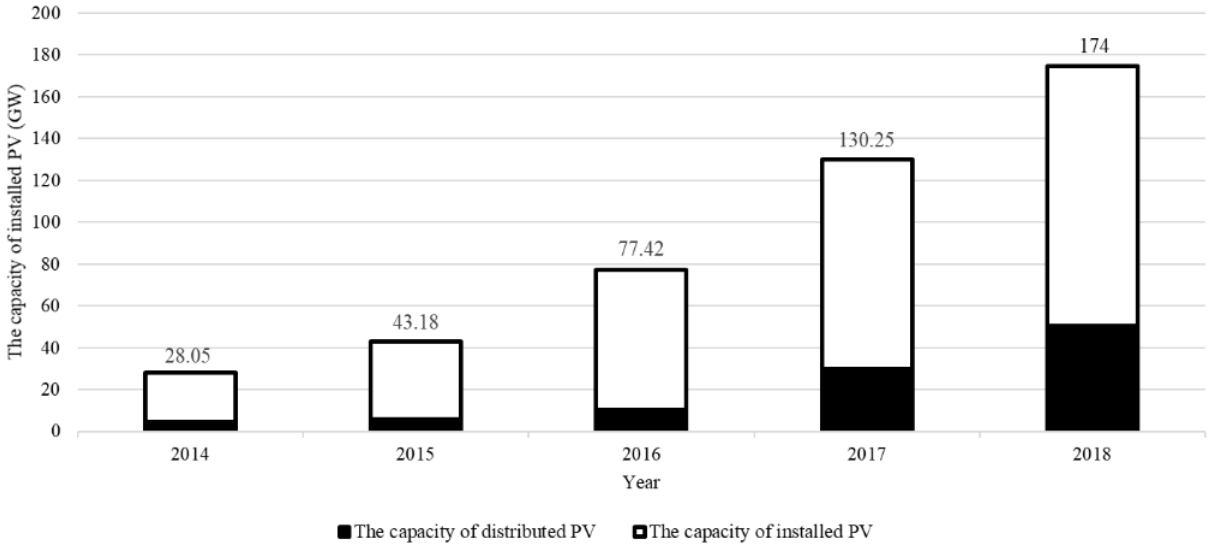


Fig. 1. The capacity of installed PV in China in the last five years

The agricultural land is usually cheap compared to other land-use destinations, pulling the investors to looking for agricultural lands for PV power plants and speculate on the public incentives [2]. PV system linked to agriculture such as PV agricultural greenhouse [3-5], PV pumps [6-8], or open fields with PV arrays installed above the crops, is a trend setting area which can integrate energy and food production on the same land unit [9, 10]. At the same time, the electricity demand of different agricultural activities can be met by harnessing the solar energy [11]. However, the installation of PV panels reduces solar radiation that falls to the plants inside the PV system, this aspect posed the problems of the competition between land uses for energy towards crop production. Given the lack of knowledge and agricultural experience, these new PV farms preferred to concentrate on the PV energy production and did not invest in the agricultural infrastructures for efficient cultivation [3].

Due to the high cost of solar energy PV power and the short sunshine duration under the solar panels, it is better to plant crops with high economic income and weak light tolerance to suit for the microclimate under the PV system. Only with a suitable planting species and planting pattern with the appropriate scale investment in PV-agriculture system can achieve double wins of crop economy and electricity generation benefits.

Tea plant (*Camellia sinensis L.*) belongs to the Theaceae family and is a popular nonalcoholic healthy beverage that is consumed in all regions of the world, with many health benefits [12]. Tea plants are adapted to the understorey of forests in their native habitat. There is evidence showing that photosynthesis of tea leaves is decreased under strong solar radiation conditions at noon, particularly in dry seasons. It is considered that the decrease of photosynthetic active radiation (PAR) falling tea plant to canopy caused by PV panels might prevente midday depression of photosynthesis and benefit the tea production [13, 14]. Furthermore, the quality of manufactured tea was improved under shading treatment in the summer [15]. The effects of PV arrays on yield and quality of tea were investigated in the present paper.

2. THE EFFECTS OF PV ON CROP PRODUCTION

The PV installations often occupy large areas of land, since they are specifically built for PV energy massive production, resulting in an ecological impact on the agricultural ecosystems such as air temperature, relative humidity, and solar radiation. These factors are important for the actively growing crops and could influence crop yield and quality in various ways. Typically, greenhouses catch about two thirds of the available solar radiation and their efficiency is strongly related to their position and geometry [16], this efficiency further decreases due to the PV panels on the roof [17]. The researchers

observed that the solar radiation inside the greenhouses embedded PV panels is 213.73kWhm^{-2} for a duration of 85 days of the experiment, being lower than that inside the the greenhouse without PV panels which is 238.04 kWhm^{-2}, because of PV shading [17]. The shading of the photovoltaic panels on the underlying tea plants changes over time throughout the day, and the shading degrees depend on the structures of the PV penels, which are 24%~42.5% and 33%~49%, under the checkerboard fixed PV system (Figure 2, A) and horizontal single-axis tracker PV system (Figure 2, B) respectively[18].

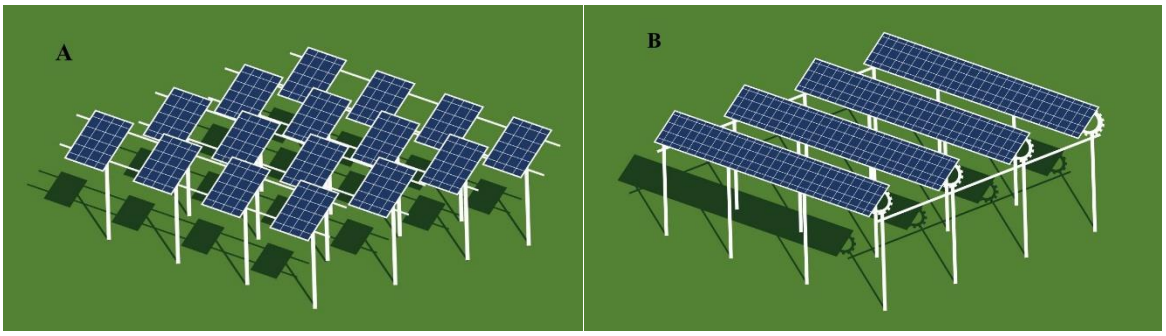


Fig. 2. Checkerboard fixed PV system (A) and horizontal single-axis tracker PV system (B)

Yano et al. [19] investigated the spatial distribution of sunlight energy in a greenhouse equipped with a large PV array of 12.9% shading rate, and it showed that the radiation received by plant differentiated between straight-line arangement and checkerboard arrangement PV array, being 81% and 77% compared with the control greenhouse, respectively. The available solar radiation inside PV system changed with the design parameters such as PV covering rate, height and orientation of PV panels, checkerboard pattern, and etc. The yearly global radiation decreased averagely by 0.8% for each additional 1.0% PV cover rate and increased by 3.8% for each additional meter of greenhouse height [20]. There are several types of semi-transparent PV modules that could be used as covering material of plants [21, 22], but their efficiencies per covered roof surface area are low and therefore cost effective systems of opaque PV panels of higher efficiency have a greater price/ performance ratio.

Agriculture performance in most cases is negatively affected by shade, including slowing down growth , reducing total biomass production at maturity, and leaf characteristics [2, 23-26]. In Germany, 57% and 34% reduction in the photosynthetic photon flux density (PPFD) integral over the growing period caused a decrease of the tomato dry weight of 31% and 19% [27]. In Japan, The accumulation of fresh and dry-weight on welsh onion cultivated under a 12.9% PV roof coverage reduced significantly [28]. In Spain, the marketable production of tomatoes did not appreciably affected inside a PV greenhouse with 9.8% PV cover ratio, but it influenced the fruit size, color and maturation [29]. In southern France, the yield of lettuce grown in an agriculture-PV system with 50% PV shade, ranged from 81% to 99% of the control, due to the enhancement of radiation interception efficiency, achieved by increasing the leaf area [26]. In Malaysia, Java Tea, a kind of herbal crop, collected final raw material with a reduction of 73.7% under PV array [30].

All these influences of PV on crops provide information on selecting crop species suitable for the weak solar light conditions inside PV system and achieving the optimal balance between agricultural income and energy production.

3. THE EFFECTS OF SHADE ON TEA PLANTS

In tea plantation, shading is one of the traditional agricultural practices to improve tea quality through modifying the structural traits, photosynthesis, color, and chemical compositions in tea leaves.

3.1. Photosynthesis of tea

Photosynthetic light compensation point (LCP), and light saturation point (LSP) of various tea cultivars vary with growing season, fertilization, irrigation and etc [31]. There were studies showing the LCP and LSP of some tea cultivars (Table 1). It shows that the radiation demanding for vigorous grow of most tea cultivar is less than 1200 μmol·m^{-2}·s^{-1}. However, according to the research of climatology and statistics, the PFD of most tea-growing areas in China it is more than 1200μmol·m^{-2}·s^{-1}, particularly in summer [32]. Tea is a weak light tolerant plant, and strong intensity of radiation will lead to photo-inhibition (PI), in which photosynthesis is inhibited [31], and hence shading is often a measure to improve yield and quality [33, 34]. The photosynthetic capacity of tea is inferred better for leaves grown under shading conditions than that in the unshaded open fields. The air temperature might be lower and the air moister increased under the lower radiation conditions, in which the tea grows well [14, 31, 35].

Tea Cultivars	LCP (μmol·m-2·s-1)	LSP (μmol·m-2·s-1)	Ref.
Fudingdabai	35~56	382~750	[36-38]
Jinguang	46~164	240~243	[37, 38]
Huangjinya	36~188	256~329	[37, 38]
Yujinxiang	42	361	[37]
Baiyeyihao	84	452	[38]
Simingxueya	100	716	[38]
Zijuan	80	392	[38]
Ziyan	76	276	[38]
Longjing43	112	1000~1200	[39]

Table 1. Different cultivars of tea's light compensation point, light saturation point

3.2 Pigments of tea

The shading cultivation by sunlight shielding using shading net affect tea quality through altering the pigments and chemical compositions. There was research showing that the shade treatment increased the amount of chlorophyll, which plays a role in light absorption in the chloroplast to maximize light absorption [15, 40]. Chlorophyll content is also closely related to the scores for the colour of dry tea and its tea infusions [41, 42]. For example, matcha is a very fine powder been ground by special green tea leaves picked from tea plants under 60-90% shade for about 7-10 days before harvesting. This shade treatment increased chlorophyll content in tea leaves, leading to darker green colour [43]. Although the mean contents of chlorophyll a and chlorophyll b were increased with increase in shading rate, the shading treatment had no effect on carotenoid content [40, 44]. Besides the green tea phenotypes, similar shade-induced response on pigments was detected from albino tea cultivars, pale yellow leaves in albino cultivars always have aberrant chloroplast development, but for the most part, could be recovered by shading treatment, in which the leaves regain green colour with increase in chlorophylls and carotenoid, and also the development of chloroplasts [45, 46].

In addtion, the ratio of chlorophyll a to chlorophyll b in shadded tea leaves was lower than that that in open culture [47]. The change in ratio of chlorophylls might be its adapated low light to mainten photosynthetic intensity [48, 49].

3.3 Chemical compositions of tea

The flavour of tea is principally depend on its chemical components. Artificial control of tea growing, i.e., typically shade treatments, can lead to significant changes of the tea metabolite compositions. Compared to the unshaded leaves, the contents of catechins and flavonols in shaded leaves decreased

by 53.37% and 43.26%, respectively [50]. The major catechins, including catechin (C), epicatechin (EC), gallocatechin (GC) and (-)-epigallocatechin (EGC), decreased significantly in tea shoots throughout the whole shading period [51]. But the concentration of (-)-Epigallocatechin gallate (EGCG) in matcha made from this leaves is higher than that in green tea [52]. It is reported that catechins biosynthesis in tea shoots is predominantly regulated by UV through the UVR8-mediated signal transduction pathway to MYB12/MYB4 downstream effectors [51]. The expression of gene encoding phenylalanine ammonia lyase which catalyzes the biosynthesis of catechin derivatives precursors was down-regulated in tea plants grown under shaded conditions [50], resulting in reduction of catechins [53].

Generally, tea leaves grown under shaded conditions contain less catechin derivatives but is more rich in amino acids [15, 50, 53-56]. The levels of most amino acids were lifted as shading period extended, along with reductions of glucose level [54]. It is reported that most enzymes involved in biosynthesis of amino acids were down-accumulated and two chloroplasts proteases were upregulated under dark treatment conditions, suggesting that amino acid accumulation in dark-treated leaves was not due to activation of amino acid biosynthesis process, but contributed by the proteolysis of chloroplast protein [57].

Apart from catechins and amino acids, some other volatile and non-volatile metabolite profiles differed significantly between shading treatment and untreated leaves [53, 58]. The levels of volatiles, especially volatile phenylpropanoids/benzenoids (VPBs), significantly increased in the tea leaves grown in shading treatment for 3 weeks. Upstream metabolites of VPBs showed lower levels in shading treated than in control leaves, whereas the contents of most amino acids including L-phenylalanine, a key precursor of VPBs, were significantly enhanced [53].

On the whole, these studies indicate that the growth and quality of tea facilitated by shady condition.

4. CONCLUSIONS AND FUTURE EXPECTATIONS

Through above analysis, it is considered that the development of PV tea plantation is a best choice in tea industry. The major effect of PV system exposure to crops is on the sunlight, but to some extent this weakness can be turned into a strength by installing PV arrays above tea plants in open fields or greenhouses. The installation of PV panels reduces solar radiation that falls to the plants inside the PV-agriculture system [19], affecting their lighting and therefore crop growing [59]. However, there is evidence that photosynthsis of tea is decreased by strong solar radiation, in which partially shielding the sun light by PV system might benefit tea growing and tea production. In China's Shandong Province, the fresh tea leaves yield in PV greenhouse was 130 kg/ 667m^2, being 62.5% higher than that in the regular greenhouse, and 117% over that in open fieid tea plantation, respectively [60]. The low productivity of tea may be related to inadequate assimilate production, as the rates of photosynthesis in tea plants in the regular greenhouse and open tea field are lower than that grow in PV greenhorse. Certainly the question of whether or not PV system is appropriate to maintain growth rates at high levels depends on so many factors such as solar radiation, temperature and humidity. It is difficult to generalize although it can be assumed that, increase of photosynthetic rate could be attributed to reduction of light intensity, as well as cooler temperatures and higher moisture induced by the decreased radiation by PV panels. Moreover, the PV tea plantation can decrease occurrence of pests and diseases, resulting in yield improvement. Investigations on diseases and insect pests on tea plants showed that tea in greenhouse imbeded with PV arrays had fewer and lower risk of pests and diseases than regular greenhouse and open tea field [60]. The exact mechanism under this phenomenon remains to be investigated.

PV system as a shade installation not only increased tea leaves yeild, but also improved the tea quality. According to the sensory evaluation and color measurement data, the shade treatment improves the nutritional and sensory quality of green tea and black tea [15, 61]. Amino acids, especially theanine, which have *umami* or brothy taste, contribute to the mellow taste of green tea, whereas catechins, caffeine and flavonoids with bitter taste contribute to the astringency. Shade treatment in summer tea palnts decreased the intensities of astringency and bitterness of tea [15], which was considered to be related to the increase in compounds with *umami* and sweet taste, such as theanine, acompanying with

decrease in catechins [43, 54, 62]. These studies delineates the possibility to produce green teas with high *umami* taste and less bitter taste in PV tea plantation.

Although tea plant has a potential of low-light-tolerance, the optimum shading rate varies with tea cultivars. The response of various tea cultivars to low-light conditions induced by PV panel system and the changes in photosynthetic characteristics and chemical compositions of tea leaves remain to be further investigated and improved.

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REFERENCES

1. Gao, X 2019, "Local demand-pull policy and energy innovation: Evidence from the solar photovoltaic market in China", *Energy Policy,* vol. 128, pp. 364-376.
2. Cossu, M 2014, "Solar radiation distribution inside a greenhouse with south-oriented photovoltaic roofs and effects on crop productivity", *Applied Energy,* vol. 133, pp. 89-100.
3. Li, CS 2017, "The economic and social performance of integrated photovoltaic and agricultural greenhouses systems: Case study in China", *Applied Energy,* vol. 190, pp. 204-212.
4. Castellano, S 2016, "Solar radiation distribution inside a monospan greenhouse with the roof entirely covered by photovoltaic panels", *Journal of Agricultural Engineering,* vol. 47, no. 1, pp. 1-6.
5. Cossu, M 2016, "Advances on the semi-transparent modules based on micro solar cells: First integration in a greenhouse system", *Applied Energy,* vol. 162, pp. 1042-1051.
6. Petroselli, A 2012, "Photovoltaic Pumps: Technical and Practical Aspects for Applications in Agriculture", *Mathematical Problems in Engineering*.
7. Campana, PE 2015, "Optimal grassland locations for sustainable photovoltaic water pumping systems in China", *Clean, Efficient and Affordable Energy for a Sustainable Future,* vol. 75, pp. 301-307.
8. Campana, PE 2017, "Suitable and optimal locations for implementing photovoltaic water pumping systems for grassland irrigation in China", *Applied Energy,* vol. 185, pp. 1879-1889.
9. Dupraz, C 2011, "Combining solar photovoltaic panels and food crops for optimising land use: Towards new agrivoltaic schemes", *Renewable Energy,* vol. 36, no. 10, pp. 2725-2732.
10. Malu, PR 2017, "Agrivoltaic potential on grape farms in India", *Sustainable Energy Technologies and Assessments,* vol. 23, pp. 104-110.
11. Cuce, E 2016, "Renewable and sustainable energy saving strategies for greenhouse systems: A comprehensive review", *Renewable & Sustainable Energy Reviews,* vol. 64, pp. 34-59.
12. Yang, CS 2018, "Studies on prevention of obesity, metabolic syndrome, diabetes, cardiovascular diseases and cancer by tea", *Journal of Food and Drug Analysis,* vol. 26, no. 1, pp. 1-13.
13. Mohotti, AJ 2002, "Diurnal variation of photosynthesis and photoinhibition in tea: effects of irradiance and nitrogen supply during growth in the field", *Journal of Experimental Botany*, vol. 53, no. 367, pp. 313-322.
14. Squire, GR 1977, "Seasonal-Changes in Photosynthesis of Tea (Camellia-Sinensis L)", *Journal of Applied Ecology*, vol. 14, no. 1, pp. 303-316.

15. Lee, LS 2013, "Metabolomic Analysis of the Effect of Shade Treatment on the Nutritional and Sensory Qualities of Green Tea", *Journal of Agricultural and Food Chemistry*, vol. 61, no. 2, pp. 332-338.
16. Pieters, JG 1999, "Modelling solar energy input in greenhouses", *Solar Energy*, vol. 67, no. 1-3, pp. 119-130.
17. Trypanagnostopoulos, G 2017, "Greenhouse performance results for roof installed photovoltaics", *Renewable Energy*, vol. 111, pp. 724-731.
18. Jiang, H. 2018. *Analysis of lighting environment of photovoltaic tea garden based on numerical.* Master, Zhejiang University.(in Chinese)
19. Yano, A 2010, "Shading and electrical features of a photovoltaic array mounted inside the roof of an east-west oriented greenhouse", *Biosystems Engineering*, vol. 106, no. 4, pp. 367-377.
20. Cossu, M 2018, "Assessment and comparison of the solar radiation distribution inside the main commercial photovoltaic greenhouse types in Europe", *Renewable & Sustainable Energy Reviews*, vol. 94, pp. 822-834.
21. Marucci, A 2012, "The Semitransparent Photovoltaic Films for Mediterranean Greenhouse: A New Sustainable Technology", *Mathematical Problems in Engineering*.
22. Emmott, CJM 2015, "Organic photovoltaic greenhouses: a unique application for semi-transparent PV?", *Energy & Environmental Science*, vol. 8, no. 4, pp. 1317-1328.
23. Cantagallo, JE 2004, "Grain number in sunflower as affected by shading during floret growth, anthesis and grain setting", *Field Crops Research*, vol. 85, no. 2-3, pp. 191-202.
24. Worku, W 2004, "Responses of common bean (Phaseolus vulgaris L.) to photosynthetic irradiance levels during three phenological phases", *Agronomie*, vol. 24, no. 5, pp. 267-274.
25. Kitaya, Y 1998, "Photosynthetic photon flux, photoperiod, and CO2 concentration affect growth and morphology of lettuce plug transplants", *Hortscience*, vol. 33, no. 6, pp. 988-991.
26. Marrou, H 2013, "Productivity and radiation use efficiency of lettuces grown in the partial shade of photovoltaic panels", *European Journal of Agronomy*, vol. 44, pp. 54-66.
27. Klaring, HP 2013, "The Effect of Constraining the Intensity of Solar Radiation on the Photosynthesis, Growth, Yield and Product Quality of Tomato", *Journal of Agronomy and Crop Science*, vol. 199, no. 5, pp. 351-359.
28. Kadowaki, M 2012, "Effects of greenhouse photovoltaic array shading on Welsh onion growth", *Biosystems Engineering*, vol. 111, no. 3, pp. 290-297.
29. Urena-Sanchez, R 2012, "Greenhouse tomato production with electricity generation by roof-mounted flexible solar panels", *Scientia Agricola*, vol. 69, no. 4, pp. 233-239.
30. Othman, NF 2015, "Embracing new agriculture commodity through integration of Java Tea as high Value Herbal crops in solar PV farms", *Journal of Cleaner Production*, vol. 91, pp. 71-77.
31. Smith, BG 1993, "Effects of Light, Temperature, Irrigation and Fertilizer on Photosynthetic Rate in Tea (Camellia-Sinensis)", *Experimental Agriculture*, vol. 29, no. 3, pp. 291-306.
32. Li, HS 2010, "Estimating daily global solar radiation by day of year in China", *Applied Energy*, vol. 87, no. 10, pp. 3011-3017.
33. Chetana, HC 2012, "Importance of shade trees (Grevillea robusta) in the dispersal of forest tree species in managed tea plantations of southern Western Ghats, India", *Journal of Tropical Ecology*, vol. 28, pp. 187-197.
34. Mukherjee, A 2008, "Productivity and radiation use efficiency of tea grown under different shade trees in the plain land of West Bengal", *Journal of Agrometeorology*, vol. 10, no. 2, pp. 146-150.

35. Hirai, M 2008, "Production of Value-Added Crop of Green Tea in Summer under the Shade Screen Net: Canopy Microenvironments", *Proceedings of the International Workshop on Greenhouse Environmental Control and Crop Production in Semi-Arid Regions*, no. 797, pp. 411-+.

36. Tao, HZ 1991, "Study on diurnal variation of photosynthesis in tea trees", *Acta Agronomica Sinica*, no. 06, pp. 444-452. (in Chinese)

37. Han, N 2015, "Photosynthetic Characteristics of Introduced Tea Cultivars Huangjinya，Jinguang and Yujinxiang in Sichuan Tea-area", *Southwest China Journal of Agricultural Sciences*, vol. 28, no. 04, pp. 1600-1605. (in Chinese)

38. Xu, Y. 2016. *Studies on photosynthetic traits and chloroplast ultrastructure of 6 tea characteristic.* Master, Sichuan Agricultural University. (in Chinese)

39. Yu, HY. 2013. *Studies on pjotosynthetic traits of tea leaves at different positions of canopy and their seasonal changes.* Master, Chinese Academy of Agricultural Sciences Dissertation. (in Chinese)

40. Sonobe, R 2018, "Monitoring Photosynthetic Pigments of Shade-Grown Tea from Hyperspectral Reflectance", *Canadian Journal of Remote Sensing*, vol. 44, no. 2, pp. 104-112.

41. Wang, LF 2004, "The compounds contributing to the greenness of green tea", *Journal of Food Science*, vol. 69, no. 8, pp. S301-S305.

42. Wang, KB 2010, "Analysis of chemical components in oolong tea in relation to perceived quality", *International Journal of Food Science and Technology*, vol. 45, no. 5, pp. 913-920.

43. Engelhardt, UH 2016, "Theanine, catechins, caffeine and flavonol glycosides in green and Matcha tea samples from Japan", *Deutsche Lebensmittel-Rundschau*, vol. 112, no. 11, pp. 499-502.

44. Sonobe, R 2018, "Estimating leaf carotenoid contents of shade-grown tea using hyperspectral indices and PROSPECT-D inversion", *International Journal of Remote Sensing*, vol. 39, no. 5, pp. 1306-1320.

45. Liu, GF 2017, "Metabolic Flux Redirection and Transcriptomic Reprogramming in the Albino Tea Cultivar 'Yu-Jin-Xiang' with an Emphasis on Catechin Production", *Scientific Reports*, vol. 7.

46. Shin, YH 2018, "Light-sensitive Albino Tea Plants and Their Characterization", *Hortscience*, vol. 53, no. 2, pp. 144-147.

47. Sano, T 2018, "Effect of shading intensity on morphological and color traits and on chemical components of new tea (Camellia sinensis L.) shoots under direct covering cultivation", *Journal of the Science of Food and Agriculture*, vol. 98, no. 15, pp. 5666-5676.

48. Delatorre, WR 1990, "Acclimation of Barley to Changes in Light-Intensity - Chlorophyll Organization", *Photosynthesis Research*, vol. 24, no. 2, pp. 117-125.

49. Hikosaka, K 1996, "Nitrogen partitioning among photosynthetic components and its consequence in sun and shade plants", *Functional Ecology*, vol. 10, no. 3, pp. 335-343.

50. Wang, YS 2012, "Influence of shade on flavonoid biosynthesis in tea (Camellia sinensis (L.) O. Kuntze)", *Scientia Horticulturae*, vol. 141, pp. 7-16.

51. Liu, LL 2018, "Metabolite profiling and transcriptomic analyses reveal an essential role of UVR8-mediated signal transduction pathway in regulating flavonoid biosynthesis in tea plants (Camellia sinensis) in response to shading", *Bmc Plant Biology*, vol. 18.

52. Weiss, DJ 2003, "Determination of catechins in matcha green tea by micellar electrokinetic chromatography", *Journal of Chromatography A*, vol. 1011, no. 1-2, pp. 173-180.

53. Yang, ZY 2012, "Characterisation of volatile and non-volatile metabolites in etiolated leaves of tea (Camellia sinensis) plants in the dark", *Food Chemistry*, vol. 135, no. 4, pp. 2268-2276.

54. Ji, HG 2018, "Diverse Metabolite Variations in Tea (Camellia sinensis L.) Leaves Grown Under Various Shade Conditions Revisited: A Metabolomics Study", *Journal of Agricultural and Food Chemistry,* vol. 66, no. 8, pp. 1889-1897.
55. Ku, KM 2010, "Metabolomics Analysis Reveals the Compositional Differences of Shade Grown Tea (Camellia sinensis L.)", *Journal of Agricultural and Food Chemistry,* vol. 58, no. 1, pp. 418-426.
56. Saijo, R 1980, "Effect of Shade Treatment on Biosynthesis of Catechins in Tea Plants", *Plant and Cell Physiology,* vol. 21, no. 6, pp. 989-998.
57. Chen, YY 2017, "Proteolysis of chloroplast proteins is responsible for accumulation of free amino acids in dark-treated tea (Camellia sinensis) leaves", *Journal of Proteomics,* vol. 157, pp. 10-17.
58. Zheng, XQ 2016, "Recent Advances in Volatiles of Teas", *Molecules,* vol. 21, no. 3.
59. Roslan, N 2018, "Dye Sensitized Solar Cell (DSSC) greenhouse shading: New insights for solar radiation manipulation", *Renewable & Sustainable Energy Reviews,* vol. 92, pp. 171-186.
60. Sun, LT 2015, "Study and Analysis of Tea Tree Growth in Photovoltaic Greenhouse", *Agriculture Engineering Technology,* no. 31, pp. 40-42. (in Chinese)
61. Owuor, PO 1988, "Studies on the Use of Shade in Tea Plantations in Kenya - Effects on Chemical-Composition and Quality of Made Tea", *Journal of the Science of Food and Agriculture,* vol. 46, no. 1, pp. 63-70.
62. Zhang, QF 2014, "Metabolomic Analysis Using Ultra-Performance Liquid Chromatography-Quadrupole-Time of Flight Mass Spectrometry (UPLC-Q-TOF MS) Uncovers the Effects of Light Intensity and Temperature under Shading Treatments on the Metabolites in Tea", *Plos One,* vol. 9, no. 11.