Multi-Factor Coordinated Control Technology for Early-Ripening Production of Southern Blueberries in Intelligent Greenhouses: Postprint

Authors: Xu Lihong, Liu Huihui, Xu He, Wei Ruihua, Cai Wentao

Date: 2023-02-17T00:00:00+00:00

Abstract

To achieve early market availability and greater economic benefits for blueberries, our team transplanted southern blueberries into environmentally controlled smart greenhouses for experimental production, exploring and developing a control technology for promoting early ripening in southern blueberry smart greenhouse production. First, a relatively detailed and comprehensive investigation and summary were conducted regarding blueberry phenological periods, variety characteristics, soil pH, water and fertilizer irrigation methods, microclimate environment ranges, and other aspects, clarifying the key points of full-cycle management and environmental regulation ranges for soilless blueberry cultivation. Subsequently, based on the Venlo-type greenhouse, a layout for blueberry production was designed, and a blueberry plant factory production control system was established based on Internet of Things technology, connecting the hardware layer, software layer, and cloud to achieve technologies such as on-site environmental monitoring and regulation, cloud data storage, and remote control. Based on a multi-factor coordinated control model for greenhouse environments, a set of multi-factor coordinated control algorithms specifically tailored to blueberry growth characteristics was explored and developed for environmental regulation. The experimental greenhouse is located in the southeastern part of Huaqiao Town, Kunshan City, Suzhou City, Jiangsu Province. After practical verification, the overall control system demonstrated significant effects, and the first wave of fruits was harvested in early May 2021, enabling southern variety blueberries to enter the fruit harvesting period nearly one month earlier. Compared with non-chilled blueberry plants, the yields per plant of chilled ‘Star’ , ‘Emerald’ , ‘Lanmei No. 1’ , and ‘Coast’ increased by 51.5%, 85.5%, 43.8%, and 94.7%, respectively, and individual fruit weights increased by 10.9%, 7.2%, 2.6%, and 5.3%, respectively. The experiments proved that regulation using the multi-factor coordinated control algorithm can improve blueberry yield and quality, achieve significant economic benefits, and provide a demonstration for

early-ripening production management of southern greenhouse blueberry plant factories.

Full Text

Preamble

Multi-Factor Coordination Control Technology of Promoting Early Maturing in Southern Blueberry Intelligent Greenhouse

XU Lihong*, LIU Huihui, XU He, WEI Ruihua, CAI Wentao
(College of Electronics and Information Engineering, Tongji University, Shanghai 201804, China)

Abstract: To achieve early market release and greater economic benefits of blueberries, our team relocated southern blueberries to an environment-controlled intelligent greenhouse for experimental production, exploring and developing early maturing production control technology for southern blueberries in intelligent greenhouses. First, a detailed and comprehensive investigation was conducted on blueberry phenological periods, variety characteristics, soil water-fertilizer irrigation methods, and microclimate environmental ranges, clarifying the key management points and environmental control parameters for soilless blueberry cultivation throughout the growth cycle. Next, based on the Venlo-type greenhouse, a layout was designed for blueberry production, and an IoT-based blueberry plant factory production control system was established, integrating hardware, software, and cloud layers to achieve on-site environmental monitoring and regulation, cloud data storage, and remote control. Building upon the greenhouse environment multi-factor coordination control model, a set of blueberry greenhouse multi-factor coordination control algorithms was developed specifically for environmental regulation. The experimental greenhouse is located in the southeast of Huaqiao Town, Kunshan City, Suzhou, Jiangsu Province. Practical verification demonstrated significant effectiveness of the overall control system, with the first wave of fruits harvested in early May, advancing the fruit picking period for southern blueberry varieties by nearly one month. Compared with non-chilled blueberry plants, the per-plant yields of 'Star', 'Emerald', 'Lanmei No. 1', and 'Coast' after chilling increased by 51.5%, 85.5%, 43.8%, and 94.7% respectively, while individual fruit weights increased by 10.9%, 7.2%, 2.6%, and 5.3% respectively. The experiments proved that using multi-factor coordination control algorithms can improve blueberry yield and quality, achieve significant economic benefits, and provide a demonstration for southern greenhouse blueberry plant factory early maturing production management.

Keywords: blueberry; cultivation management; plant factory; promoting early-ripeness; production control system; multi-factor coordination control algorithm; Internet of Things

1 Introduction

Blueberry, also known as bilberry, is a perennial low shrub belonging to the Ericaceae family and Vaccinium genus, recognized by the Food and Agriculture Organization of the United Nations (FAO) as one of the five healthiest foods for humans [1]. As a high-value fresh fruit crop, its market has expanded significantly in recent years, with considerable economic benefits. Compared with other fruits and vegetables, blueberry cultivation requires not only suitable climate conditions such as temperature, humidity, light, and CO2, but also has specific production characteristics including poor drought resistance, need for acidic soil and precise water-fertilizer conditions, chilling requirement accumulation, and low light saturation point. Currently, most blueberry production bases in China adopt open-field soil cultivation or simple protected ground cultivation, which cannot achieve plant factory production standards and are unsuitable for forming large-scale intelligent planting bases [2]. This restricts blueberry introduction in regions with unsuitable climates, and few reports mention control measures for high-end greenhouse blueberry cultivation. In the Shanghai region, alkaline soil, short low-temperature periods, and extended rainy Meiyu weather present special climate challenges that constrain local blueberry cultivation. The solution lies in using advanced facility agriculture methods to circumvent geographical limitations.

Plant factory represents the advanced stage of modern agricultural development. Through computer control systems, it precisely controls temperature, humidity, CO2 concentration, and nutrient solution environmental conditions throughout plant growth and development, enabling year-round continuous crop production [3-5]. This approach can serve as a method for large-scale southern blueberry production. Additionally, while open-field blueberry cultivation in Shanghai and surrounding areas typically matures from mid-to-late June through August, plant factory production can regulate the growing environment to achieve early market release and increased economic value. In recent years, greenhouse-cultivated blueberries have commanded prices of 150-200 RMB/kg, with earlier market entry yielding higher economic returns [6]. Therefore, using plant factory control methods to advance blueberry maturation in Shanghai is of significant importance.

To achieve early blueberry market release and greater economic benefits, this study designed and implemented an IoT-based intelligent greenhouse control system for blueberries, relocating southern blueberries to environment-controlled intelligent greenhouses for experimental production. Drawing on Shanghai blueberry cultivation experience, we investigated and summarized phenological periods, variety characteristics, soil pH, water-fertilizer irrigation methods, and microclimate environmental ranges to provide an important basis for subsequent environmental regulation. Based on blueberry phenological environmental characteristics and the greenhouse environment multi-factor coordination control model [7], we developed a set of blueberry greenhouse environmental multi-factor control algorithms for regulation. By implementing and summarizing full-cycle plant factory production technology for blueberries, we can effectively reduce pest and disease incidence during cultivation, increase yield and fruit commercial value and quality, improve regional adaptability, solve geographical constraints on blueberry production, and ultimately achieve early market release and improved economic benefits.

2.1 Blueberry Production Factors

Blueberry is a perennial crop with stringent requirements for climatic environmental factors such as temperature, humidity, light, and CO2, typically characterized by poor drought resistance, need for acidic soil and precise water-fertilizer conditions, chilling requirement accumulation, and low light saturation point. Different blueberry varieties have vastly different production requirements. Therefore, to achieve the goal of promoting early maturing, thorough investigation of blueberry phenology, varieties, soil, water-fertilizer, and climate factors is necessary before constructing a blueberry plant factory greenhouse.

Blueberry phenology can be broadly divided into several stages: bud break, flowering, fruiting, flower bud differentiation, and dormancy. From a varietal perspective, blueberries can be roughly classified into four categories: Northern Highbush blueberries with strong cold resistance, high chilling requirement, and preference for cool weather; Southern Highbush blueberries suitable for southern planting with low chilling requirement and preference for humid, warm climate conditions; Half-highbush blueberries, hybrids of Northern Highbush and wild lowbush blueberries with very high chilling requirements and strong cold resistance; and Rabbiteye blueberries with tall plants, long lifespan, no cold tolerance, heat and humidity resistance, slightly lower soil acidity requirements, and higher chilling requirements compared to Southern Highbush blueberries.

Blueberries have specific chilling requirements—the accumulated effective low temperature (0-7.2°C) time needed for normal flowering and fruiting, generally measured in hours [8]. When environmental conditions fail to meet blueberry chilling requirements, flower bud differentiation is significantly affected, leading to severely reduced flowering and fruit set and substantially lower yields [9], seriously impacting economic benefits. Shanghai has a subtropical monsoon climate with distinct seasons, abundant sunshine, but short low-temperature periods and extended rainy Meiyu weather, resulting in insufficient natural chilling accumulation time [10]. Therefore, low-chill blueberry varieties should be selected for Shanghai cultivation. Based on existing literature [11,12], this study selected representative varieties from "Southern Highbush" considering their fruiting periods to create a planting combination that can mature sequentially in the greenhouse. The selected varieties are 'Star', 'Emerald', 'Coast', and 'Lanmei No. 1'.

Regarding soil factors, soil pH is the most significant limiting factor for blueberry growth and cultivation [13]. Soil pH that is too high or too low affects normal blueberry growth, development, and physiological metabolism [14], leading to poor water and nutrient absorption, slow growth, yellowing and shrinking leaves, and reduced yield. Therefore, the soil pH range for blueberry cultivation should be 4.5-5.5. Additionally, blueberry roots are mostly distributed in shallow soil layers [15]. Insufficient soil permeability, high bulk density, or poor drainage are detrimental to blueberry root growth. Using soilless cultivation technology [16] to create a blueberry growth soil microenvironment can effectively solve nutrient deficiency problems [17], promote blueberry respiration and mineral element absorption [18], and facilitate precision management without regional land condition limitations, promoting standardized blueberry production [19]. This experiment used peat-based nutrient soil.

For irrigation, blueberry roots prefer moisture but are susceptible to waterlogging. Improper irrigation measures can cause drought stress, and poor water stress tolerance can lead to irreversible losses in yield and growth [20]. Based on comprehensive literature [18,21-23], blueberry irrigation patterns are: irrigate with winter water before dormancy while reducing irrigation frequency; maintain soil moisture at 60%-70% during bud forcing, avoiding excessive irrigation; use small, frequent irrigation during flowering and fruiting to prevent extended flowering periods, with maximum water demand during fruit expansion requiring adequate supply; maintain soil moisture at 40%-60% after harvest to promote re-entry into dormancy in late autumn. Tap water must not be used throughout the irrigation cycle, as it causes chlorine toxicity and prevents normal growth. Water should not be sprayed directly on flowers or leaves during flowering, as this hinders pollination and fruit set [20]. Drip irrigation offers precise, controllable advantages [24-26], so this experiment adopted drip irrigation.

2.2.1 Greenhouse Overview

The experimental greenhouse in this design is located in the southeast of Huaqiao Town, Kunshan City, Suzhou, Jiangsu Province (121°11' E, 31°33' N), at the border between Jiangsu and Shanghai, adjacent to Anting Town, Jiading District, Shanghai to the east, and Chengxiang Town, Taicang City to the north, and Qingpu District, Shanghai to the south. The region belongs to the southern edge of the north subtropical zone, dominated by Southeast Asian monsoons, with a mild, humid climate, distinct seasons, abundant light, and plentiful rainfall. The annual average temperature is approximately 16.7°C.

The experimental greenhouse is a typical Venlo-type small glass greenhouse, with the structure shown in [Figure 1: see original paper]. The basic dimensions are: eave height 5.9 m, span 17 m, bay 17.5 m, ridge height 7.2 m, gutter height 5.7 m, and total volume 1918.875 m^3.

The main control equipment in this greenhouse includes: (1) Roof vents for natural ventilation and temperature regulation; (2) Side windows for natural ventilation and temperature regulation; (3) Wet curtain fans for cooling and humidification; (4) Internal thermal screens for insulation and protection against low spring temperatures; (5) Internal shading screens for light and indoor temperature regulation; (6) Air conditioning for cooling/heating and temperature-humidity regulation; (7) Supplemental lighting to increase light during the growing season; (8) CO2 fertilization to increase concentration; (9) Irrigation system for watering, fertilizing, and acid application.

2.2.2 Full-Cycle Control Targets

This study employs a greenhouse multi-factor coordination control algorithm for environmental regulation. The algorithm aims to maintain main environmental factors such as temperature, humidity, light intensity, and CO2 concentration within optimal ranges for crop growth. Based on years of blueberry production experience from a Shanghai cooperative and relevant literature [6,8,27,28], the optimal meteorological environmental conditions for full-cycle blueberry growth can be determined, as shown in . Southern Highbush blueberry cultivation is used as an example here.

Blueberries differ from other crops in requiring adequate chilling accumulation and low light during dormancy. The bud forcing period serves as a transition between dormancy and growth, requiring gradual temperature increase. Throughout the blueberry flowering and fruiting period, nighttime temperatures must be maintained above 10°C to prevent growth cessation and delayed fruit maturation. Additionally, maintaining day-night temperature differences during flowering and fruiting increases fruit sweetness. In actual greenhouse regulation, the above cultivation experience must be summarized to reasonably divide daily temperature ranges for each growth stage. Since blueberries possess certain heat tolerance, the suitable temperature range can be appropriately expanded without exceeding critical temperatures, considering energy conservation and greenhouse facility structure.

3 Greenhouse IoT Intelligent Control System

In recent years, with continuous improvements in IoT communication technology, sensors, and information fusion processing, IoT has been widely applied across various fields. In agriculture, as smart agriculture advances nationwide, greenhouse IoT technology has become key to industrial intelligentization implementation, attracting significant research attention [29-31]. Therefore, for blueberry factory production, this study designed and implemented an IoT-based information collection and control system, proposing an effective blueberry greenhouse environment multi-factor coordination control algorithm, introduced from three aspects: overall system architecture, system hardware design, and system control software design.

3.1 System Architecture Overview

According to actual blueberry production requirements, the greenhouse control system is divided into software and hardware layers, with the overall architecture shown in [Figure 2: see original paper]. The hardware layer primarily consists of environmental digital sensor nodes and actuator controllers, with information aggregated via RS485 bus. The software layer comprises three components: on-site control base station, host computer aggregation terminal, and cloud service platform.

3.2 System Hardware Design

The system hardware is divided into sensor and actuator sections. This system implements unified management of greenhouse sensors using Zigbee data collection gateways to organize sensor nodes into a network. The on-site node layout is shown in [Figure 3: see original paper], mainly including data collection cabinets, indoor temperature, humidity, light, CO2 sensors, and soil temperature, humidity, EC, and pH sensors.

The greenhouse control system consists of climate environment and irrigation subsystems. The climate environment subsystem includes light regulation, temperature regulation, humidity regulation, and CO2 regulation. The irrigation subsystem includes water, fertilizer, and acid application. The greenhouse actuators used in this study can be divided into two-state and three-state actuators. Two-state actuators have only on/off states, primarily using relay controllers such as supplemental light tubes and wet curtain fans. Three-state actuators have on, off, and stop working states, corresponding to forward rotation, reverse rotation, and stop of the actuator motor, such as internal shading screens, thermal screens, and roof vents.

3.3 System Software Design

The software portion of the blueberry production greenhouse control system is divided into three components: on-site control base station, host computer aggregation terminal, and cloud server. The on-site control base station uses an ARM series chip as the core processor in an embedded system, based on the MODBUS-RTU protocol, connecting to on-site actuator control relay ports and distributed sensor nodes via RS485 interface. The host computer aggregation terminal is programmed in C++, communicates with the control base station via TCP protocol below, and sends information to the cloud server. The greenhouse cloud server is based on Python's Flask framework, exchanging information with the host computer via TCP/IP protocol, with the front-end interface based on the JQuery framework, providing users with interactive interfaces for monitoring and issuing control commands.

4.1 System Application Implementation

The control system has been successfully operating for nearly two years in a small Venlo-type greenhouse in Huaqiao Town, Kunshan City, Jiangsu Province. The software and hardware components have been connected one-to-one, implementing algorithms and execution. The greenhouse site is shown in [Figure

4: see original paper], including the greenhouse power control cabinet, on-site control base station, and actual blueberry production area.

This IoT-based blueberry plant factory production control system not only supports manual control but also operates its core multi-factor coordination control algorithm normally, enabling automated management of blueberry greenhouse regulation and providing an experimental platform and data source for theoretical optimization development.

The host computer aggregation terminal interface mainly includes a main page, node data display, data communication interface, and algorithm parameter setting page, allowing users to view detailed environmental data and actuator status data in the experimental greenhouse and flexibly change parameters, as shown in [Figure 5: see original paper].

4.2 Multi-Factor Coordination Control Algorithm

4.2.1 Algorithm Basic Principles and Concepts

The greenhouse environment features coupling among multiple environmental factors including temperature, light, humidity, and gas (CO2). Traditional threshold control is based on single-factor threshold control, which cannot simultaneously regulate multiple coupled environmental factors to appropriate target ranges. Therefore, this study proposes a greenhouse environment multi-factor coordination control algorithm [7]. The core concept is to establish independent control methods for all control actuators such as heating and ventilation. Each actuator’ s control action (variable threshold) is determined primarily based on temperature as the main environmental factor, while other environmental factors such as light, humidity, and gas (CO2) are coordinated with the main temperature factor according to a coordination model to dynamically correct temperature thresholds and obtain actuator action variable values.

Below, using the natural ventilation control of greenhouse roof vents as an example, we explain how to obtain its multi-factor coordination control threshold.

4.2.2 Algorithm Basic Control Model

The multi-factor coordination control model is given by formula (1):

$$U(X)=\alpha F(T_{set},H_{set},R_{set},P_{set})+\beta G(t_{in},h_{in},r_{in},p_{in})+\gamma H(t_{out},h_{out},r_{out},p_{out},W_{rain},F_v,F_d) \tag{1}$$

Where U is the control variable for each actuator action; X is the variable related to environmental target setpoints and indoor climate environment; the right side of the equation consists of three coordination functions with corresponding weights α, β, γ; F is the function of greenhouse environmental target setpoints, where T_{set} is temperature setpoint (°C), H_{set} is humidity setpoint

(%), R_{set} is light setpoint (lux), and P_{set} is CO2 concentration setpoint (‰), varying with crop growth stages and daily time periods; G is the function of indoor climate environment state, representing the coordination of indoor climate factors, where t_{in} is indoor temperature (°C), h_{in} is indoor humidity (%), r_{in} is indoor light intensity (lux), and p_{in} is indoor CO2 concentration (‰); H is the function of outdoor climate environmental interference, representing the coordination of outdoor meteorological factors, where t_{out} is outdoor temperature (°C), h_{out} is outdoor humidity (%), r_{out} is outdoor sunlight intensity (lux), p_{out} is outdoor CO2 concentration (‰), W_{rain} is rainfall (mm/min), F_v is wind speed (m/s), and F_d is wind direction (°).

The determination of coordination functions among environmental or meteorological factors on the right side of formula (1) is based on actual greenhouse crop production experience and obtained through actual data mining and modeling.

According to formula (1), in roof vent ventilation control, the ventilation temperature threshold is considered primarily based on temperature for roof vent control. When indoor temperature reaches the ventilation temperature threshold, roof vents open for ventilation, with opening size increasing as the temperature difference between indoor and outdoor increases until fully open. According to the multi-factor coordination control model, the ventilation temperature V_t is calculated by formula (2):

$$V_t = V_{ti} + V_{tRad} + V_{tRadSum} + V_{th} + T_{set} \tag{2}$$

Where V_t is ventilation temperature (°C); V_{ti} is initial ventilation temperature for each time period (°C); V_{th} is indoor humidity correction (°C); V_{tRad} is instantaneous light correction (°C); $V_{tRadSum}$ is accumulated light correction (°C).

The selection of initial ventilation temperature V_{ti} is mainly related to indoor temperature setpoints for each time period, with indoor humidity, light, and accumulated light as secondary environmental factors correcting the initial ventilation temperature. The correction amounts V_{tRad} and $V_{tRadSum}$ are both calculated by formula (3):

$$V_{tx}[°C] = f(x) = \begin{cases} x + B & x < X_{Low} \\ X_{Low}, X_{High} & x > X_{High} \end{cases} \tag{3}$$

Where the independent variable x represents indoor relative humidity H_{in} (%), light R_{Sun} (lux), and accumulated light R_{SunSum} (J/m^2) respectively.

The corrections of various environmental factors to ventilation temperature are shown in [Figure 6: see original paper]. Figure 6(a) shows humidity correction of ventilation temperature, where V_{th} is maximum positive influence of low humidity (°C) and $MinV_{th}$ is maximum negative influence of high humidity (°C). Figure 6(b) shows light correction of ventilation temperature, where $MinV_{trad}$

is maximum negative influence of light (°C). Figure 6(c) shows the influence of accumulated light (daily accumulated light) on ventilation temperature, where $MinV_{tradsum}$ is maximum negative influence of accumulated light (°C). These parameter initial values can be selected based on experience, then finally determined through on-site control system debugging based on control performance feedback, or optimized based on relevant crop models.

The calculation diagram for roof vent opening U_{roof} is shown in [Figure 7: see original paper]. In Figure 7, the temperature band T_b (°C) correction follows formula (4):

$$T_b = T_{b0} + \Delta T_{bTOut} + T_{bWind} \tag{4}$$

Where T_b is temperature band (°C); T_{b0} is initial set temperature band (°C); ΔT_{bTOut} is indoor-outdoor temperature difference correction term (°C); T_{bWind} is outdoor wind speed correction term (°C).

The roof vent opening U_{roof} is calculated based on temperature band T_b, corrected ventilation temperature V_t, and indoor temperature V_{in}:

$$U_{roof} = \begin{cases} 100\%, & V_{in} \geq V_t + T_b \\ (V_{in} - V_t)/T_b \times 90\% + 10\%, & V_t < V_{in} < V_t + T_b \\ 0\%, & V_{in} \leq V_t \end{cases}$$

The control thresholds for other greenhouse actuators such as heating equipment are obtained similarly to the above roof vent ventilation control threshold variable calculation, 详见文献 [7]. The control variable calculation of the control algorithm still follows the multi-factor coordination control model formula (1), with the control flow shown in [Figure 9: see original paper].

When roof vents are fully open but indoor temperature remains above the set range, internal shading screens are deployed and side windows are opened to enhance convection. If ventilation still cannot reduce indoor temperature, all roof vents and side windows are closed, and wet curtain fans are activated for cooling.

4.2.3 Actual Control Effects

Based on actual blueberry greenhouse production experience, corresponding control strategies were formulated to monitor abnormal weather by setting alarm limits for indoor and outdoor environmental data. According to blueberry growth requirements at different stages, corresponding control parameters were set to coordinate the status of different actuators in the greenhouse and achieve ideal microclimate ranges. Based on optimal environmental conditions for full-cycle blueberry growth, the target value ranges for blueberry multi-factor coordination control were determined. The system parameters for blueberry multi-factor coordination control are shown in through .

Taking the multi-factor control effects during the fruiting period in May 2021 as an example, the comparison of multi-factor coordination control algorithm effects is shown in [Figure 10: see original paper] (page 95). May 1-7 used the multi-factor coordination control algorithm, primarily for cooling. When indoor temperature exceeded 35°C, fans were activated for cooling. After regulation, the maximum daytime indoor temperature was 35.79°C with an average of 31.36°C; nighttime maximum was 31.18°C with an average of 26.22°C. Daytime maximum humidity was 82.60% with an average of 68.05%; nighttime maximum was 82.69% with an average of 77.41%. The average daytime outdoor temperature during this period was 28.46°C.

To compare the control effects, similar unregulated climate dates were selected. May 9-10 showed unregulated greenhouse environmental data, with average daytime outdoor temperature of 29.25°C, greenhouse maximum temperature reaching 50°C, and average daytime indoor temperature of 37.20°C, seriously harming blueberry growth and development. This fully demonstrates that using the multi-factor coordination control algorithm can better meet blueberry environmental requirements and promote healthy growth and development.

4.3 Actual Production Effects

Based on the summarized blueberry production factors and full-cycle control targets, the greenhouse environmental control system implemented through IoT technology and multi-factor coordination control algorithms achieved early maturing experiments for blueberries. The first wave of fruits was harvested in early May 2021, nearly one month earlier than open-field blueberry harvest time. Indoor blueberries all underwent chilling treatment for approximately 400 hours and used the multi-factor coordination control algorithm for full-cycle growth environment regulation. Comparison showed that blueberries regulated by the multi-factor coordination control algorithm were harvested mainly from early May to early June, while unregulated blueberries were harvested mainly from late May to late June. Moreover, after regulation by the multi-factor coordination control algorithm, yields of different blueberry varieties were all higher than unregulated yields, with individual fruit weights also increased.

The indoor blueberry growth status is shown in [Figure 11: see original paper], while the simultaneous outdoor blueberry growth status is shown in [Figure 12: see original paper].

Compared with non-chilled blueberry plants, the per-plant yields of ‘Star’ , ‘Emerald’ , ‘Lanmei No. 1’ , and ‘Coast’ after chilling increased by 51.5%, 85.5%, 43.8%, and 94.7% respectively, with individual fruit weights increasing by 10.9%, 7.2%, 2.6%, and 5.3% respectively. The experiments proved that using multi-factor coordination control algorithms can improve blueberry yield and quality.

The experiments also revealed yield relationships among 'Southern Highbush' blueberry varieties: 'Lanmei No. 1' > 'Star' , 'Coast' > 'Emerald' . Individual fruit weight relationships were: 'Emerald' > 'Star' > 'Coast' > 'Lanmei No. 1' . 'Lanmei No. 1' had the highest per-plant yield but the lowest individual fruit weight, while 'Star' showed optimal performance in both per-plant yield and individual fruit weight. Comprehensive comparison concluded that 'Star' variety provides the best overall benefits. The yield comparison of different blueberry varieties after chilling is shown in .

5 Conclusion

This study designed and implemented a blueberry plant factory greenhouse production control system. For soilless blueberry cultivation production factors—including variety characteristics, soil pH, water-fertilizer irrigation key points, and microclimate environmental ranges—detailed and comprehensive investigation and summary were conducted to determine suitable environmental elements for different blueberry production stages in Shanghai.

The existing Venlo-type greenhouse was deployed for blueberry production, with geographical, climatic, and internal structural conditions described, and full-cycle control targets planned. Finally, a production control system was designed and implemented based on IoT technology, providing technical support for blueberry production environmental regulation.

Building upon the greenhouse environment multi-factor coordination control model, a set of blueberry greenhouse multi-factor coordination control algorithms was developed according to blueberry growth environment characteristics for environmental regulation. The control system effectively met blueberry environmental requirements, successfully achieved early fruiting and market release, and effectively improved blueberry yield and quality, serving as a demonstration for southern blueberry plant factory greenhouse production control system construction.

The developed system has broad application scenarios, being suitable not only for southern blueberry production but also for other regions, requiring only corresponding adjustment of environmental control target values for different blueberry varieties. Additionally, the system is applicable to other greenhouse crop productions.

References

[1] SHI H, LIU H. The current research situation of blueberry[J]. Journal of Jiangsu Forestry Science Technology, 2009, 36(4): 48-51.

[2] NIE F, ZHANG Y. Development situations and prospects of vegetable industry of China[J]. Northern Horticulture, 2014(4): 165-170.

[3] AI H, WEI J, QIU Q. Design of intelligent control system for micro plant

factory[J]. Transactions of the CSAM, 2013, 44(S2): 198-204.

[4] TU J, QIU Q, QIN L, et al. Development and test on experimental platform for inner environment control of micro plant factory[J]. Transactions of the CSAE, 2015, 31(2): 184-190.

[5] YANG Q. Present situation and development strategy of plant factory[J]. Agricultural Engineering Technology, 2016, 36(10): 9-12.

[6] YANG Y, WEI X, SUN B, et al. Key cultivation techniques for early maturation of blueberry in sunlight greenhouse[J]. Northern Horticulture, 2015(19): 209-210.

[7] XU L, WEI R, SU Y, et al. Multi-factor coordinated energy-saving optimization control method for greenhouse environment: CN 201710261551.7[P]. 2017.

[8] WANG H, LIU F, HAN X, et al. Grape chilling requirement estimated models and heat requirement estimated models and selection of early cultivars in greenhouse[J]. Transactions of the CSAE, 2017, 33(17): 187-193.

[9] ZHOU Y. Cold treatment and cultivation techniques for blueberry cultivation in facility[J]. Rural Science and Technology, 2020, 11(34): 105-106.

[10] SHI J, CUI L, YANG H, et al. Spatial pattern and temporal change of climate in Shanghai[J]. Journal of Geo-information Science, 2015, 17(11): 1348-1354.

[11] SHI C, XU F, WANG X, et al. Comparison of quality and antioxidant capacity between Vaccinium corymbosum land and Vaccinium corymbosum in Shanghai[J]. Chinese Agricultural Science Bulletin, 2013, 29(31): 201-205.

[12] PEI J, LI Y, ZHANG C, et al. A preliminary report on the introduction of six high cluster blueberry varieties in Shanghai[J]. Deciduous Fruits, 2016, 48(2): 27-29.

[13] LI Q, LU S, ZHANG H, et al. Physiological response to different soil pH values between Vaccinium bracteatum and Vaccinuum ashei[J]. Journal of Zhejiang University (Agriculture and Life Sciences), 2017, 43(4): 469-475.

[14] SHEN Y. Cultivation technology of Semen Trionellae in the open field[J]. Tianjin Agricultural Sciences, 2009, 15(3): 62-64.

[15] YARBOROUGH D E. Cultivated lowbush blueberry (Vaccinium angustifolium) establishment and management[J]. Journal of Jilin Agricultural University, 2009, 31(5): 556-560.

[16] LIN Y, ZHANG J, HU J, et al. Effects of different seedling substrates on physiological characters and grain yield of mechanized-transplanted rice[J]. Transactions of the CSAE, 2016, 32(8): 18-26.

[17] DI H, CHEN X, HUO H, et al. Research progress on soil improvement techniques for blueberry cultivation[J]. Contemporary Horticulture, 2021, 44(1):

44-45, 47.

[18] HUANG T, WU C, WANG M, et al. Soil free cultivation technology of blueberry in greenhouse[J]. Northern Fruits, 2018(3): 31-32.

[19] LI M. On soil improvement methods for blueberry planting[J]. Agriculture and Technology, 2020, 40(18): 106-107.

[20] CAI Y, JIA Y, MU X. Application of drip irrigation technology in facility blueberry industry[J]. Hebei Fruits, 2020(3): 52, 54.

[21] HE Y. Talking about the water and fertilizer management of blueberry practical cultivation[J]. New Agriculture, 2020(15): 27.

[22] XIE Z. Design of Dalian blueberry irrigation scheme under the coupling of water and fertilizer[J]. Jilin Water Resources, 2019(5): 9-11.

[23] DONG K, JIANG H. Analysis of key factors affecting the success or failure of blueberry cultivation[J]. Northern Horticulture, 2015(14): 49-51.

[24] LIU L, HOU P, LIU Z, et al. Selection of suitable drip-emitters for Yellow river water drip irrigation[J]. Transactions of the CSAE, 2021, 37(6): 99-107.

[25] CARLOS K, PEKKA S J, MARKUS T, et al. Smart water management platform: IoT-based precision irrigation for agriculture[J]. Sensors(Basel, Switzerland), 2019, 19(2): ID 276.

[26] MUANGPRATHUB J, BOONNAM N, KAJORNKAISIRAT S, et al. IoT and agriculture data analysis for smart farm[J]. Computers and Electronics in Agriculture, 2019, 156: 467-474.

[27] TAN Y, XU L, ZHU S. Performance and key cultivation techniques of two blueberry varieties in cold shed[J]. Deciduous Fruits, 2021, 53(5): 71-72.

[28] GUO J. Blueberry high-quality and high-efficiency production technology[M]. Beijing: China Science and Technology Press, 2018.

[29] ZHANG H, LI Y, ZHANG Y, et al. Design and implementation of intelligent terminal service system for greenhouse vegetables based on cloud service: A case study of Heilongjiang province[J]. Smart Agriculture, 2019, 1(3): 87-99.

[30] ANTONACCI A, ARDUINI F, MOSCONE D, et al. Nanostructured(Bio) sensors for smart agriculture[J]. Trends in Analytical Chemistry, 2018(98): 95-103.

[31] PRAKASH P J, ALI Y, DIMITRIOS G, et al. Internet of things platform for smart farming: Experiences and lessons learnt[J]. Sensors (Basel, Switzerland), 2016, 16(11): ID 1884.

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.