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SCREENING STUDY ON THE FORMULATION OF NUTRIENT SOLUTION FOR HYDROPONIC GREEN LEAF LETTUCE IN PLANT FACTORY WITH ARTIFICIAL LIGHT

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The article presents the data of screening studies of the optimal composition of the nutrient medium for the hydroponic cultivation of green lettuce leaves in rooms with piece light. With the rapid development of soilless cultivation and artificial light plant lighting technology, the greenhouse and the plant factory with artificial light (PFAL) have become the main production base of vegetables and played an important role in agricultural production. An PFAL is a completely closed agricultural production mode that relies on artificial light, does not need soil and is not affected by climate. It can be built in urban centers, underground, deserts, ruins, and even the universe and space, so as to realize annual uninterrupted, large-scale, industrialized and clean vegetable production and ensure high-quality and sufficient market supply in four seasons. It may become the mainstream mode of productive urban agriculture in the future.

In order to screen the nutrient solution formula suitable for the large-scale hydroponic culture mode of green leaf lettuce in PFALs, the effects of different water-soluble fertilizer nutrient solutions on its growth were studied through hydroponic cultivation experiments. Arnon and Hoagland general formula were selected as treatment group I (T1), leaf vegetable A formula from the Agrochemical Laboratory of South China Agricultural University as treatment group II (T2), Yamazaki formula (lettuce) as treatment group III (T3), Japanese Garden test general formula as treatment group IV (T4), and the commercial water-soluble leaf vegetable fertilizer produced by Henan Xinlianxin enterprise as experimental control group (CK). The experimental results showed that in terms of fresh mass of stems and leaves, fresh mass of roots, root to crown ratio, plant height, stem thickness and number of leaves, both T2 and T4 could be used and followed by T3 for hydroponic green leafy lettuce in PFALs. T3 was the best formula in terms of appearance. This paper provides a reference to large-scale hydroponic production of green leaf lettuce in greenhouses and PFALs.

Key words: *soilless culture, greenhouse, industrialized production of crops, PFAL, green leaf lettuce.*

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Introduction. Hydroponics is a soilless culture (Sambo et al., 2019; Son et al., 2021; Fussy et al., 2022), which has developed rapidly in recent years, is widely used in plant greenhouses (Khan, 2018; Koukounaras, 2020) and plant factories with artificial light (PFALs). Its cultivation methods do not use soil or substrate to grow plants directly in a nutrient solution (Wild, 1985; Peyvast et al., 2010; Khater et al., 2021). Hydroponics has many advantages such as short growth cycle, high yield, good quality, fewer pests and diseases, water and fertilizer saving, and automatic management (Hyunjin et al., 2021), but without soil buffer and microorganisms, the selection of nutrient solution formulation becomes very important for crop growth and development (Kilinc et al., 2007; Lele et al., 2020; Lu et al., 2022). In production, the formulation of nutrient solutions for hydroponic leafy vegetables is closely related to the water source and water quality (Vandam et al., 2017; Jakobsen et al., 2020). It can be said that the water source and water quality determine the nutrient solution formulation (Schwarz et al., 2005; Dias et al., 2018; Elisa et al., 2020). According to the characteristics of water quality, selecting the best nutrient solution formulation to achieve high yield and quality of leafy vegetables is an urgent problem in leafy vegetable hydroponic production.

Lettuce, also known as leaf lettuce, is a one- to two-year-old herb in the Asteraceae family that is crisp, tender and refreshing, and can be eaten raw (Martínez-Sánchez et al., 2012), and is an indispensable leafy vegetable in people's daily lives (Sirsat et al., 2018). Green leaf lettuce is very suitable for hydroponic lettuce varieties in PFALs, with characteristics such as resistance to seedling, resistance to dry heartburn, resistance to mildew and frost disease, and firmness at the base of the leaf bulb, etc. (Saengtharatip et al., 2018; Lee et al., 2019) It has a bright green appearance like an open green rose. Therefore, it has ornamental, edible, and commercial values at the same time.

This paper aims to screen the most suitable nutrient solution formula for hydroponic Lettuce in the greenhouse and the PFAL. According to the local water quality and artificial light layer frame hydroponic culture model in Henan Province, the effects of different water-soluble fertilizer nutrient solutions on the growth of Hydroponic Lettuce were studied with green leafy lettuce varieties as experimental materials and the existing common nutrient solution formulas of leafy lettuce.

Materials and methods. *Experiment site and overview.* The experiment was conducted from July 2021 to March 2022 in the PFAL Laboratory of the Henan Institute of Science and Technology. The laboratory is located on the campus of Henan Institute of Science and Technology, Xinxiang City, Henan Province, and is built on the first floor of a comprehensive teaching building with a building area of about 200m^2 and a floor height of about 3.3 m. The laboratory equipment includes air conditioner, dehumidifier, water and fertilizer integrated irrigation system, intelligent LED plant lighting system, fresh air system, intelligent environmental monitoring system, water purification and treatment equipment, nutrient solution disinfection and recycling equipment, CO2 automatic control equipment, ultraviolet disinfection lamp, wireless Internet of things system, front integrated control system, etc. These devices or systems are mainly used for the regulation of the environment, illumination, fertilization, and irrigation required for plant growth. During the light period, the ambient temperature of the growing room is maintained at around 23°C and the CO_2 concentration at 800 ml/l. During the absence of light, the ambient temperature of the growing room is maintained at around 18°C and the CO_2 concentration at 500 ml/l. The humidity in the growing room is maintained at around 70%. The light time is set at 14 hours.

Experiment materials. The trial was conducted using hydroponics. Two three-tier cultivation racks were used. The top of each tier is equipped with LED lights adjustable by red-blue-white colors. The light quality, light intensity and light period of each tier can be adjusted individually. Each layer of the cultivation rack consists of a cultivation tank, a fixing plate, a reservoir, a circulating and filling pump, with automatic circulation of the nutrient solution on a single layer. Each cultivation tank is 120 cm long, 80 cm wide and 8 cm high with a capacity of 46 liters, allowing up to 96 leafy greens to be hydroponically grown in one layer at a time. Each treatment was planted with 48 green leafy lettuces and replicated three times, random arrangement. The seedling age of green leaf lettuce was 3 leaves. The hydroponic experiment of green leaf lettuce in PFAL laboratory is shown in Fig. 1.

Nutrient formulation and management. In the experiment, Arnon and Hoagland general formula (Arnon), Huanong a formula (Hunong A), Yamazaki formula (Yamazaki) and Japanese garden experiment general formula (GE) (Petropoulos et al., 2018), which are most conducive to leaf vegetable cultivation, were used, and compared with the water-soluble chemical fertilizer produced by commercial enterprises. The general formula was used for the proportion of microelements (Laland et al., 1955), and the commercial water-soluble leaf vegetable fertilizer produced by Henan Xinlianxin enterprise was used as the control. The formula details are shown in Table 1. The water used for nutrient solution preparation is purified water treated by reverse osmosis purification equipment, with a pH of 7.1 to 7.3, no

Fig. 1. The hydroponic experiment of green leaf lettuce in PFAL laboratory

fluoride, arsenic, selenium, copper, lead, cadmium, or zinc detected in the water, chloride < 0.25mg·L^{-1} in the water, and an EC value of 0.25 to 0.4mS·m^{-3}. The nutrient solution is intelligently prepared by water and fertilizer integrated irrigation equipment, and is fed by an oxygen pump to maintain Dissolved Oxygen (DO) $DO \geq 10\,mg/L$, the EC value is set at 1.8～2. $mS \cdot m^{-3}$ 2 and the pH value is set at 6.0-6.9. The nutrient solution is changed every 7 days.

Determination items and methods. After 35D (Days) planting, the number of green leaf lettuce leaves was counted manually, root length, maximum leaf length and maximum leaf width were measured using a straightedge, and the fresh weight of individual green leaf lettuce and the fresh weight of the roots were weighed by an electronic scale. For data processing and analysis, Excel 2021 and SPSS 20.0 were used.

Results. *Effect of different nutrient solution formulations on leaf growth of green leaf lettuce.* As can be seen from Table 2, after 35D planting, the number of leaves was more in T1 and T4, with no significant difference between them, but the T4 treatment was significantly higher than the other formulations and the controls. The maximum leaf length was longer in T3 and the control, with no significant difference between them, but the T3 treatment was significantly higher than the other formulations. The maximum leaf width was wider in control and T3, with no significant difference between them, but the control treatment was significantly higher than the other formulations.

Effect of different nutrient solution formulations on root growth of green leaf lettuce. As can be seen from Table 1, after 35D planting, T2 was significantly higher than T3 and T3 was significantly higher than the other treatments in terms of maximum root length. The root weight of control and T2 was the largest with no significant difference between them, but significantly higher than the other formulations.

Effect of different nutrient solution formulations on fresh weight of green leaf lettuce. As can be seen from Table 1, after 35D planting, the largest fresh weights were T4, control and T2 with no significant difference between the three treatments, significantly higher than T1 and T3, while formulation T1 fresh weight was significantly lower than T3.

Discussion. The production of vegetables using the hydroponic model requires the screening of optimal nutrient solution formulations for vegetable growth (Miller et al., 2020). In this experiment, under the hydroponic mode and management method of PFALs, comparing the four nutrient liquid formulations with the commercial leafy vegetable nutrient liquid fertiliser, the fresh weight of lettuce was significantly higher in the T2 and T4 than the other formulations, but not significantly different from the commercial nutrient liquid fertiliser. The next best formula was the T3, with a slightly lower fresh weight than the above three formulations. Therefore, in terms of yield factors, the T2 and T4 can be used for hydroponic leafy lettuce in PFALs, and the T3 is the second best. The maximum leaf length and maximum leaf width are one of the most important fac-

Table 1

Specific formula of nutrient solution

<table>
<tr><th rowspan="2">formula</th><th colspan="2">macro-elements (mg/L)</th><th rowspan="2">micro-elements (mg/L)</th></tr>
<tr><th>A solution</th><th>B solution</th></tr>
<tr><td>Arnon and Hoagland (T1)</td><td>Calcium nitrate tetrahydrate 945
Potassium nitrate 506
Ammonium nitrate 80</td><td>Potassium dihydrogen phosphate 136
Magnesium sulfate 493
Iron salt solution 2.5</td><td rowspan="4">Disodium EDTA 30
boric acid 2.8
Manganese sulfate 2.2
zinc sulfate 0.22
copper sulphate 0.08
ammonium molybdate 0.02</td></tr>
<tr><td>Formula A of Leafy Vegetables in Agricultural Chemistry Room of South China Agricultural University (T2)</td><td>Calcium nitrate tetrahydrate 472
potassium nitrate 267
ammonium nitrate 53</td><td>Potassium dihydrogen phosphate 100
potassium sulfate 116
magnesium sulfate heptahydrate 264</td></tr>
<tr><td>Japanese Yamazaki (lettuce) (T3)</td><td>Calcium nitrate tetrahydrate 472
potassium nitrate 267</td><td>Ammonium dihydrogen nitrate 77
magnesium sulfate heptahydrate 246</td></tr>
<tr><td>Japanese Garden general formula (T4)</td><td>Calcium nitrate tetrahydrate 945
potassium nitrate 809</td><td>Ammonium dihydrogen nitrate 153
magnesium sulfate heptahydrate 493</td></tr>
</table>

Table 2

Indexes of green leaf lettuce with different nutrient solutions at harvest

Experimental group	Leaf number	leaf length /cm	leaf width /cm	root length /cm	Root weight /g	Fresh weight /g
T1	29ab	18.6d	12.3b	24.6c	6.2b	106.7c
T2	27c	19.5c	13.7b	32.7a	8.6a	137.3ab
T3	27c	21.6a	13.8ab	27.9b	6.7b	128.8b
T4	30a	20.1bc	13.6b	23.5c	6.3b	139.6a
CK	28bc	21.3ab	14.3a	23.6c	8.9a	138.1ab

Note: No identical lowercase letters after the data in the same column indicate significant differences between groups ($P < 0.05$).

tors in measuring the appearance and quality of green leaf lettuce. T3 has better maximum leaf length and width than other experience group. Because hydroponic green leaf lettuce is mostly sold by individual plants, T3 is the best from the perspective of ornamental quality factors.

Zhang (Zhang, 2005) used 1/4 concentration of Hoglan-Anon formulation, Yamamoto Yamazaki lettuce formulation and South China Agricultural University leafy lettuce formulation to test growing 2 to 17 leaf age American fast-growing lettuce. The results showed that 1/4 concentration of the Hoglan-Anon formulation had the best yield. Li (Li et al., 2019) used the Japanese garden test formula and the Hoagland formula to grow Italian lettuce tolerant to drawl, and the results showed that the Japanese garden test formula was superior to the Hoagland formula in terms of yield, plant height and leaf width. Ding (Ding et al., 2012) compared Hogeland, Japanese Garden test, Japanese Yamazaki and South China Agricultural University leaf lettuce formulations for planting Italian lettuce under 8 leaves old, and the results showed that the South China Agricultural University leaf lettuce formulation produced the highest yield.

Soilless vegetable cultivation is a complex reaction system. Environmental factors, cultivation methods and nutrient supply are the main factors affecting soilless cultivation (Balliu et al., 2021). In hydroponic management, nutrient solution temperature, dissolved oxygen, pH and EC values are all key factors in root growth and nutrient absorption, and all these influencing factors need further in-depth study (Suyantohadi et al., 2010). Therefore, in planting and production, suitable nutrient solution formulations should be screened according to vegetable variety, fertility period, cultivation pattern, water quality and other factors.

Conclusions. Through experimental research, it can be concluded that in terms of fresh mass of stem and leaf, fresh mass of root, ratio of root to crown, plant height, stem diameter and number of leaves, both the Japanese Garden Trial General and the A formula from the Agrochemical Laboratory of South China Agricultural University could be used for hydroponics of green leafy lettuce in artificial light factory, followed by the Japanese Yamazaki formula; from the appearance, the Yamazaki formula is the best formula.

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Скринінгові дослідження складу поживного розчину для гідропонного вирощування зеленого листя салату в теплицях зі штучним світлом

У статті наведено дані скринінгових досліджень оптимального складу поживного розчину для гідропонного вирощування зеленого листя салату в приміщеннях з штучним світлом. Завдяки швидкому розвитку технологій безґрунтового вирощування і впровадженням штучного освітлення рослин теплиці і фабрики по вирощуванню рослин зі штучним освітленням (PFAL) стали основною виробничою базою вирощування овочів і відіграли суттєву роль у сільськогосподарському виробництві. PFAL – це повністю закритий режим сільськогосподарського виробництва, який базується на штучному освітленні, не потребує ґрунту та не піддається впливу кліматичних факторів. Його можна будувати в міських центрах, під землею, у пустелях, на пустирях і навіть у всесвіті та космосі, щоб реалізувати щорічне безперебійне, масштабне, промислове та екологічно чисте виробництво овочів та забезпечити якісне й достатнє постачання їх на ринок упродовж усіх періодів року. У майбутньому це може стати основним способом продуктивного міського сільського господарства.

Щоб підібрати оптимальний склад поживного середовища, який би міг відповідати вимогам широкомасштабного гідропонного вирощування зеленого листя салату в PFAL, вивчити вплив різних поживних водорозчинних розчинів добрив на збільшення його виробництва було проведено дослідження в умовах гідропонного вирощування.

Загальна формула розчинів Арнона і Хоугланда була взята для обробки у якості групи I (T1), формула розчину для листових овочів A з агрохімічної лабораторії Южно-Китайського сільськогосподарського університету була обрана в якості групи II (T2), формула розчину Ямазаки (салат) була обрана в якості групи III (T3), японська

Загальна формула обробки саду в якості групи IV (T4) і комерційне водорозчинне удобрення для листових овочів виробництва підприємств Хенань Xinlianxin в якості експериментальної контрольної групи (CK).

Результати досліджень показали, при вирощуванні гідропонних рослин зеленолистого салату в PFAL за показниками свіжої маси стебел і листків, свіжої маси кореню, співвідношення підземної та надземної частин рослин, висоти рослин, товщини стебла та кількості листків більш ефективним є використання поживних середових T2 і T4, дещо менша ефективність була у T3. Слід зазначити, що на варіанті із застосуванням формули T3 рослини салату мали кращий зовнішній вигляд у порівнянні із іншими варіанту дослідження.

Ключові слова: *безґрунтове вирощування, теплиця, промислове вирощування сільськогосподарських культур, фабрика із зовнішнім освітленням (PFAL), зелене листя салату.*