Is there potential for hops production in an indoor system using LED lighting?

Há potencial para produção de lúpulo em sistema indoor com iluminação LED?

¿Existe potencial para la producción de lúpulo en un sistema indoor con iluminación LED?

DOI: 10.55905/oelv22n7-124

Receipt of originals: 05/27/2024
Acceptance for publication: 06/28/2024

Matheus Kainan de Paula Manjavachi
Master’s degree in Tropical and Subtropical Agriculture
Institution: Instituto Agronômico de Campinas (IAC)
Address: Campinas, São Paulo, Brazil
E-mail: kainan.mpm@gmail.com

Felipe Marques de Lima
Master’s degree in Tropical and Subtropical Agriculture
Institution: Instituto Agronômico de Campinas (IAC)
Address: Campinas, São Paulo, Brazil
E-mail: felipelima.agronomia@gmail.com

Andressa Jociane Franzotti Menas
Master’s degree in Tropical and Subtropical Agriculture
Institution: Instituto Agronômico de Campinas (IAC)
Address: Campinas, São Paulo, Brazil
E-mail: andressafranzotti@gmail.com

Bianca Machado de Lima
Master’s degree in Plant Production and Bioprocesses
Institution: Instituto Agronômico de Campinas (IAC)
Address: Campinas, São Paulo, Brazil
E-mail: bianca.eng.agro@gmail.com

Tiago José Leme de Lima de Nadai
Master’s degree in Plant Production and Bioprocesses
Institution: Centro Universitário de Araras Dr. Edmundo Ulson (UNAR)
Address: Araras, São Paulo, Brazil
E-mail: tiagoxleme@hotmail.com
ABSTRACT
Hops production largely depends on daylength shortening for proper flowering. Innovative systems like indoor cultivation with LED lighting allow a precise control of photoperiod regardless of season. However, such systems are still under development for most crops and there isn’t a solid framework on which indoor hops cultivation can be referred to. The aim of this study is to provide a descriptive report on how hops plants can develop and flower in an indoor system. A growth chamber was designed to accommodate hops plants, providing lighting and two training methods: parallel and spiral. Within 90 days of vegetative growth the plants had substantially developed and photoperiod was reduced from 16 to 10 h. Flowering began 6 days after photoperiod shortening. Spiral training can provide a more ergonomic usage of vertical space, allowing hops plants to better develop length-wise. Although structural adjustments and further research are still needed, there is potential for hops production in an indoor system using LED lighting.

Keywords: *Humulus lupulus* L., Vertical Farming, Artificial Lighting, Photoperiod.

RESUMO
A produção de lúpulo depende da redução do comprimento do dia para uma floração adequada. Sistemas inovadores, como o cultivo indoor com iluminação LED, permitem um controle preciso do fotoperíodo independentemente da estação. No entanto, tais sistemas ainda estão em desenvolvimento para a maioria das culturas e não existe uma estrutura consolidada para a qual o cultivo indoor de lúpulo possa ser referenciado. O objetivo deste estudo é fornecer um relatório descritivo sobre como as plantas de lúpulo podem se desenvolver e florescer em um sistema indoor. Uma câmara de crescimento (growth chamber) foi projetada para acomodar plantas de lúpulo, fornecendo iluminação e dois métodos de condução: paralelo e espiral. Em 90 dias de crescimento vegetativo, as plantas se desenvolveram substancialmente e o fotoperíodo foi reduzido de 16 para 10 horas. A floração começou 6 dias após a redução do fotoperíodo. A condução em espiral pode proporcionar um uso mais ergonômico do espaço vertical, permitindo que as plantas de lúpulo se desenvolvam melhor em comprimento. Embora ajustes estruturais e pesquisas adicionais ainda sejam necessários, há potencial para a produção de lúpulo em um sistema indoor utilizando iluminação LED.

RESUMEN
La producción de lúpulo depende en gran medida del acortamiento del fotoperíodo para una floración adecuada. Los sistemas innovadores como el cultivo *indoor* con iluminación LED permiten un control preciso del fotoperíodo sin importar la estación. Sin embargo, dichos sistemas aún están en desarrollo para la mayoría de los cultivos y no existe un marco sólido al que se pueda referir el cultivo de lúpulo *indoor*. El objetivo de este estudio es proporcionar un informe descriptivo sobre cómo las plantas de lúpulo pueden desarrollarse y florecer en un sistema *indoor*. Se diseñó una cámara de crecimiento para alojar plantas de lúpulo, proporcionando iluminación y dos métodos de entrenamiento: paralelo y en espiral. Dentro de 90 días de crecimiento vegetativo, las plantas se habían desarrollado sustancialmente y el fotoperíodo se redujo de 16 a 10 horas. La floración comenzó 6 días después del acortamiento del fotoperíodo. El entrenamiento en espiral puede proporcionar un uso más ergonómico del espacio vertical, permitiendo que las plantas de lúpulo se desarrollen mejor en longitud. Aunque aún se necesitan ajustes estructurales e investigaciones adicionales, existe potencial para la producción de lúpulo en un sistema *indoor* utilizando iluminación LED.

Palabras clave: *Humulus lupulus* L., Cultivo Vertical, Iluminación Artificial, Fotoperíodo.

1 INTRODUCTION

Hops (*Humulus lupulus* L.), a member of the Cannabaceae family, is a species predominantly used in beer production. As an essential component of the majority of beer recipes, more than 130,000 tons are yearly produced worldwide (Cagle, 2023). It is sought after for the extraction of lupulin from its cone-like inflorescences, which is subsequently applied to augment attributes such as bitterness, flavor, aroma, and the extension of the beer's shelf life (Knight, 2015). On-field hops are mainly grown vertically on trellises attached to wires connected to poles ranging from 4 to 7 meters tall. As such, growth conditions and farming techniques that enable proper flowering are considerate key elements in hops production.

Despite the diversity of genetic materials available, hops generally require a substantial shortening of daylength in order to initiate flowering (Neve, 1991; Sirrine *et
al. 2010). Although geographical characteristics have traditionally limited many regions’ potential of producing hops, farming techniques such as hormonal treatment and on-field supplementary lighting are shifting the previously established scenario (Agehara, 2020). Combined with a recent growth on craft beer market and the appeal of locally produced goods, innovative farming systems are in demand for hops production (Cagle, 2023).

Indoor agriculture has substantially developed throughout the past decade. Indoor growth systems are characterized by a closed environment where sunlight is substituted by LEDs as artificial lighting and ambience, mainly temperature and air humidity, is actively controlled (Pescarini et al. 2023). It’s main advantages when compared to conventional outdoor agriculture are higher production potential, growth cycle shortening and the potential of a year-round production, regardless of external climate conditions (Pattison et al. 2018; Loconsole et al. 2019). However, as indoor agriculture is still a relatively new and initially expensive farming model, development and optimization of specific techniques are required to achieve economically feasible systems (Kozai et al. 2020).

While traditional field agriculture’s daylength is regulated by latitude and season, indoor agriculture uses photoperiod as a tool (Silva et al. 2022). The complete control over photoperiod through analog or digital timers enable adequate growth of any photoperiod-sensitive species. Studies analyzing supplementary lighting for hops flowering have been carried out (Agehara, 2020), however there aren’t many studies on hops completely grown within an indoor system. On the other hand, companies like Goose Island are already brewing recipes that only contain hops grown in indoor systems (Aerofarms, 2021).

Given the context, the aim of this study is to describe an initial overview on how hops can be grown in an indoor system and suggest a few guidelines on how future systems may be adapted to hops production.
2 METHODOLOGY

The laboratory in which the test was carried out is 3.1 m in height, so the development of a low-cost growth chamber that allows a compact yet proper growth was required and started on February, 2021.

A 0.9 x 0.6 x 2.8 m galvanized steel shelf was built and only the bottom layer was kept, so the plants could potentially grow above the space the top layer occupied (Figure 1A). LED lamps are commonly installed horizontally in indoor systems, but since hops plants are taller than wider, a vertical module was adapted for a more efficient light incidence (Figure 1B). Also seeking better light utilization, the shelf’s sides were covered with white canvas to keep radiance from leaking out.

Figure 1. Galvanized steel shelf designed for hops cultivation. A) Overview of the structure. B) LED lamps installed vertically.

Source: own authorship.

The LED lamps used were the model GLP-v.11.7.6-23 (LEDs-Up). Photosynthetic photon flux density (PPFD), i.e., the light intensity emitted from LEDs within the growth chamber was measured. Throughout the structure the average PPFD was 100 µmol m\(^{-2}\) s\(^{-1}\).
Seedlings of the Hallertau Mittelfrüh variety were individually transplanted to four 4.5 L pots on April, 2021. Two distinct methods of hop plant training were tested, employing plastic strings as the supporting structure. The initial approach adhered to conventional practices, training hop plants with parallel vertical bines. Conversely, the second method entailed a spiral training of a singular bine, strategically designed to optimize vertical growth within the confines of the laboratory's restricted vertical space (Figures 2A and 2B).

Figure 2. Methods of hops training on an indoor system. A) Training of parallel bines. B) Training of a spiral bine.

Source: own authorship.

Photoperiod was initially set as 16 h using a digital timer. When plants had grown for 90 days the program changed to 10 h in order to induce flowering.

3 RESULTS AND DISCUSSION

In 30 days, the plants developed to the point of reaching the top of the 2.8 m structure, slightly above the maximum height of the growth chamber. At this stage, red spider mites began to infest older leaves. It is believed that the pest insects may have been introduced when seedlings were transplanted, and control methods were promptly implemented. The low humidity levels in indoor cultivation systems can create optimal
conditions for such infestations and should be managed accordingly. As with on-field agriculture, the occurrence of pests and diseases can hinder plant production and controlling larger infestations is bound to be difficult due to a lack in adapted equipment for indoor systems.

Furthermore, it was observed that the leaves developing closest to the LED lamps exhibited symptoms of burning, most likely due to photooxidative and heat stress (Figures 3A and 3B). Even though heat dissipation from LEDs is minimal and generally plants grow close to the light source on indoor systems, direct contact and extended exposition may result in such damage.

Figure 3. Leaves that are close to the light source suffer photooxidative stress. A) LED light reflected on hops leaf. B) Tissue damage caused by proximity to LED light.

Despite the mentioned limitations in this initial cycle, the hop plants developed satisfactorily and occupied the majority of the upper section of the growth chamber within 90 days of system installation. The spiral training of a single main bine resulted in overall better plant growth since the space it occupied still provided ergonomic conditions for development. A tendency was observed for lateral branching to extend towards the outer sides of the structure, and even under reduced radiance, these branches displayed substantial growth capacity (Figures 4A and 4B). At this stage photoperiod was changed from 16 to 10 h.
Flowering started 6 days after photoperiod shortening, on July 2021. Around 30 days after the reproductive stage began, hop cones reached the harvest point (Figures 5A, 5B and 5C). The total production was not substantial, as hop plants in their first cycle are still significantly below the productive potential. After harvest plants were pruned and entered dormancy, a characteristic phase of the species.
The cultivation of hops in an indoor system was successful, although several adjustments may be recommended based on this initial study. Increased light intensity is most likely beneficial since it relates to higher biomass production (KOZAI et al. 2020); bigger pots that allow a better root development are advisable; the timing for photoperiod reduction and the hour differential can be further explored, especially on short-cycle cultivars. The proposed growth chamber provides a solid insight on how hops plants behave when grown indoors and may even serve as blueprint for other tall plants such as vanilla (*Vanilla planifolia* J.) and certain tomato varieties.

4 CONCLUSION

In conclusion, fully indoor hops production with artificial lighting is possible, although further research aiming technical and economic viability is encouraged. Hops and other long-cycle, large plants can incur high production costs in indoor systems. Conversely, aspects of the hops production chain such as seedling propagation, maintenance of parent plants for breeding programs, speed breeding, or even ornamental uses in consumer environments can be explored in future studies, using the observations from this work.

ACKNOWLEDGEMENTS

The authors acknowledge Gabriel de Cássia Fortuna, LEDs-Up and Amafibra for providing, respectively, hops seedlings, LEDs and substrate used on this study.
REFERENCES


