PORTABLE MINI-SCALE VERTICAL FARMING SYSTEM DESIGN: GROWING MICROSPROUT IN SOIL-LESS MEDIA

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Abstract

Introduction and Objective: Commercial or individual efforts to grow microgreens/microflora indoors have gained momentum with the increasing awareness of access to healthy and safe food. With this awareness, microgreens/microflora seem to be the rising trend of recent years, but they have been at the center of life since the very beginning of life with the germination of each seed. In countries such as Turkey, where the rate of urban life is higher than rural life in terms of population density, various projects and studies are carried out to increase small-scale growing environments. The aim of this study is to design an environment that will enable people to access fresh greenery easily and economically with portable systems in places such as residential areas and shopping centers where there is no possibility of soil farming. **Materials and Methods:** In this study, a small-scale portable vertical agriculture production center was designed. Containers are used as growing media and the structure, which is divided into germination, production and control rooms, can be designed as grid-dependent/independent for energy and water needs. In order to fully meet the light spectrum needs of the plant for rooting, germination, sprouting and greening periods, LED- based artificial light sources covering 400-700 nm wavelengths were designed. In addition, a sensor-dependent control algorithm was used to support growth performance in germination and production environments. In the study, white radish was used as microgreens and no macro or micro elements were used in solid culture to understand the effect of the designed luminaire.

Results: White radish microgreens were observed from the sprouting stage to the harvest stage and plant height, Ph and Ec values were recorded. The effects of photosynthetic photon flux density (PPFD), wavelength and color temperature parameters of the artificial light used during harvesting on the plant growth process were comparatively analyzed. It was observed that the designed LED-based artificial light effectively provides the entire PAR region light spectrum required for plant growth stages. **Discussion and Conclusion:** At the end of the study, it was determined that the white radish microgreens grown reached harvest size in approximately 20% shorter time than the commonly used production elemental growing media products.

Keywords: Microgreens/microsprouts in solid culture media, microsprout cultivation armature design, sustainable agriculture, portable vertical farming system.

Introduction

The goal of vertical farming is to produce a large amount of crops in small areas in inverse proportion to the small size of the area. [1] These farms, called vertical farms, are also known as indoor farms. These farms are closed plant production organizations where environmental factors such as temperature, humidity, light, CO2 concentration are observed and communication with external factors is minimized. [2]

The aim of the vertical farming system is to create a controlled agriculture system with plants grown in closed areas by keeping the plant growing conditions at optimum levels. It is possible to grow different types of plants such as vegetables, fruits or ornamental plants in vertical farming. The biggest reason why vertical farming is especially preferred is to grow plants in limited areas due to the lack of necessary land in urban areas. Likewise, it is preferred for growing plants in areas with unfavorable climatic conditions. In addition to these reasons, vertical farming will provide fresh, stable and reliable products all year round.[3]

One of the most important reasons for the growth and development of a plant is light. The time that any plant spends under the light is called the insolation period. Insolation periods for plants vary according to the growing season, year, and day of the plant. When calculating the optimal insolation time for a plant, the photosynthesis performed by the plant and the photoperiod illumination time are taken into account. [4]

UV and IR values are extremely important in the growth and development stages of a plant. At the same time, the spectrum values of the light source during the growth and development phase should be in the range of 400-700nm. [5]

In a study conducted in the Asian region, the effect of LED colors projected on the potato plant on the growth of the plant was examined. In this study, it was observed that the blue LED light spectrum as well as the combined red blue and green LED light spectrum had a positive effect on the potato plant. [6]

In a study for horticultural applications, a lighting module with 550/350mm dimensions was designed. The number of red and blue LEDs was determined as 50 and 40 respectively. LED selection is extremely important for the correct and effective operation of the luminaire and the selected LED was selected depending on the desired luminous flux, spectral distribution of the radiation, photosynthetic photon flux PPF (mol/s), operation control capabilities. SAMSUNG LED was selected within these required specifications. With the designed luminaire, it was concluded that an efficient luminaire was designed for plant cultivation. It was concluded that an effective, cheap and reliable system was established with this armature. [7]

In an experiment for vertical farming, a soybean plant was used. This study was divided into 2 parts. In the first part, light was placed for a period of 24 hours and in the second part, the effect of lighting on the different developmental stages of the plant was compared with the crop yield. The first part of the experiment resulted in a high number of flowering and production from the seeds. In the second experiment, as a result of partial illumination in different developmental stages, it was observed that illumination can also have an effect if the other conditions for the development of the plant are complete. As a result, it was reached as a result of the experiment that effective solutions can be produced in additional and correct lighting system in horticultural culture. [8]

Photosynthetically active radiation (PAR) distributions of LED light sources with different characteristics (A, B, C, D) designed by different lighting companies, which are widely preferred in greenhouse lighting systems, were evaluated. According to the measurement results of the study, the implicit PAR distributions of the LED light distribution in different distribution ranges (400-700nm

wavelength) were determined and different distribution uniformity evaluation criteria were examined in detail. The results are as follows; When analyzed on the daily lighting side, type A and B lighting scopes can be used as both full artificial and complementary photosynthesis lighting fixtures according to the designed layout, while type C and D lighting scopes gave results as complementary photosynthesis lighting fixtures when applied according to the designed layout. [9]

In an LED study on growing basil plants, hyper red and dark blue LED light combinations were applied and no difference was observed. In addition, different combinations of LED light were applied to the plant in question and were found to be beneficial for the germination and growth of the basil plant compared to daylight. Height increased by 30% and total wet weight increased by 50%. [10]

As a result of research and applications, it was concluded that with the application of one or two rows of intermediate lighting LEDs, mini cucumber yield increased by 22.3% and 30.8% compared to no intermediate interior lighting. [11] In another study conducted in this regard, it was observed that mini cucumber yield increased with intermediate lighting only in the early production stage and gradually decreased towards the late production period. [12]

The cucumber plant was subjected to a research process of diversion. As the amount of blue light increases, the amount of dry matter decreases. In addition, it was observed that as the amount of blue light increased, chlorophyll content per leaf area increased along with net photosynthetic rate and stomatal conductance. [13]

Microgreens, also known as micro sprouts, are young and tender plant varieties produced using seeds of various vegetable species, herbaceous plants, different aromatic plants and edible wild plants. Germination takes between 7-21 days depending on the selected seedling. Harvesting time is ready for harvesting when the first real leaves appear after the leaves emerging from the seed complete their development after germination is over. [14]

Microgreens are a new class of specialty crops produced from immature greens produced from the seeds of vegetables, herbs or grains, including wild species. [15]

Microgreens are good sources of nutrients and antioxidants, mainly minerals, carotenoids, and phenolic compounds. Due to their richness in vitamins and phytochemicals, microgreens have a strong antioxidant capacity and are effective in regulating plasma lipoprotein and cholesterol metabolism. These properties also indicate a potential value in the prevention and treatment of chronic diseases. Many studies have shown that microgreens have higher nutritional values than mature plants. [16]

As a result of a research, it was proved that the vitamin C and protein ratio increased in lettuce and spinach plants by adjusting the ratio of LED light quality well. [17] In another study, when the pepper plant was exposed to LED supplementation and fluorescent light under the same conditions in a dark environment in the process after grafting and comparing the two different types of illumination, it was observed that there was a higher survival rate and recovery efficiency with LED. [18]

The darkness level was set as the controllable factor to elucidate whether LED supplementation applied in plant cultivation affects the rate of necrotic base formation in the plant and to know the light intensity required. Inoculated cucumber seedlings were exposed to four different LED light intensities for three consecutive days. The light intensities were 25 μmol/(m2s), 50 μmol/(m2s), 75 μmol/(m2s), and 100 μmol/(m2s). As a result of this experiment, the white light intensity applied at an intensity of 50 μmol/(m2s) was found to be the ideal light level for the formation of the neocrotic layer of cucumber seedlings. [19]

The spinach plant was simultaneously illuminated with a warm white LED lamp, a cool white LED lamp and a garden LED lamp. A table showing the dry mass of the plants illuminated with each LED lamp compared to the dry mass of the plant illuminated with daylight was created. The observed results show that the dry mass of spinach illuminated with LED grow lamp is 15% higher than the dry mass illuminated with cold white lamp and 87.5% higher than the dry mass illuminated with warm white lamp.[20]

LED lighting was applied to the purple leaf lettuce plant, which has high nutritional value, before harvesting and the result of this application was observed in terms of the formation of nutritional quality and flavor of the plant. Red blue color LED light was applied in a ratio of 4 to 1 as a light source. The application method was carried out at different intensities and durations. As a result of this application, the optimum continuous lighting (CL) intensity and duration were found. It was an example for theoretical and technical guidance of artificial lighting (PFAL) for lettuce production. 2 different experiments were conducted. In these experiments, lighting was provided at different stages. According to the results of Experiment 1, it was observed that there was no change in lettuce sprout and fresh root weights as a result of CL treatment, but higher light intensity and CL duration significantly increased both sprout and root dry weights. In Experiment 2, ascorbic acid (ASA) content was not significantly different. However, it was concluded that the antioxidant levels in the leaves increased as the duration of CL increased. [21]

In this study, a portable vertical agriculture system was designed based on a container physical environment. In the designed environment, an LED artificial light source arrangement, air conditioning system, irrigation system and control system projects were made for the purpose of growing micro greens / micro sprouts. In the small-scale equivalent of the designed system, white radish microgreens/micro sprouts application was carried out under the same climate and LED source artificial light. The results were evaluated by comparative analysis of the application.

Portable Vertical Farming System Design Project

Within the scope of the study, it was found appropriate to use a 40' container for the portable scale vertical farming system project. The design system was realized with Dialux Evo program. The design stages are as follows:

- The total container area is divided into control room, production room and germination room.

- Vertical agricultural shelves, plant trays, irrigation system, air conditioning system and doors were added to these spaces.
- A water tank and solar panels are positioned on top of the container for places without mains connection.
- The colors and surface materials of the objects were determined.
- Finally, artificial light sources were added and the planning and calculations of the sections to grow plants with horticultere LEDs were completed.

Portable Vertical Farming

Within the scope of the project, a 40' container (length 12 m, width 2.35 m, height 2.4 m) was preferred as a portable production system space for microfilter/microgreens cultivation. The main reason for the

preference of the container is that it is more advantageous in terms of investment and installation cost compared to other alternatives as well as being an easily transportable structure

The container designed in Dialux evo program is shown in Figure 2.1.

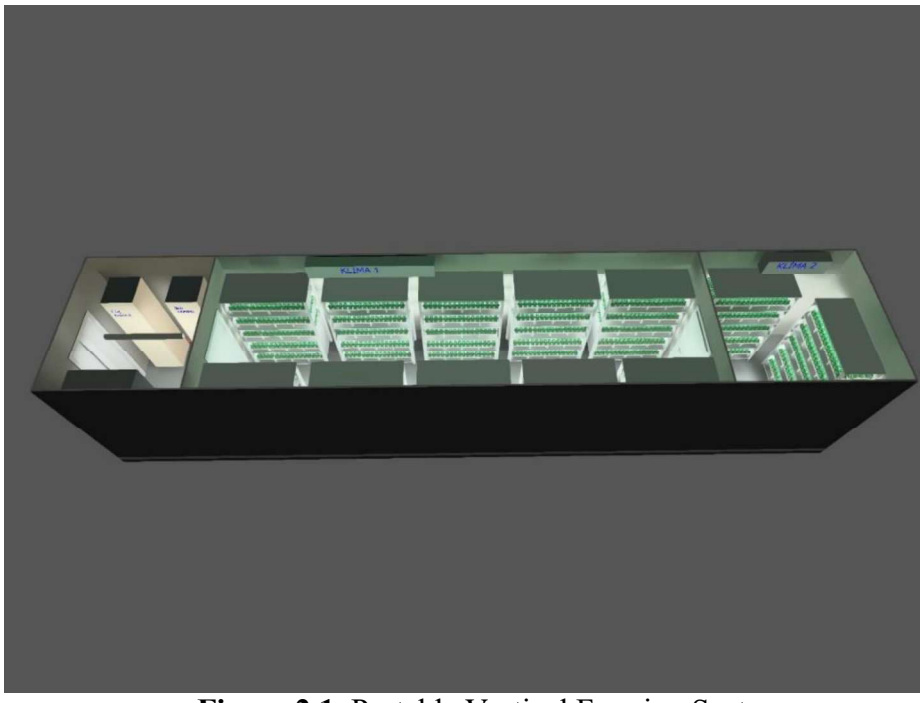


Figure 2.1. Portable Vertical Farming System

The production room, sprouting room and control room of the vertical agricultural container designed in Dialux Evo program are shown in Figure 2.2, Figure 2.3, Figure 2.4.



Figure 2.2. Portable Vertical Farming System Production

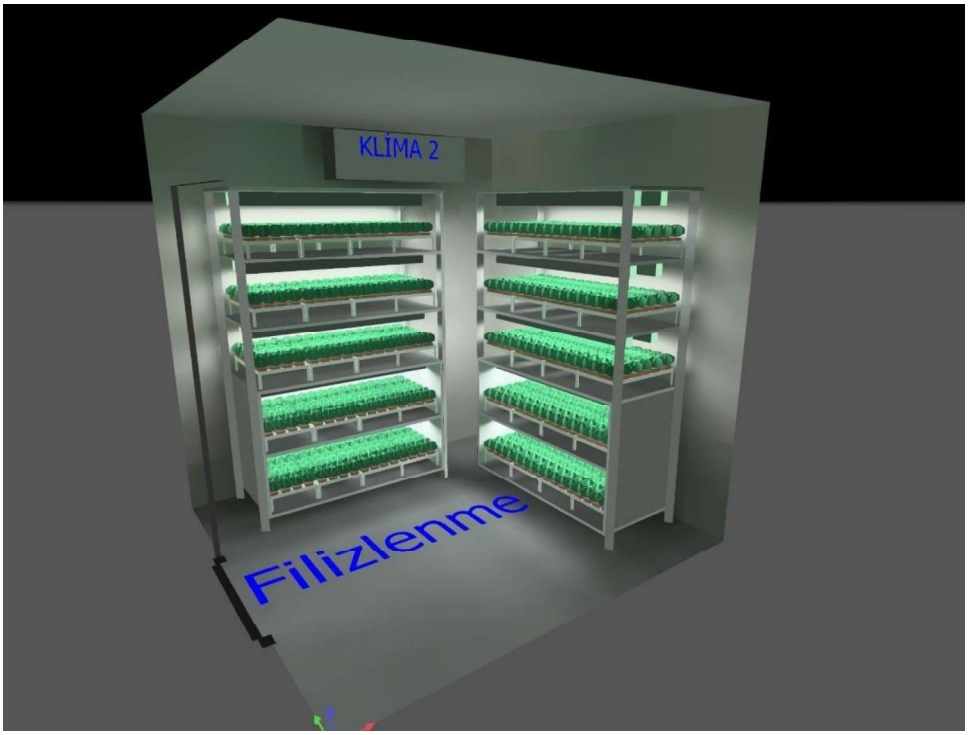


Figure 2.3. Portable Vertical Farming System Sprouting Room

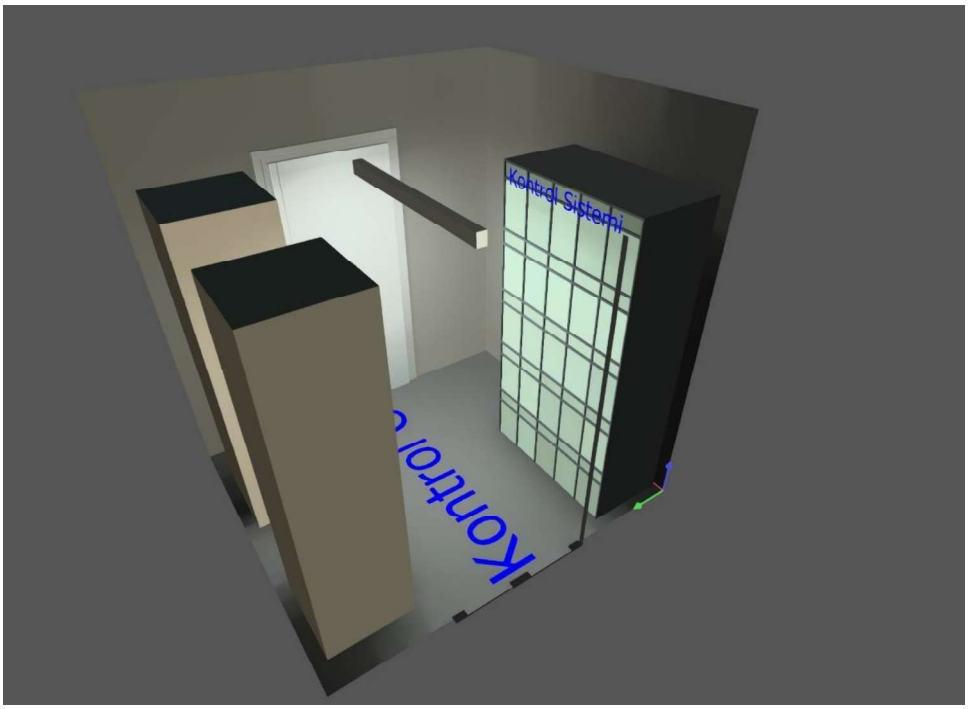


Figure 2.4. Portable Vertical Farming System Control Room

Portable micro sprout/micro greenery growing media control room is designed with dimensions of approximately 2,35X2X2,4 meters. Production room is designed approximately 2,35X7,5X2,4 meters. Germination room is designed approximately 2,35X2,5X2,4 meters.

The design of the shelves where the plants are placed in the vertical agriculture container designed in Dialux Evo program is shown in Figure 2.5.

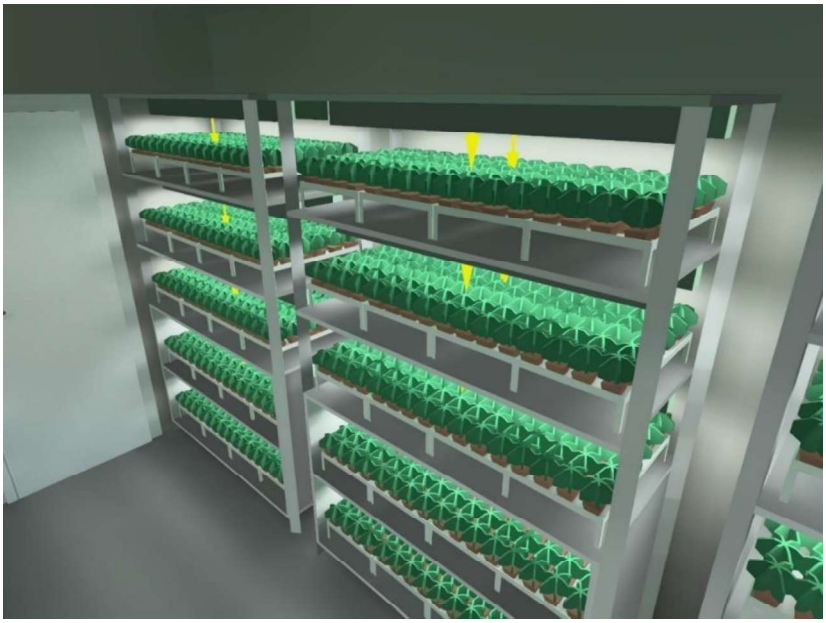


Figure 2.5. Vertical Farming System production racks

The dimensions of the shelf selected for the cultivation of micro sprout plants were drawn in the dialux evo program and shown as follows width: 120cm, length: 60cm, height: 200cm.

The size of the trays used for growing micro sprouts will be 30x50cm.

There are 12 shelves in the portable micro sprout/micro greens growing environment and each shelf has 5 tiers. The distance between the shelves is 35 cm and the lowest floor of the shelf is 10 cm above the ground. There are 4 trays on each floor of the shelf. 10 of the 12 shelves are in the production room and 2 shelves are in the sprouting room. There is one inverter air conditioner each in the sprouting and production room. Air filter is used to balance the air circulation in the room. In addition, small fans were used and a thermometer was used to control the temperature inside the room.

The portable structure is divided into control, germination and production rooms, with the addition of a water tank and solar panels for locations where grid connection may be difficult.

The exterior view of the micro sprout growing container designed in Dialux evo program is shown in Figure 2.6

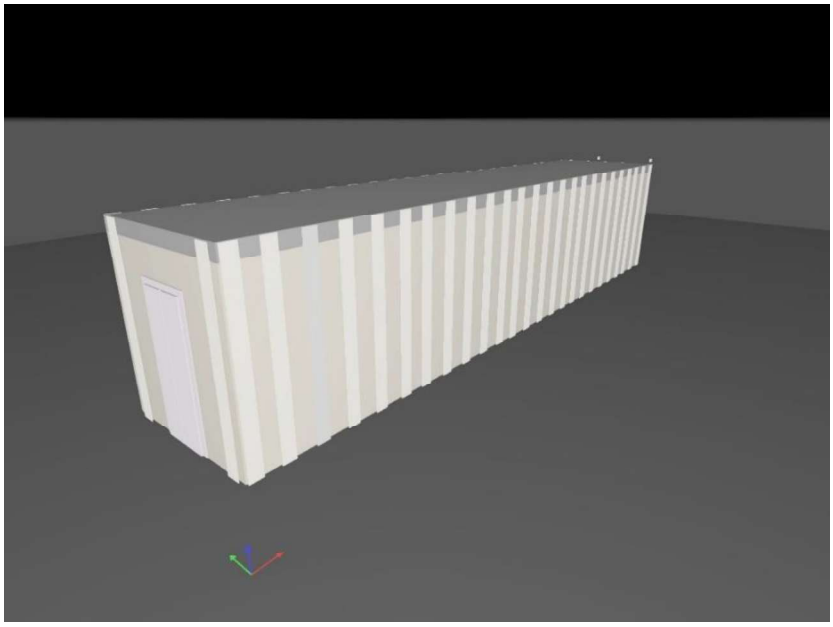


Figure 2.6 Microfilis Growing Container

Artificial Light Design

It is known that plants have different morphologies under different wavelengths of light and this is studied under the name of photomorphogenesis. For example, it is known that the formation of leaves and roots is supported more in plants fed with blue light, while fruit formation is triggered more in plants fed with red light [5,9].

The wavelength plot of the photon and energy weights of the PAR range of the designed light is shown in Figure 2.8

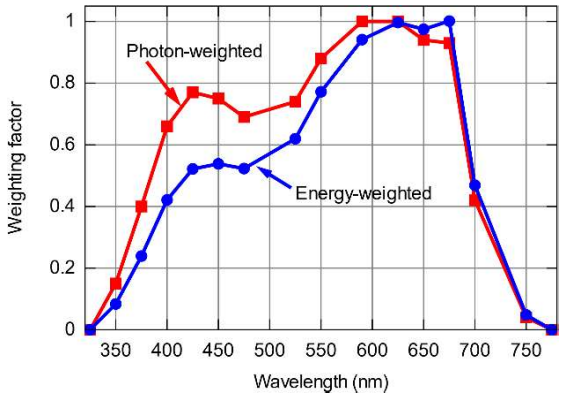


Figure 2.8 Wavelength dependence of the photon and energy weight of the PAR range[22-24]

PAR defined by PPF does not distinguish between different wavelengths between 400 and 700 nm and assumes that wavelengths outside this range have zero photosynthetic effect. If the exact spectrum of light is known, photosynthetic photon flux density (PPFD) values (µmol s 1·—·— 2 m) can be varied by applying different weighting factors to different wavelengths. This results in a quantity called the yield photon flux (YPF).[22] The red curve in the graph shows that photons around 610 nm (orange-red) have the highest amount of photosynthesis per photon. However, since shorter wavelength photons

carry more energy per photon, the maximum amount of photosynthesis per event unit is at a longer wavelength, around 650 nm (dark red).[23,24]

It is seen that red and blue light are generally emphasized as effective wavelengths for growth in artificial light sources in plant growing environments. Along with these wavelengths, green light has also been shown to play an important role in the direction and efficiency of photosynthesis. It is understood that artificial light sources containing warm or cold white wavelengths are used to obtain green light.[20] The PAR region, which is the photosynthetic wavelength range for plants, is shown in Figure 2.9.

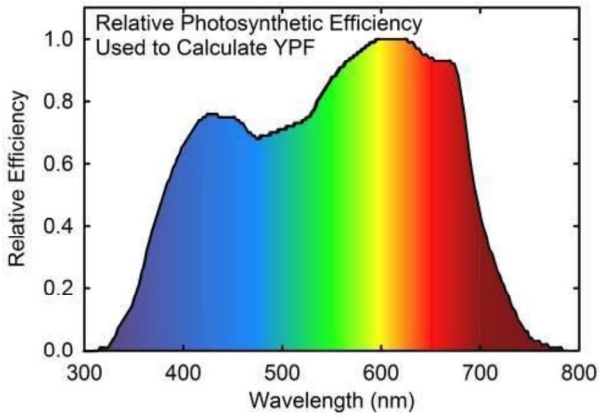


Figure 2.9 Yield photon flux curve [20]

The photon flux spectral distribution curve of the designed LED-based artificial light source is shown in Figure 2.10. SAMSUNG_4A4B0 Blue LED chips containing approximately 5% blue light at 400 nm wavelengths were preferred in the artificial light design of the microgreens/microphilis growing environment to support the root formation of the plant.

SAMSUNG vertical agricultural LED chips containing intense red light at effective wavelengths of 650-660 nm were preferred for the plant's stem growth, leaf number and leaf area. SAMSUNG_F2RNYZ WHITE LED chips with 572.8 nm effective wavelength at 6500 K^0 color temperature and 572.8 nm effective wavelength containing green light wavelengths were preferred to help the plant use PAR region light with high energy for photosynthesis. Samsung brand LED chips produced for vertical agriculture were preferred to provide light as an artificial light source.

The spectral distribution curve of the PAR region, the photosynthetic wavelength range for plants, is shown in Figure 2.10.

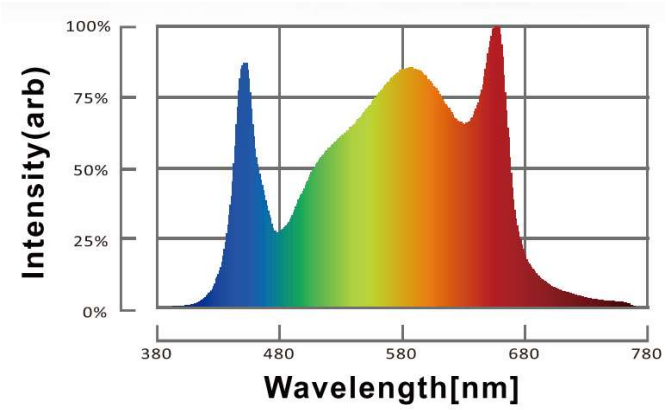


Figure 2.10 Photon flux spectral distribution curve of LED-based artificial light source

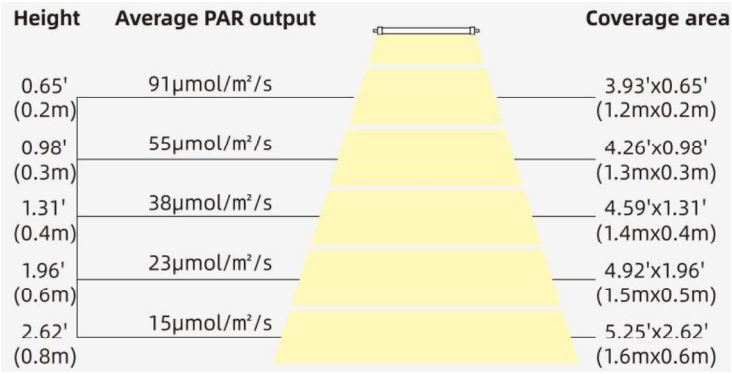


Figure 2.11 Vertical axis PAR value variation of LED based luminaire

Photosynthetically active radiation (PAR) variation values of the designed vertical farming LED-based artificial light source as a function of height are shown in Figure 2.11.

The cultivation process was carried out by illuminating the tray 25 cm above the tray where 4 microfilis were grown using 2 lights of 120cm. During this process, PPFD measurements were made with a 10x15 grid and these measurement patterns are shown in Figure 2.12

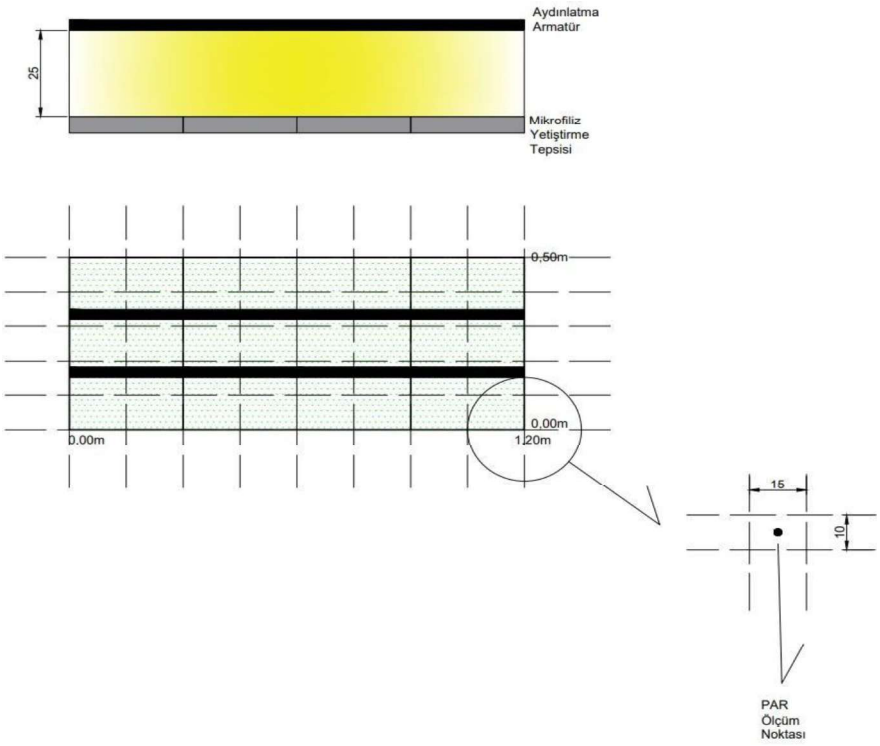


Figure 2.12 Growing area and PPFD measurement

The illumination of the skylight angle form of the LED-based light source in the dialux evo program is shown in Figure 2.13

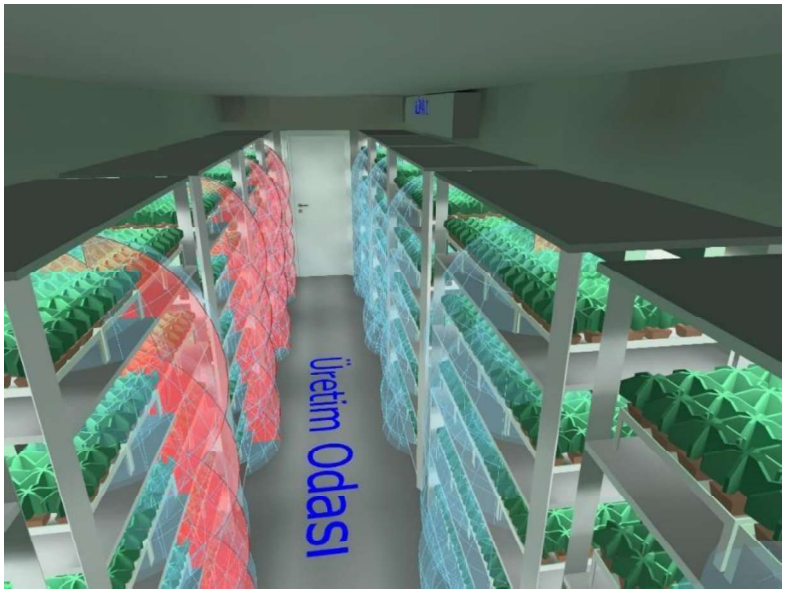


Figure 2.13 Skylight Angle Form of LED Luminaire shown in Dialüx program

The arrangement of the LED-based light source on a PCB is shown in Figure 2.14.

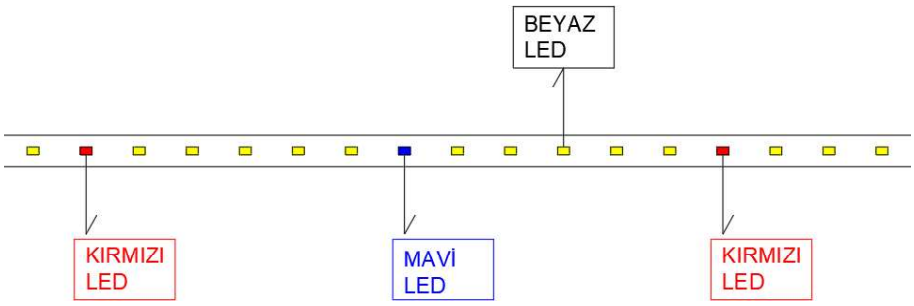


Figure 2.14: LED PCB Board

There are 72 LEDs on the PCB. Of these LEDs, 6 blue, 6 red and 60 white LEDs were used. 2835 Samsung brand LED chips produced for vertical agriculture were used. The visuals of the LED-based artificial light source are shown in Figure 2.15

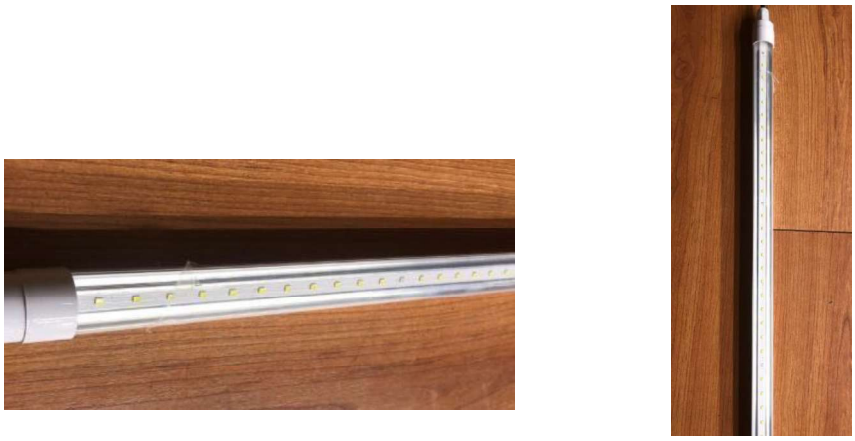


Figure 2.15 Micro Sprout Plant Growth Luminaire

The technical specifications of the LED-based artificial light source are given in Table 1.

Table 1: Specifications of the Microphilisis Magnification Armature Used

Input Voltage/Current	230 V, 0.12 A
Input Power	28 WATT
LED LIGHT ANGLE	120°
LED Chip	SAMSUNG White-Blue-Red LED
Light source PAR region	400nm-700nm
Light source effective wavelength	660 nm
Photosynthetic Photon Flux (PPF)	67.5 µmol/s
Heat generated	95.54 BTU
Length	1200 mm
Weight	0.5 kg

A driver model known as DOB LED (Driver On Board), which is expressed as on the driver by adding it to the modules (driver), was used.



Figure 2.16 Micro Sprout Plant Growth Armature Driver

In this luminaire, there is no need for an external driver. With this driver mounted under the PCB, a useful luminaire design has emerged in order to create a ready finished product design. This constant current driver is 27.6 Volt input 220-230V output voltage value for the driver driven with 120 mA. The visualization of the driver with the specified features is shown in Figure 2.16.

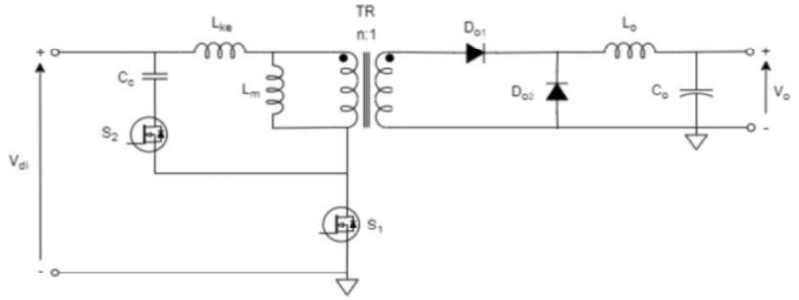


Figure 2.17 DC /DC Driver circuit diagram with active suppression

The DOB drive first converts the AC input energy into DC unregulated signal by AC/DC converter. In order to convert the unregulated DC signal into a constant DC voltage signal in a controlled manner, an isolated type forward DC-DC converter is used. In the active suppression forward converters shown in Figure 2.17, where the suppression switch and capacitor are connected upwards, the S2 switch and the Cc suppression capacitor are connected in parallel to the primary windings of the TR transformer.

Here, in addition, the circuit works as a classical step-down converter. Thus, the voltage stress of the switch is equal to the sum of the voltages Vdi and Cc.

Air Conditioning and Irrigation System

In the portable vertical farming system, an air conditioning system was designed for two spaces: germination room and production room. The germination room is designed as approximately 6 m^2. For the heating, cooling and ventilation needs of the germination room, it was found appropriate to position a 9000 btu inverter wall type air conditioner. The production/growing room is designed as approximately 19 m^2. For the heating, cooling and ventilation needs of the production/growing room, an inverter wall type air conditioner with 18000 btu power was found suitable.

For use in vertical farming applications, a solution tank in the control room and an irrigation system for liquid circulation from the production trays on the shelves were added to the project. According to the number of trays and the length of the pipe, the liquid circulation pump was found to be suitable with a power of approximately 150 W. It is planned to have a water tank with a capacity of 1 ton on the roof for places without mains water connection and to feed the irrigation system.

Energy and Control System

Portable mini-scale vertical farming system is designed as a system with energy management system. Designed as a hybrid energy system of interconnected grid and photovoltaic solar panels, the system can be fed only by interconnected grid connection for projects where low investment cost is desired. Approximately 20 PV panels of approximately 2000X1000 mm in size can be positioned on approximately 26 m^2 roof area. Depending on the grid-dependent or -independent connection status, the number of PV panels, charging control unit with MPPT feature, inverter power for AC conversion of DC energy and battery capacity required for storage can be integrated into the project portable mini-scale vertical agriculture system.

The design of the micro sprout growing container, which was designed in Dialux evo program, is shown in Figure 2.18, where PV panel and water tank can be positioned on the top of the container

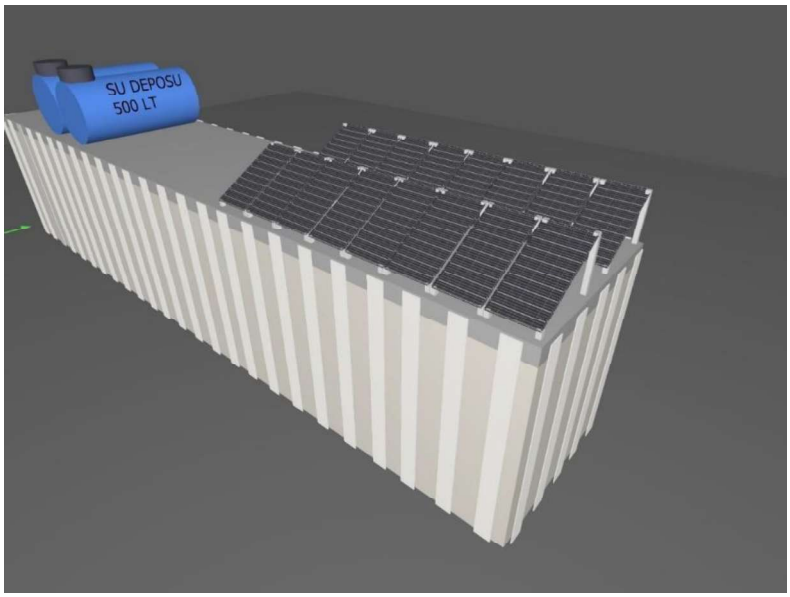


Figure 2.18 Microfiltration Container

Air conditioning automation has been realized in the production and germination rooms so that temperature/humidity sensors control the heating/cooling inverter air conditioners. In addition, ambient measurements will be made with carbon dioxide sensors and carbon dioxide cylinders will be checked at specified intervals.

White Radish Microgreens Growing Results

In order to understand the effects of the LED-based artificial light source of the portable vertical farming system designed within the scope of the project on the growth parameters of the plant, Nitrogen/Nitrogen (N), which are the main macro elements that support growth in solid culture (cocopeat), Secondary microelements such as Phosphorus (P), Potassium (K) and Calcium (Ca), Magnesium (Mg), Sulphur (S), Iron (Fe), Zinc (Zn), Boron (B), Manganese (Mn), Copper (Cu), Molybdenum (Mo), Chlorine (Cl) were also not used.

The white radish microgreen plant has 4 different main stages. These are; rooting, germination period, sprouting period, greening period. These stages are shown in figure 3.1, figure 3.2, figure 3.3



Figure 3.1 White Radish Microgreens Germination-Rooting Stage



Figure 3.2 White Radish Microgreens Sprouting Stage



Figure 3.3 White Radish Microgreens Greening Stage

Some important values were recorded day by day during the period from rooting to the end of the greening period of white radish microgreens. The table of values is shown in table 2.

Table 2. Table of Values of White Radish Microphilis During the Growing Process of White Radish Under Plant Growth Lighting Fixture

	FERTILIZER	IRRIGATION	PLANT		LIGHT
History	pH	Method	Boy	Period	Distance
5.02.2025	7,5	Spraying	0cm	Rooting	25cm
6.02.2025	7,5	Spraying	0cm	Rooting	25cm
7.02.2025	6	Spraying	1cm	Germination	25cm
8.02.2025	6	Spraying	3cm	Germination	25cm
9.02.2025	6	Bottom irrigation	5cm	Germination	25cm
10.02.2025	6	Bottom irrigation	8cm	Sprouting	25cm
11.02.2025	6	Bottom irrigation	9cm	Sprouting	25cm
12.02.2025	6	Bottom irrigation	10cm	Sprouting	25cm
13.02.2025	6	Bottom irrigation	12cm	Greening	25cm
14.02.2025	6	Bottom irrigation	15cm	Greening	25cm
15.02.2025	6	Bottom irrigation	15cm	Greening	25cm

The period from seed to harvest time was 10 days for white radish microphilis plant. After 4 main periods of rooting, germination, germination, sprouting and greening, the microphilis plant

completed its growth as of the 10th day and reached a height of 15 cm. And harvested. Ph values were generally around 6 and spraying and bottom irrigation method was used

Conclusion

The results of the PAR region measurement, which is the photosynthetic wavelength range of the light used during the design and white radish cultivation process, are shown in table 3.

Table 3: PPFD Measurement Results for the cultivation area

28,6	33,9	43,3	43,2	43,2	43,3	34	28,7	0,50 m
36,7	42,1	51,4	52,6	52,6	51,4	42,2	36,8	
36,8	42,5	51,7	52,8	52,8	51,7	42,6	36,9	
36,7	42,1	51,4	52,6	52,6	51,4	42,2	36,8	
28,6	33,9	43,3	43,2	43,2	43,3	34,1	28,7	0,00 m
0,00 m							1,20 m	

When other methods on the market for the cultivation of microphilis/microgreens were investigated, it was concluded that mostly chemical fertilizers are used. Elements containing heavy metals such as Nitrogen/Nitrogen (N), Phosphorus (P), Potassium (K) are used to accelerate plant growth. However, in our production technique, 100% plant-based growing media (coconut fiber (cocopeat), 100% plant- based fertilizer (seaweed fertilizer) and 100% organic matter (beneficial bacteria and enzymes) are used. Our microfilizers are grown with tap water and we use organic fertilizers, beneficial bacteria and enzymes in a way that is most suitable for nature and human health.

When grown in normal daylight, microphyllis/microgreens complete their development in 30 days. When these plants are grown with special plant growth lighting fixtures with special cultivation methods, their development is completed in about 12-13 days. The white radish microphilis, which was designed within the scope of the project, completed the development process in about 10 days with Samsung vertical agriculture LED chip light source luminaires. When the project product is compared with its counterparts in the market, it has been determined that the harvesting time of microphilis/microgreens is shortened by approximately 20%. Since climate, weather conditions, humidity, temperature, wind, etc. conditions are uncontrolled, it is concluded that products produced with vertical farming techniques can be produced with the same operation every day of the year through air conditioning, air conditioning equipment and artificial lights.



Figure 4.1 White Radish Microphyllis Plant Just Before Harvest

The last image of the white radish microgreen plant before it completes its development and is harvested is shown in Figure 4.1. White radish, which does not contain Nitrogen (N), Phosphorus (P), Potassium (K) macro-elements, or desired microgreens / microfoliage applications are very suitable for use in sectors such as the pharmaceutical industry by dehydration in the mini-scale portable vertical agriculture system designed. At the same time, thanks to its additive-free growth feature, it is easy to integrate into biotechnology products and is also suitable for use as plant-based protein food supplements

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