

Article

Expanding the Level of Technological Readiness for a Low-Cost Vertical Hydroponic System

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Abstract: Climate and social changes are deeply affecting current agro-food systems. Unsustainable agricultural practices and the low profitability of small farmers are challenging the agricultural development of rural areas. This study aims to develop a novel, modular and low-cost vertical hydroponic farm system through reviews of the patented literature, research literature and variants of commercial products. After a detailed conceptualization process, a prototype was fabricated and tested at my university to validate its technology readiness level (TRL). The outcomes supported the usability and performance of the present utility model but highlighted several changes that are necessary before it can pass to the next TRL. This study shows that the prototype has the potential to not only solve food sovereignty but also to benefit society by advancing the innovations in food production and improving quality of life.

Keywords: vertical farming; indoor farming; low-cost vertical farming; small farming; vertical hydroponics; technology readiness level; utility model



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1. Introduction

By 2025, the world's population will number 9.7 billion [1]. Consequently, the agricultural sector will need to produce more food [2]. However, crop production is currently affected by many factors such as climate change, a lack of water and arable land shortages [3,4]. Despite these issues, agricultural productivity needs to be improved.

Agriculture is responsible for 60% of the total water use in Europe [5] and 70% in the world [6]. In addition, agriculture for food uses large amounts of fertilizer and pesticide: the European Union (EU) uses more than 11 million tons of fertilizer each year [7] and the total EU pesticide sales volume was around 350,000 tons per year on average during the 2011–2019 period [8]. We need to protect our environment and natural resources, but excessive fertilizer use can pollute the surface and groundwater, while the use of pesticides damages both human health and the environment.

The need for a sustainable and cheaper source of food production has led to increasing research on several vertical farm systems [9–13]. To meet the increasing demand for food in concentrated areas or big cities, the research on last-mile consumption has also recently increased [14,15]. If fresh food is produced locally, then it is not necessary to travel far to obtain it, which reduces carbon footprint [16].

Currently, there are numerous farming techniques used to reduce water consumption, environmental impacts, and space for crops. Vertical farming innovations provide both food security and ensure environmental sustainability in small sites [17,18]. Vertical farms could also provide young farmers, constrained by land or credit access [19], with the opportunity to run a centrally located farm while pursuing a university degree [20].

The technology developed in this paper has three general aims: the efficient use of natural resources and space, sustainability, and efficiencies in the food value chain which reduce the carbon footprint by producing food locally.

Vertical hydroponic farming is a combination of vertical production and hydroponic methods that are proven to be useful [9–13].

Hydroponics is a method of growing crops without soil by using mineral nutrients in a water solution [21]. Various hydroponic techniques, such as a drip system, nutrient film, deep flow, or aeroponics, are available [21]. Different crops can be grown in a vertical hydroponic system, making indoor farming possible [22].

Several types of commercial vertical hydroponic system products such as A-frame, Zig-zag tower, or ZipGrow are available, as well as vertical hydroponic plant factories (e.g., Aerofarms, Plenty, or Bowery) which produce vegetables in urban areas [23–25]. Although these systems are helping to meet the local demand for food, they remain costly and complex for small growers.

The aim herein is to build and test a modular and low-cost invention that may be utilized by citizens or small farmers, indoors or outdoors, in urban or rural areas. In this way, every home could be a farm, and a small farm based around a city could supply enough food to the local villagers. These are the major motivations for this paper.

Although the literature on vertical farming focuses on various aspects, no studies promote a local food sovereignty solution through a scalable low-cost structure. While some research emphasizes technology, none provides a detailed solution for modular structures [26–33].

Moreover, these studies do not include detailed designs that could be useful for other researchers to use to replicate or improve this innovation. To my knowledge, this is the first implemented vertical hydroponic system with a Technology Readiness Level (TRL) analysis.

In this paper, a specific methodology is implemented to develop a utility model, i.e., a system similar to the patents which provide protection via minor improvements [34], before passing to the engineering stage.

Thus, the present invention consists of a system based on a modular support structure, which is intended for the hydroponic cultivation of a wide variety of crops. Specifically, the invention focuses on the creation of a multi-level structure with a fully adjustable height. This structure is modular and can be used in both large and small areas, i.e., in greenhouses, both indoors or outdoors, in gardens, or on balconies.

The remainder of the paper is presented as follows: Section 2 covers a review of vertical farms in patents, describes the TRL methodology, and provides a comprehensive description of the vertical farming system designed and developed. Section 3 presents the results of the implemented system and compares them with some commercial and research solutions. Finally, the conclusions are presented in Section 4.

2. Materials and Methods

In the following section, the most current patents related to hydroponic vertical systems, which are already published, are reviewed and critically evaluated. Secondly, the design of the low-cost invention is described, which is considered a utility model, and, finally, the methodology is presented.

2.1. Integrative Research Review

In patent document EP 2 904 894 A1 [35], a modular hydroponic growing system with hanging units in the form of geotextile bags is shown. This same structure serves as a support for irrigation and drainage systems. The solution is designed mainly for the planting of small vegetables both in greenhouses and indoors.

In patent document US2011/0067301 A1 [36], a hydroponic growing system is shown to provide a continuous flow of nutrients to plants. The system is made up of large-diameter tubes comprising a plurality of cutouts and interconnected to each other with a slight slope. A pump supplies the nutrients through the upper part of the structure, collecting the drainage water from the lower part. As in the previous document, the system is designed for small crops. Furthermore, this solution cannot be made modular.

Patent document US2012/0066972 A1 [37] shows a vertical planting system with the plants in bags hanging from the structure. In the lower part of it, there is a water storage

tank with a pump capable of supplying water to the upper part of the structure. In this case, a modular system is not possible either.

Patent document US 7,055,282 B2 [38] shows a vertical hydroponic cultivation device for greenhouses. The system consists of a tower comprised of modules with hollow interiors, along with inclined support cups where crops are planted. As in the previous cases, this system is designed for small crops.

None of the patents mentioned are versatile enough to be used with both small crops such as greens (e.g., lettuce, kale, or basil), medium crops such as strawberries, or larger crops such as blueberries. They are all only suitable for crops of small sizes and weights, while the present invention is capable of supporting the growth of all of these crops.

It is also important to note that, although all the aforementioned patents describe the increase in plant density (number of individuals per unit ground area), none of them suggest or disclose that the modules can be assembled together. The present invention allows for the coupling of modules with telescopic legs to guarantee water drainage throughout the entire system. In addition, no solution was designed for cultivation in rural farms, where simple structures such as those presented in this invention were needed, structures which made it possible to join many modules.

Another advantage of the present invention is that it allows the use of commercial substrates (e.g., perlite, fiber) and containers (e.g., sacks, bags, and pots). Therefore, the structure is compatible with the commercial components from hydroponics, fertigation (e.g., drip irrigation), or drainage (e.g., gutters), while the patents mentioned need to adapt the commercial components to the patented structure.

Finally, the present invention can be used for both hydroponics and aeroponics, for which the invention comprises interchangeable components.

Taking into account the aforementioned points, it can be said that there are a multitude of solutions. However, a system with a high degree of versatility that can be used in different environments and situations is essential and, so far, this system has not been demonstrated by the systems and structures put forward to date. In addition, because hydroponics are used more and more in all types of plantations, a system adaptable to any type of crop is needed. To solve this technical problem and the needs raised above, the invention that is described below makes it possible to obtain a vertical system for totally versatile hydroponic cultivation, which can be used in a great variety of situations and crops.

2.2. System Design

Although it was not the objective of this study and the data are not presented since the experiment was not concluded, a pilot test was conducted that covered other interventions such as studying the behavior of small crops. Strawberries (*Fragaria* spp.) were planted in the first module, and lettuce (*Lactuca sativa*) and purple cabbage (*Brassica oleracea* var. *capitata* f. *rubra*) were planted in the second. The heights of the different levels were studied with the aim of optimizing the farming labor required for these crops. The degree of the influence of shaded areas in the different levels of the structure and their influence on the final production yield were evaluated, and two AC-powered LED strip lights were located in the module that received the most shade to assess the influence on the crop development.

The construction of two vertical hydroponic modules with fixed heights were commissioned for the pilot test. According to the ES 1 242 949 U utility model [39], the system (Figure 1a,b) was made up of two floor stands (1) on which the rest of the structure was attached. The main mission of the floor stand was to prevent the crop from tipping over, as well as to distribute the weight of the structure on the ground.

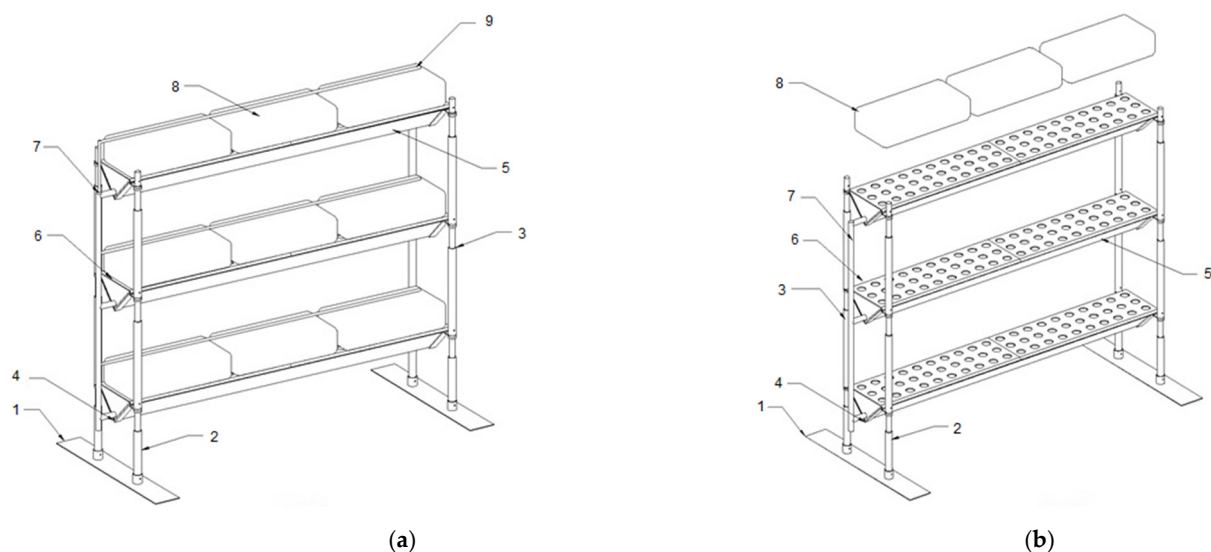


Figure 1. View of the system with all the components that make up the structure. With substrate sacks (a) Without substrate sacks (b).

On the floor stand, two telescopic legs (Figure 2b (2)) of a short length (30–40 cm) are installed, made up of two parts: the lower part (A) consists of a hollow tube with an internal thread, while the upper part (B) is a tube with an external thread. By spinning both parts together, the desired height can be achieved at each point.

To be able to attach the telescopic legs to each other or to the floor stand, there are two holes at each of their ends through which a screw (see Figure 2a between (2) and (3)) is installed, thus joining the two pieces. In addition, in the upper part of the telescopic leg, there is a stop that supports an elevated gutter.

The telescopic legs of the upper levels (Figures 1 and 2a (3)) are configured in a similar way to those of the lower level, with the only difference being that the tube with the lower thread has a greater length, so that a greater separation between cultivation levels is achieved.

The following elements are the supports (Figures 1 and 2a (4)) which are responsible for joining the telescopic legs to the drainage channel. These supports are V-shaped with two rings at the ends which are inserted into the telescopic legs.

One of the main elements which makes up the system is the drainage gutter (Figure 2d (5)). It is a V-shaped Polyvinyl chloride (PVC) channel in charge of collecting the excess water from the plant and directing it to the end of the system where it is guided into a tank. The gutters can be coupled longitudinally by means of reinforcements (13) or clamps (see Figure 2e). The tubes (Figure 1 (7) and Figure 3 (12)) are pipes which lead the drainage water from the lower end of the drainage gutter to the lower part of the structure where it is stored in a container or tank.

There is a metal lattice (Figure 2d (6)) that supports the substrate sacks (8) attached to the drainage gutter.

Additionally, the system has a drip irrigation tape (Figure 1a (9)) that is arranged on top of the substrate sacks.

The structure described above can also be adapted to aeroponic crops using plastic tubes (Figure 3) with a plurality of holes in their upper part where the crops are housed. These tubes serve as drainage gutters (11). In this case, straight sheets (10) must be used as supports with two holes at each of their ends (Figure 2f (10), instead of Figure 2a (4)). Although not designed for this utility model, the seeds are “planted” in pieces of foam stuffed into tiny pots, which are exposed to the light at one end, leaving the roots to dangle in the air, where they are periodically sprayed by aerosol-generating nozzles inside the pipes.

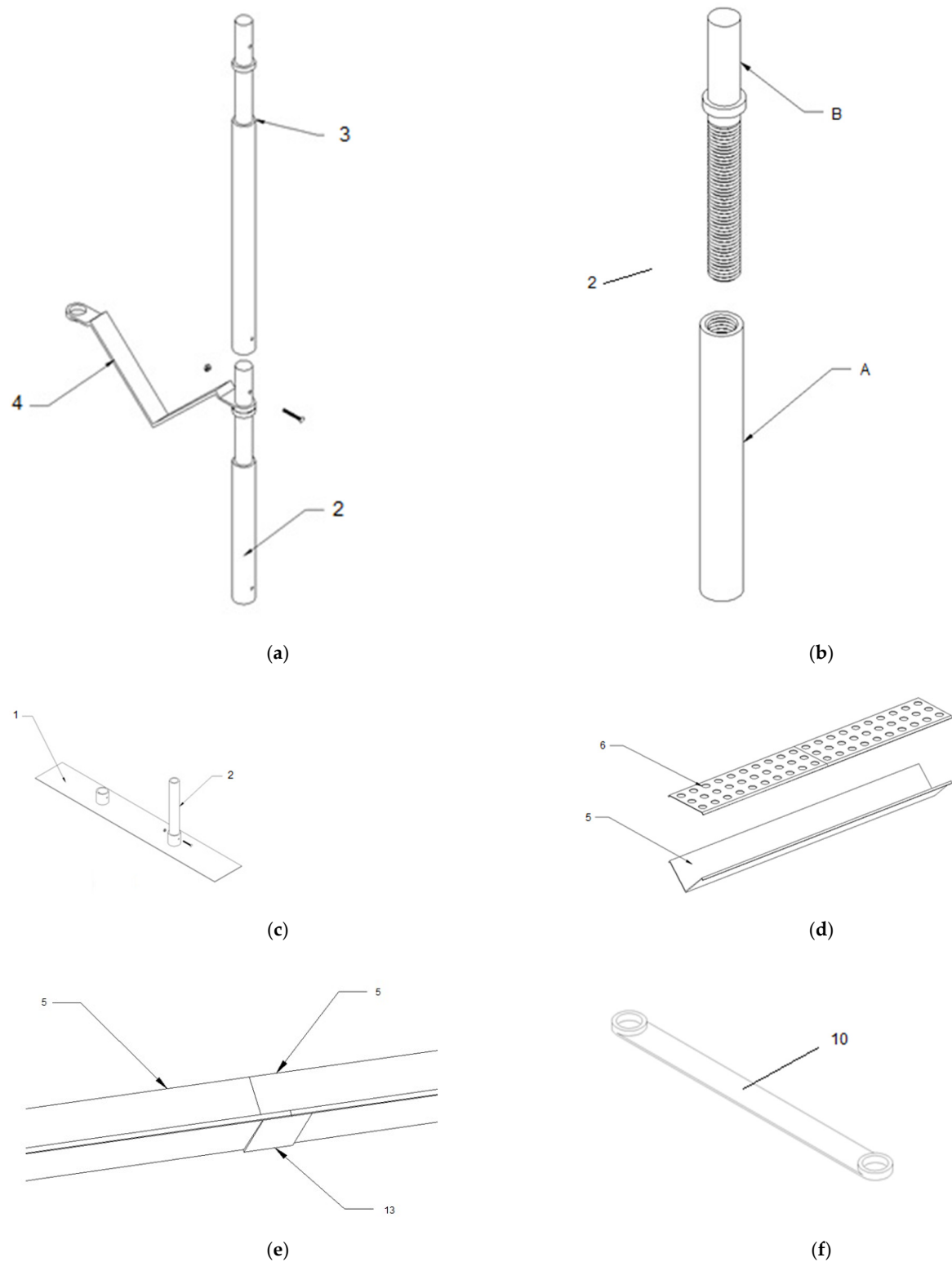


Figure 2. Components in detail. From left to right and from top to bottom: (a) Junction of two levels. (b) Telescopic leg. (c) Splicing of the legs with the floor stand. (d) Configuration of a drainage gutter and a metal lattice. (e) The splice between two gutters. (f) Component for aeroponic cultivation.

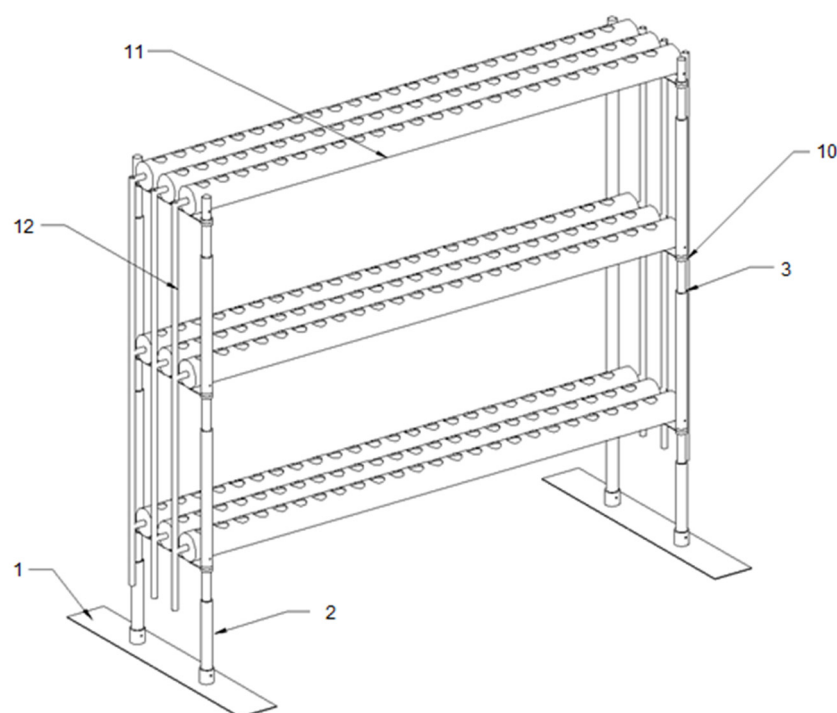


Figure 3. Detail of the adaptation to an aeroponic system.

Using only the lower level, the system can accommodate large crops which are planted in pots, such as blueberries (Figure 4).

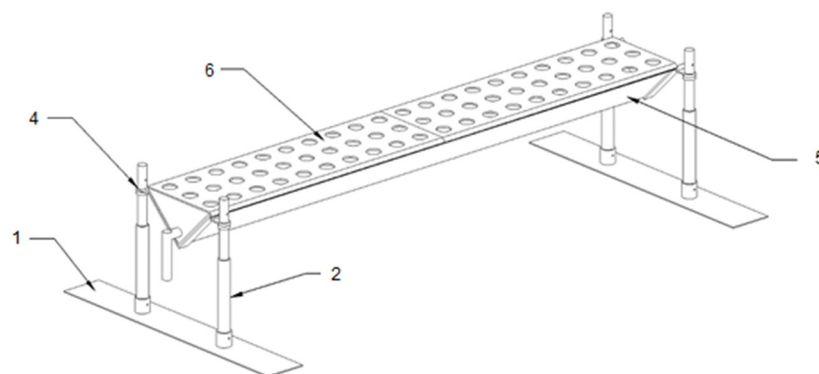


Figure 4. Representation in a free perspective of the adaptation of the system to large crops.

Another feature of this invention is that it is designed to be able to couple the modules that are necessary, thus it is able to cover long distances (Figure 5). In this case, the height of each level must be correctly adjusted, using the telescopic legs and ensuring the hermetic seal of the gutters (see Figure 2e (13)) to achieve a slight slope that runs through the entire row of a crop.

Furthermore, the use of LED lights is possible as they can stimulate the growth of crops in locations with a few hours of daylight. LEDs are solid-state elements (they do not require ballasts) which emit very little heat and can be located very near to the crops [40–42].

Aside from these advantages, the low energy consumption, high durability (the average useful life is 50,000 h), instantaneous ignition, different types of LEDs offered, the fact that they can be contained in a single strip, the low cost, and the improved energy efficiency of LEDs are factors which justify their adoption in agriculture.

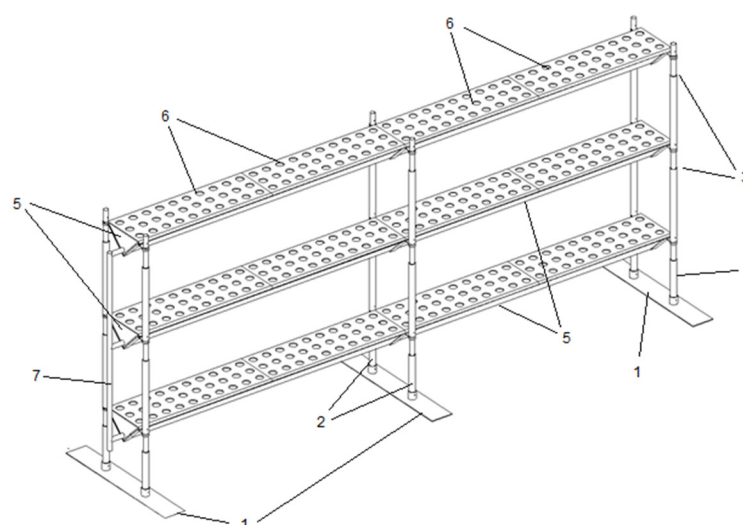


Figure 5. Free perspective representation of the adaptation to dimensions and heights by joining several modules.

The wavelengths of light corresponding to photochemical processes are in the range from 400 to 520 nanometers (nm) corresponding to the visible spectrum, and comprise violet, blue, and green light, which have a strong influence on vegetative growth and photosynthesis; and 610 and 720 nm, also corresponding to the visible spectrum, comprising red light, which stimulates the vegetative growth, photosynthesis, flowering, and germination by means of the crops' photosensitive pigments [43].

Naznin et al. [44] investigated the growth of strawberry plants with different red:blue LED ratios (5:1, 10:1, 19:1) versus High Pressure Sodium vapor (HPS) lights, obtaining better results in all parameters (leaf number, runner number, inflorescences number, crown number, length of flowering, stems per plant, and dry mass) with LED lights.

Other research carried out on strawberries by Hanenberg, Janse and Verkerke [45] also found better results for brix and vitamin C production and in sensory tests with LED lighting near the leaves or fruits. According to these authors, the illumination of the leaves resulted in the highest brix levels, while the illumination of the fruits resulted in the highest levels of vitamin C. These observations were in agreement with Gautier et al. [46].

According to Mochizuki et al. [47], the short-distance lighting with LEDs in strawberry production, irradiated on the underside of the leaves with blue LEDs, improved assimilation in young leaves compared to the use of red LEDs.

As the province of Huelva (Spain) has a good number of hours of daylight [48], the strawberry plant already obtained the required luminosity; therefore, red LEDs were, in this case, more necessary than blue ones to promote flowering and achieve a better performance.

Thus, two LED strips were used, one with red and blue 3:1 (3Red:1Blue) and the other with 5:1 (5Red:1:Blue) color combinations. These strips were placed on the module that received the most shade, placing the 5:1 strip on the upper level (red marking) and the 3:1 (blue marking) on the intermediate level (Figure 6).

Compared to the technologies and commercial solutions known in the agricultural sector, the structure on which the invention is based allows a modular system for hydroponic cultivation to be achieved which is totally versatile and adaptable to a wide variety of crops and situations, cultivating crops in several vertical segments, and thus increasing the plant density.

2.3. Technological Readiness Level (TRL)

TRLs are the constitutive scales of a method to estimate the technical maturity of different types of technologies. The main objective of using the TRL is to help make decisions related to technology development.

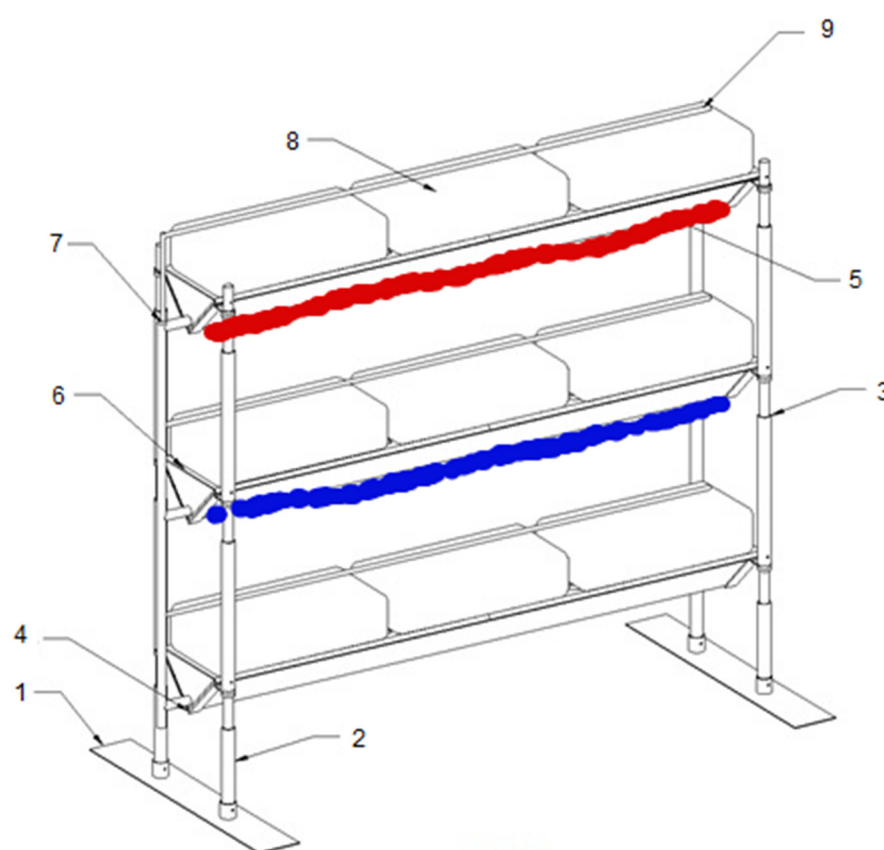


Figure 6. Installed LEDs in the vertical farm system.

This concept was developed at the National Aeronautics and Space Administration (NASA) during the 1970s for the space programs [49] and was subsequently formally adopted worldwide [50]. In the 2000s, the US Department of Defense used the scale for acquisitions [51]. In 2008, the scale was also used by the European Space Agency (ESA) [52]. In 2013, the TRL scale was formalized through the ISO 16290 [53].

In Europe, TRLs are determined using nine levels [54]:

- TRL 1. This is the lowest level of technological maturity at which scientific research begins to translate into applied research.
- TRL 2. Once fundamentals are verified, practical applications are devised. The examples are limited to speculative studies or utility models.
- TRL 3. In this stage, the product development starts. The work proceeds to the experimental phase to verify that the concept operates as expected.
- TRL 4. This level is considered as “low-fidelity” and determines if the individual elements could work as a system (Systems Readiness Level, SRL) [55].
- TRL 5. The basic technology components are integrated in a “high-fidelity” lab-scale system.
- TRL 6. The engineering development begins. The prototype must be able to perform all the functions required for a real environment. This represents an important step in demonstrating the maturity of a technology.
- TRL 7. This step requires the demonstration of the prototype in a real situation. The final design is practically complete.
- TRL 8. This TRL constitutes the end of system development, with testing in its final form and under the expected conditions.
- TRL 9. The technology is ready and the commercial manufacturing process can begin.

The approach of this paper is based on the transfer of a utility model from TRL 2 to TRL 4.

3. Results and Discussion

In the section that follows, the performance and functionality of the utility model ES 1 242 949 U [39] are validated, the plant density is determined, and the costs of the system are compared with those of conventional hydroponics.

The pilot was developed inside one of the greenhouses of the experimental farm at the University of Huelva (Andalusia, Spain) during the months from October 2020 to June 2021 (Figure 7).



Figure 7. Experimental site for the pilot test.

3.1. Dimensions of the Modular System Built

The modular system was made up of a galvanized iron structure with two parallel floor stands at each end, on which three levels are supported. Each level is made up of a triangular structure, which serves to support the substrate sacks, two per level, and collect the drainage water. Each module has dimensions of $220 \times 170 \times 30$ cm (Figure 8).

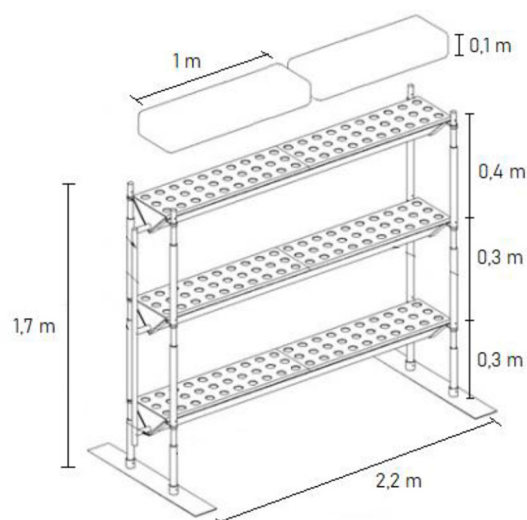


Figure 8. Dimensions of the vertical farm module system.

By carefully studying the heights at which the different levels were located, it was detected that the lower level, although higher than in a soil crop, was too low for the operator to easily pick fruit. In the same way, between the lower level and the intermediate one, the available height was 30 cm which, when subtracting the height of the sack, forced the plants (small crops) to grow up to 20 cm high. The height between the intermediate

and upper level (40 cm) seemed to be optimal for the crop and its subsequent harvest. In addition, this intermediate level was at a height of 60 cm from the ground, which was ideal for carrying out management tasks. Finally, the upper level, although at an adequate height, made harvesting difficult for those operators of short stature.

To solve this technical problem, it was recommended to incorporate the telescopic legs indicated in the design of the utility model, and to replace the galvanized iron with aluminum and PCV.

3.2. LED Technology and Shading Influence

Using LED lights as supplementary lighting, with the addition of a single daily work cycle (six hours of light phase and two of dark phase) until the beginning of spring, I was able to visually verify that artificial lighting increased both the growth rate of the strawberry plants and their yield. Although more trials and repetitions are needed, provisional results show that the treatment with LED lights reduced the vegetative cycle of the plant by 5 days, from 60 to 55 days.

Due to how the modules were arranged inside the greenhouse (west–east), a slight shading was observed in some hours of the day which was eliminated with the use of artificial lighting.

3.3. Production and Costs

In a conventional macrotunnel (a simple structure that allows coverage of a large area where several rows of plants are grown in a controlled and protected environment), 12 plants were cultivated in each substrate sack, with four rows of plants separated by 100 cm (Figure 9a) between each. Instead, in this pilot (Figure 9b), the number of plants per sack was 13 and the corridors were narrowed by 10 cm to achieve a greater space for the structure and assure the optimal separation of the rows for harvesting so that they operated successfully (70–160 cm).

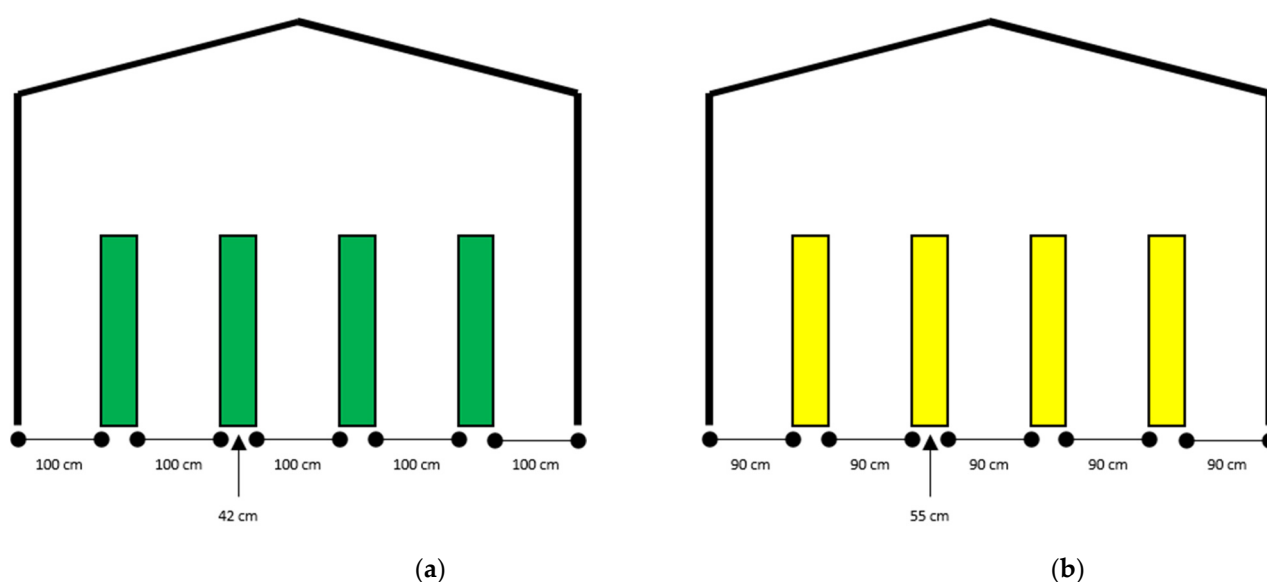


Figure 9. Arrangement of crop rows in the macrotunnel. 100 cm wide pathways (a) and 90 cm wide pathways (b).

Twenty-five macrotunnels of 7 m × 60 m can be used per hectare, so there can be 108 modules per tunnel. Although this does not imply more crop rows per macrotunnel, with these data, and assuming the same yield per plant (provisional results show that the yield production increased by 10%, from 900 g/plant to 1000 g/plant), the production per hectare can be increased by two to three times compared to conventional hydroponic systems (Table 1).

Table 1. Comparative plant density.

tunnel_width (m)	7
tunnel_length (m)	60
number_tunnels_per_ha	25
module_length (m)	2
number_modules_per_row_and_tunnel	27
number_rows_per_tunnel	4
number_modules_per_tunnel	108
number_substrate_bags_per_module_3_levels	6
number_substrate_bags_per_module_2_levels	4
number_substrate_bags_per_conventional_hydroponic_system	2
number_substrate_bags_per_tunnel_module_3_levels	648
number_substrate_bags_per_tunnel_module_2_levels	432
number_substrate_bags_per_tunnel_conventional_hydroponic_system	216
number_plants_per_tunnel_module_3_levels	8424
number_plants_per_tunnel_module_2_levels	5616
number_plants_per_tunnel_conventional_hydroponic_system	2592
number_plants_per_ha_module_3_levels	210,600
number_plants_per_ha_module_2_levels	140,400
number_plants_per_ha_conventional_hydroponic_system	64,800

The cost results (Table 2) show that when the pilot experiment was extended to cover one hectare, the total implementation costs were a little over twice as expensive as the conventional solution, but the cost per plant was much lower. If these data are compared with cost of the ZipGrow technique, the utility model proposed in this study is much cheaper [9]. According to ZipGrow [56], a fully equipped system of 92 m² for local production costs approximately USD 124,000 (fixed cost).

Table 2. Comparative system costs for a strawberry farm (EUR /ha).

	Conventional Hydroponic Solution	Three-Level Modules
Variable costs	22,680	69,660
Substrate sacks	16,200	48,600
Strawberry plants	6480	21,060
Fixed cost		
Hydroponic system	160,200	337,500
Total implementation cost	182,880	407,160
Total implementation cost per plant	28.22	19.33

Finally, Figures 10 and 11 show the images and provide further details of the pilot.

**Figure 10.** Drip irrigation.



Figure 11. LED lighting.

4. Conclusions

Having developed and tested the utility model, it can be affirmed that this innovation increases plant density and achieves a lower unit cost per plant.

The advantages provided by the pilot are: the linear square meters of the cultivated space and the number of plants grown per linear square meter are tripled, while the system is easy to install, easy to handle, makes for easy fruit picking, and enables the user great versatility to modify the structure according to the type of crop.

However, the built structure was overly heavy, as it was made of galvanized iron. Furthermore, one of the prototypes had leaky gutters (built to save weight) which caused the drainage water to run down onto the lower-level plants.

The improvements proposed for the next TRL are: to use lighter and cheaper materials such as aluminum and PVC, to design a drip irrigation system integrated into the structure itself by a quick connection, to develop a thinner and narrower structure, and to test LED light strips with other mixtures of colors such as 10:1 and 19:1.

Adopting these recommendations will help to optimize the system and increase the final yield compared to the commercial and conventional hydroponic systems.

In conclusion, I deployed a modular and low-cost innovative solution suitable for small-scale farmers and citizens, an innovation that could offer new opportunities for job creation, particularly for young or small-scale growers. The results of this study provide information to be used as a reference for managers, trainers, and growers, as well as innovators.

5. Patents

The information used for the experimental analysis is protected under Spanish Law (Utility model Number: ES 1 242 949 U).

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The information used for the experimental analysis is protected under Spanish Law (Utility model Number: ES 1 242 949 U).

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Conflicts of Interest: The author declares no conflict of interest.

References

1. United Nations, Department of Social Affairs. World Population Prospects. Available online: <https://www.un.org/development/desa/en/news/population/world-population-prospects-2019.html> (accessed on 15 June 2021).
2. FAO. *Regional Overview of Food Security and Nutrition in Europe and Central Asia 2019. Structural Transformations of Agriculture for Improved Food Security, Nutrition and Environment*; FAO: Budapest, Hungary, 2019; ISBN 978-92-5-132000-6.
3. European Environment Agency. Soil, Land and Climate Change. Available online: <https://www.eea.europa.eu/signals/signals-2019-content-list/articles/soil-land-and-climate-change> (accessed on 11 June 2021).
4. FAO Plant Production and Protection Division (AGP). Implementing the Save and Grow Approach. Building the Basis for Sustainable and Climate Resilient Cropping Systems. Available online: <http://www.fao.org/sustainable-agricultural-mechanization/strategies/save-and-grow/en/> (accessed on 15 June 2021).
5. European Environment Agency. Available online: <https://www.eea.europa.eu/data-and-maps/indicators/use-of-freshwater-resources-3/assessment-4> (accessed on 15 June 2021).
6. Khokhar, T. Chart: Globally, 70% of Freshwater Is Used for Agriculture. 2017. Available online: <https://blogs.worldbank.org/opendata/chart-globally-70-freshwater-used-agriculture> (accessed on 7 March 2021).
7. EUROSTAT. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_mineral_fertiliser_consumption#Analysis_at_EU_level (accessed on 11 June 2021).
8. EUROSTAT. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_consumption_of_pesticides#Analysis_at_EU_and_country_level (accessed on 11 June 2021).
9. Avgoustaki, D.D.; Xydis, G. Indoor vertical farming in the urban nexus context: Business growth and resource savings. *Sustainability* **2020**, *12*, 1965. [CrossRef]
10. Stein, E.W. The transformative environmental effects large-scale indoor farming may have on air, water and soil. *Air Soil Water Res.* **2021**, *14*, 1–8. [CrossRef]
11. Kalantari, F.; Tahir, O.M.; Lahijani, A.; Kalantari, S. A review of vertical farming technology: A guide for implementation of building integrated agriculture in cities. *Adv. Eng. Forum* **2017**, *24*, 76–91. [CrossRef]
12. De Anda, J.; Shear, H. Potential of Vertical Hydroponic Agriculture in Mexico. *Sustainability* **2017**, *9*, 140. [CrossRef]
13. Butturini, M.; Marcelis, L.F.M. Vertical Farming in Europe: Present Status and Outlook. In *Plant Factory—An Indoor Vertical Farming System for Efficient Quality Food Production*, 2nd ed.; Kozai, T., Niu, G., Takagaki, M., Eds.; Academic Press—Elsevier: Cambridge, MA, USA, 2020; pp. 77–91. [CrossRef]
14. Melkonyan, A.; Gruchmann, T.; Lohmar, F.; Kamath, V.; Spinler, S. Sustainability assessment of last-mile logistics and distribution strategies: The case of local food networks. *Int. J. Prod. Econ.* **2020**, *228*, 107746. [CrossRef]
15. Sitaker, M.; Kolodinsky, J.; Wang, W.; Chase, L.C.; Kim, J.V.S.; Smith, D.; Estrin, H.; Vlaanderen, Z.V.; Greco, L. Evaluation of Farm Fresh Food Boxes: A Hybrid Alternative Food Network Market Innovation. *Sustainability* **2020**, *12*, 10406. [CrossRef]
16. Jia, S. Local food campaign in a globalization context: A systematic review. *Sustainability* **2021**, *13*, 7487. [CrossRef]
17. Zhang, H.; Asutosh, A.; Hu, W. Implementing Vertical farming at university scale to promote sustainable communities: A feasibility analysis. *Sustainability* **2018**, *10*, 4429. [CrossRef]
18. Al-Kodmany, K. The vertical farm: A review of developments and implications for the vertical city. *Buildings* **2018**, *8*, 24. [CrossRef]
19. European Commission. Young Farmers in the EU—Structural and Economic Characteristics. Available online: https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/agri-farm-economics-brief-15_en.pdf (accessed on 27 February 2021).
20. Kalantari, F.; Mohd, O.; Akbari, R.; Fatemi, E. Opportunities and challenges in sustainability of vertical farming: A review. *J. Landsc. Ecol.* **2017**, *11*, 35–60. [CrossRef]
21. Resh, H.M. *Hydroponic Food Production: A Definitive Guidebook for the Advanced Home Gardener and the Commercial Hydroponic Grower*; CRC Press: Boca Raton, FL, USA, 2016; ISBN 1439878676.
22. Baras, T. *DIY Hydroponic Gardens. How to Design and Build an Inexpensive System for Growing Plants in Water*; Quarto Publishing Group: Minneapolis, MN, USA, 2018; ISBN 9780760357590.
23. We Are Transforming Agriculture. Available online: <https://aerofarms.com/> (accessed on 16 July 2021).
24. Zero Pesticides. Just Picked. Craveable Flavor. Available online: <https://www.plenty.ag/> (accessed on 16 July 2021).
25. What Grows Here Changes Everything. Available online: <https://boweryfarming.com/> (accessed on 16 July 2021).
26. Rius-Ruiz, F.X.; Andrade, F.J.; Riu, J.; Rius, F.X. Computer-operated analytical platform for the determination of nutrients in hydroponic systems. *Food Chem.* **2014**, *147*, 92–97. [CrossRef] [PubMed]
27. Ibayashi, H.; Kaneda, Y.; Imahara, J.; Oishi, N.; Kuroda, M.; Mineno, H. A reliable wireless control system for tomato hydroponics. *Sensors* **2016**, *16*, 644. [CrossRef] [PubMed]
28. Montoya, A.; Obando, F.; Morales, J.; Vargas, G. Automatic aeroponic irrigation system based on arduino's platform. *J. Phys. Conf. Ser.* **2017**, *850*, 012003. [CrossRef]
29. Eridani, D.; Wardhani, O.; Widiyanto, E.D. Designing and implementing the arduino-based nutrition feeding automation system of a prototype scaled Nutrient Film Technique (NFT) hydroponics using Total Dissolved Solids (TDS) sensor. In Proceedings of the 2017 4th International Conference on Information Technology, Computer and Electrical Engineering ICITACEE 2017, Semarang, Indonesia, 18–19 October 2017; pp. 170–175.

30. Ruengittinun, S.; Phongsamsuan, S.; Sureeratanakorn, P. Applied Internet of Thing for Smart Hydroponic Farming Ecosystem (HFE). In Proceedings of the Ubi-Media 2017: The 10th International Conference on Ubi-media Computing and Workshops, Pattaya, Thailand, 1–4 August 2017; pp. 1–4.
31. Palande, V.; Zaheer, A.; George, K. Fully automated hydroponic system for indoor plant growth. *Procedia Comput. Sci.* **2018**, *129*, 482–488. [CrossRef]
32. Tagle, S.; Benoza, H.; Pena, R.; Oblea, A. Development of an indoor hydroponic tower for urban farming. In Proceedings of the 6th DLSU International Conference on Innovation and Technology Fair, Manila, Philippines, 22–23 November 2018; pp. 1–7.
33. Marques, G.; Aleixo, D.; Pitarma, R. Enhanced hydroponic agriculture environmental monitoring: An internet of things approach. In Proceedings of the International Conference on Computational Science, Faro, Portugal, 12–14 June 2019; pp. 658–669.
34. World Intellectual Property. Utility Models. Available online: https://www.wipo.int/patents/en/topics/utility_models.html (accessed on 20 September 2021).
35. Martínez, R.; Héctor, A.L. Double Vertical Hanging Unit, in the Form of Pouches, for Hydroponic Plant Cultivation, Panel of Double Vertical Hanging Unit, in Pouch Form, and Greenhouse Structure. EP 2 904 894 A1, 4 October 2013.
36. DeMitchell, M.; Tarzian, M. Vertical Hydroponic System. U.S. Patent 2011/0067301 A1, 24 March 2011.
37. Lin, P. Vertical Planting Apparatus. U.S. Patent 2012/0066972 A1, 31 January 2011.
38. Bryan, M. Hydroponic Plant Cultivating Apparatus. U.S. Patent 7,005,282 B2, 6 June 2006.
39. Borrero, J.D.; Fernández, G. Sistema Modular para Cultivo Hidropónico o Aeropónico. Utility Model No. ES 1 242 949 U, 6 March 2020.
40. Barta, D.J.; Tibbitts, T.W.; Bula, R.J.; Morrow, R.C. Evaluation of Light Emitting Diode Characteristics for a Space-based Plant Irradiation Source. *Adv Space Res.* **1992**, *12*, 141–149. [CrossRef]
41. Tennessen, D.J.; Singsaas, E.L.; Sharkey, T.D. Light-emitting diodes as a light source for photosynthesis research. *Photosynth. Res.* **1994**, *39*, 85–92. [CrossRef]
42. Krames, M.R.; Shchekin, O.B.; Mueller-Mach, R.; Mueller, G.O.; Zhou, L.; Harbers, G.; George Craford, M. Status and future of high-power light-emitting diodes for solid-state lighting. *J. Disp. Technol.* **2007**, *3*, 160–175. [CrossRef]
43. Trotter, M.; Whitehead, D.; Pinkney, J. The photochemical reflectance index as a measure of photosynthetic light use efficiency for plants with varying foliar nitrogen contents. *Int. J. Remote Sens.* **2002**, *23*, 1207–1212. [CrossRef]
44. Naznin, M.T.; Lefsrud, M.; Gravel, V.; Hao, X. Using different ratios of red and blue LEDs to improve the growth of strawberry plants. *Acta Hort.* **2016**, *1134*, 125–130. [CrossRef]
45. Hanenberg, M.A.A.; Janse, J.; Verkerke, W. LED light to improve strawberry flavour, quality and production. *Acta Hort.* **2016**, *1137*, 207–212. [CrossRef]
46. Gautier, H.; Massot, C.; Stevens, R.; Serino, S.; Genard, M. Regulation of tomato fruit ascorbate content is more highly dependent on fruit irradiance than leaf irradiance. *Ann. Bot.* **2008**, *103*, 495–504. [CrossRef] [PubMed]
47. Mochizuki, Y.; Sekiguchi, S.; Horiuchi, N.; Aung, T.; Ogiwara, I. photosynthetic characteristics of individual strawberry (*Fragaria × ananassa* Duch.) leaves under short-distance lightning with blue, green, and red LED lights. *HortScience* **2019**, *54*, 452–458. [CrossRef]
48. EPDATA. Available online: <https://www.epdata.es/> (accessed on 16 July 2021).
49. Mankins, J.C. Technology readiness assessments: A retrospective. *Acta Astronaut.* **2009**, *65*, 1216–1223. [CrossRef]
50. Héder, M. From NASA to EU: The Evolution of the TRL Scale in Public Sector Innovation. *Innov. J.* **2017**, *22*, 1–23.
51. U.S. Department of Energy. *Department of Energy Technology Readiness Assessment Guide*; U.S. Department of Energy: Washington, DC, USA, 2009.
52. European Space Agency. *Technology Readiness Levels Handbook for Space Applications*; European Space Agency: Paris, France, 2008; TEC-SHS/5551/MG/ap.
53. ISO. Available online: <https://www.iso.org/standard/56064.html> (accessed on 16 July 2021).
54. European Commission. Technology Readiness Levels (TRL). Extract from Part 19—Commission Decision C(2014)4995. Available online: <https://ec.europa.eu> (accessed on 16 July 2021).
55. Sauser, B.; Verma, D.; Ramirez-Marquez, J.; Gove, R. A Systems Approach to Expanding the Technology Readiness Level within Defense Acquisition. *Int. J. Def. Acquis. Manag.* **2008**, *1*, 39–58.
56. Zipgrow. 2021. Available online: <https://zipgrow.com/commercial-grower-survey/> (accessed on 16 July 2021).