

ADJUSTABLE LAMPSHADE-TYPE REFLECTOR FOR OPTIMISING LIGHT DISTRIBUTION IN INDOOR FARMING

FIELD OF INVENTION

- 5 The present invention relates broadly to an adjustable lampshade-type reflector and a method of illuminating an indoor farm rack, in particular to an adjustable lampshade-type reflector for optimising light distribution in indoor farming.

BACKGROUND

- 10 Indoor farms are gradually becoming more popular due to the ability to grow more crops per unit area compared to outdoor farms, and the ability to provide continuous and steady artificial lighting instead of relying on sunlight which fluctuates according to cloud cover and season. Indoor farm racks contain multiple shelves arranged in a vertical manner, which maximizes space utilization in all three dimensions, and therefore dramatically increases productivity of the indoor farm. Artificial light sources, consisting typically of fluorescent or LED lights, are placed directly on top of each shelf. However, typical designs for indoor farm racks do not consider the issue of light distribution along the shelf. A significant amount of light rays emitted by the artificial light sources installed at the margins of the racks is lost to the environment, rather than being directed to the shelf. Even light rays that originate from lighting sources located at the center directly above the rack may also be lost, because a majority of these light sources emit their rays in a wide angle manner, such as 120° of Lambertian type LED chips, and 360° of fluorescent lamp. This loss may result in energy wastage, and consequently increase the cost of plant cultivation. A possible solution is to redirect such stray light rays towards the desired direction by using reflectors that are arranged in a lampshade configuration.

- Lampshade-type reflectors are essential auxiliary devices that are connected to light sources to focus light energy onto a desired area. For decades, typical lampshade-type reflectors have comprised reflective boards with fixed shapes and angles which are designed to complement a particular light source, which would limit the application of such reflectors (Armstrong, 1978; Michaloski, 1991). In response to this inflexibility, lampshade-type reflectors with adjustable parts have been proposed in recent decades (Lee, 1987; Cronk, 2000; Chelf & Nigel, 2002; Cronk, 2007; Keen, 2011; Dumont, 2013). However, these adjustable designs may still be unable to cater to new light sources, especially, for indoor farm racks, wherein the configuration of light sources on the shelf may be varied from time to time, depending on the types of light sources required.. US 1978/4,078,169 depicted an apparatus for promoting plant growth using artificial light, designed to direct the majority of the light rays emitted by the light source onto a light delivery plane in a uniform manner. This apparatus, called the reflector, was designed as a regular shape that could provide over a 60° included angle of light rays along its

length, to the plants (Armstrong, 1978). Another similar apparatus for the reflective intention was also presented in US 1991/5,040,329. The novel feature of this apparatus was that it was designed for multiple light sources instead, whereas the earlier mentioned apparatus was designed for a single light source. However, its configuration design is consistent with the
5 earlier invention by virtue of the design of a regular shape which provides fixed light distribution along the light delivery plane depending on the number of light sources applied (Michaloski, 1991). Both reflectors exhibited the basic characteristic of light reflective function by setting fixed included angles of reflective boards to cater to specific light source assembly. Their drawback is apparent as the included angle for reflection purpose is fixed, which angle
10 applied may not achieve the optimal reflective effect onto the shelf of the indoor farm racks.

For the concept of adjustable lampshade-type reflector, there are diverse designs and configurations that have been presented through the decades (Lee, 1987; Cronk, 2000; Chelf & Nigel, 2002; Cronk, 2007; Keen, 2011; Dumont, 2013). For example, an adjustable optical reflector for fluorescent lamps under US patent 1987/4,669,033 was introduced in the 80s, in
15 which the approach to regulate various included angles of reflective board was through using malleable wires/strips to secure the both ends of a web-shape reflector to ensure that its different facets might be oriented to various focusing directions, where a plurality of its facets was made in a hingedly-joined manner (Lee, 1987). Another similar lampshade-type invention (US 2013/0343048 A1) was disclosed recently, which also used planar reflective boards for
20 horticultural use (Dumont, 2013). The structure of the reflector apparatus is initially composed of a first reflector member located above the light source along the first side, followed by downwardly extending to the second reflector member along the second side and then by further downwardly towards the third one along the third side. To perform the adjustment function, each of the reflector members is individually adjustable to increase or decrease their
25 respective angles with respect to each other. Metal is suggested as the material for manufacturing this reflector, and it was shown that the included angle of the reflective board in this invention could be adjusted by means of the flexibility of metal that allows the metal to be folded at any angle, thereby obtaining different reflective effects (Dumont, 2013).

Apart from planar reflective boards, curved reflective boards have been used. For instance, an
30 adjustable-curvature lamp reflector under US patent 2000/6,053,624 was disclosed in 2000, whose structure included an adjustable double parabolic reflective board that consisted of two singular parabolic parts hingedly-joined together. A flexible double parabolic shape was thus formed in this reflective board to generate various included angles of reflection through tightening or loosening the adjustable chain retainers attached to the both ends of the board
35 (Cronk, 2000). This specific structure of reflector was further modified in 2007 (US 2007/7,156,539 B2) regarding the manner of connection between the two arched configurations of reflective boards by positioning them to either side of a spine like two pages of a book and through forming an obtuse angle to achieve better regulation of the reflective board (Cronk, 2007). As described, such invention was commonly applied in a singular light source such as
40 a long LED tube or a fluorescent lamp. This conclusion is further supported by another invention of a similar adjustable reflector (US patent 2002/6,382,817 B1) which was

introduced to the common lighting fixture by mounting two arched shapes of reflective boards directly on both sides of the light source, wherein a locking element was simultaneously employed within for locking both boards at different positions to form various included angles for reflective purpose (Chelf & Nigel, 2002).

- 5 Sometimes the curvature of whole reflective board in a reflector can be constituted by adopting multi pieces of curved boards. This could be seen from a high-intensity light reflector apparatus with air-cooled function under US patent 2011/7,954,982 B2, which was employed in indoor horticultural applications (Keen, 2011). This invention was claimed to include a concave main body assembly connected by hingedly-segmented longitudinal members for producing uniform
10 light distribution along the light delivery plane for plant growth. The regulation of the included angle of reflective board in this concave main body assembly may be achieved by increasing or decreasing the number of hingedly-segmented longitudinal members. Such curved design was claimed by the inventor to be superior to other angled designs due to improved photometric properties of the reflector. Another advantage claimed by the inventor of was that this apparatus
15 possesses an adjustable socket holder of light source which is connected to the main body of reflector at the horseshoe-curve apex that allows any specification of light source to be applied within (Keen, 2011).

- Although many prior related inventions have been introduced through the last decades, there are several disadvantages which are yet to be overcome. Firstly, most of the inventions only
20 focused on the reflection of a singular light source. Secondly, the majority of reflector-related inventions are only strictly adaptable to the specific configuration of light source it was designed for, which significantly limits the application of such reflectors under different circumstances. Thirdly, all the prior inventions seem to consider only the reflection issue along the main body of a light source.
- 25 Embodiments of the present invention seek to address at least one of the above problems.

SUMMARY

In accordance with a first aspect of the present invention, there is provided an adjustable lampshade-type reflector comprising:

- 30 a main frame having opposing first and second length-sides and opposing first and second width-sides;
- first and second reflective boards pivotably coupled to the main frame at the first and second width-sides of the main frame, respectively; and
- third and fourth reflective boards pivotably coupled to the main frame at the first and second
35 length-sides of the main frame, respectively;

wherein a distance between respective pivot axes of the first and second reflective boards is adjustable for adjusting a reflective region of the adjustable lampshade-type reflector.

In accordance with a first aspect of the present invention, there is provided a method of illuminating an indoor farm rack using the adjustable lampshade-type reflector of the first aspect.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will be better understood and readily apparent to one of ordinary skill in the art from the following written description, by way of example only, and in conjunction with the drawings, in which:

FIG. 1 is a three-dimensional schematic view of an adjustable lampshade-type reflector according to an example embodiment.

FIG. 2 is a three-dimensional schematic view of the adjustable lampshade-type reflector according to an example embodiment showing the movements of the two movable reflector racks along the tracks located at the main reflector frame.

FIG. 3 is the top view of the adjustable lampshade-type reflector according to an example embodiment showing the movements of the two movable reflector racks along the tracks located at the main reflector frame.

FIG. 4 is the front, width-side view, partly in cross-section of the adjustable lampshade-type reflector according to an example embodiment.

FIG. 5 is the left length-side view of the adjustable lampshade-type reflector according to an example embodiment.

FIG. 6 is a three-dimensional schematic view of the adjustable lampshade-type reflector according to an example embodiment with 5 LED tubes placed inside, illustrating its application in an indoor farm rack lighting system.

FIG. 7 is a three-dimensional schematic view of the adjustable lampshade-type reflector according to an example embodiment with 5 shorter LED tubes placed inside when decreasing the distance between two width-side boards to produce an appropriate reflective region, illustrating its advantages for application in an indoor farm rack lighting system.

FIG. 8 is the front width-side view of the adjustable lampshade-type reflector according to an example embodiment installed at the indoor farm rack.

FIG. 9 is the left length-side view of the adjustable lampshade-type reflector according to an example embodiment installed at the indoor farm rack.

FIG. 10(A) shows erected and FIG.10(B) inverted schematic views of the three-dimensional simulative model of an adjustable lampshade-type reflector according to an example embodiment designed by the light simulative software TracePro.

FIG. 10(C) shows a schematic width-side view of the adjustable lampshade-type reflector according to an example embodiment illustrating the definition of the included angle of reflective board.

FIG. 11(A) shows the arrangement of germination trays on the shelf of indoor farm rack.

FIG. 11(B)-(H) show the sketchy screening of the appropriate included angles for the optimization of simulated light intensity distribution along the rack shelf with the application of an adjustable lampshade-type reflector according to an example embodiment, specifically the screened included angles are (B) 90°, (C) 75°, (D) 60°, (E) 45°, (F) 30°, (G) 15° and (H) 0°. The width of reflective board is set as 10 cm. The scale unit on the figures is cm.

FIG. 12 shows the fine screening of the appropriate included angles for the optimization of simulated light intensity distribution along the rack shelf with the application of an adjustable lampshade-type reflector according to an example embodiment. The screened included angles are (A) 24°, (B) 25°, (C) 26°, (D) 27°, (E) 28°, (F) 29°, (G) 30°, (H) 31°, (I) 32°, (J) 33°, (K) 34° and (L) 35°. The width of reflective board is set as 10 cm. The scale unit on the figure is cm.

FIG. 13 show the screening of the appropriate width of reflective board under the optimal included angle (32°) for the optimization of simulated light intensity distribution along the rack shelf with the application of an adjustable lampshade-type reflector according to an example embodiment. The screened widths are (A) 13 cm, (B) 12 cm, (C) 11 cm, (D) 10 cm, (E) 9 cm, (F) 8 cm, (G) 7 cm and (H) 6 cm. The scale unit on the figure is cm.

FIG. 14 shows the heat maps of (A) temperature, (B) relative humidity, (C) light intensity (380 - 780 nm) and (D) PAR Energy (400 - 700 nm) along the shelf of Indoor Farm Rack under different included angles of an adjustable lampshade-type reflector according to an example embodiment. PAR, photosynthetically active radiation.

FIG. 15 shows the comparisons of (A) temperature, (B) relative humidity, (C) light intensity (380 - 780 nm) and (D) PAR energy (400 - 700 nm) in different shelf zones of indoor farm rack under different included angles of an adjustable lampshade-type reflector according to an example embodiment, as well as available shelf area percentages within different deviations of light intensity distribution under (E) light-intensity-based and (F) PAR-energy-based manners.

FIG. 16 shows the comparison on the fresh weights of (A) seedling, (B) shoot, (C) root and (D) total leaf, as well as (E) FW-based harvest index and (F) FW-based shoot root ratio of choy sum grown in Indoor Farm Rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment.

FIG. 17 shows the comparison on the dry weights of (A) seedling, (B) shoot, (C) root and (D) total leaf, as well as (E) DW-based harvest index and (F) DW-based shoot root ratio of choy

sum grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment.

FIG. 18 shows the comparisons on the (A) total leaf area, (B) hypocotyl length, (C) hypocotyl diameter and (D) root length of choy sum grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment

FIG. 19 shows the comparisons on the moistures of (A) seedling, (B) shoot and (C) root, as well as (D) photosynthetic efficiency of choy sum grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment.

FIG. 20 shows the comparison on the concentrations of (A) total chlorophylls, (B) chlorophyll *a*, (C) chlorophyll *b* and (D) total carotenoids, as well as (E) chlorophyll *a/b* ratio and (F) total carotenoids/chlorophyll *a* ratio of choy sum shoots grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment.

FIG. 21 shows the comparison on the (A) total phenolic content and (B) DPPH of choy sum shoots grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment.

FIG. 22 shows the comparison on the light distributions along the shelf of indoor farm rack under different specifications of 5-LED-tube panel with or without the application of adjustable lampshade-type reflector according to an example embodiment. (A) 96-chip of LED tubes with reflector; (B) 96-chip of LED tubes without reflector; (C) 72-chip of LED tubes with reflector; (D) 72-chip of LED tubes without reflector; (E) 48-chip of LED tubes with reflector; (F) 48-chip of LED tubes without reflector; (G) 24-chip of LED tubes with reflector; (H) 24-chip of LED tubes without reflector.

FIG. 23 shows the cultivation of choy sum seedlings with the application of the adjustable lampshade-type reflector. (A) The position of the 200 choy sum seedlings along the working shelf of indoor farm rack. (B) The definition of five zones on the working shelf for cultivating choy sum seedlings. (C) The outer view of the reflector. (D) The inner front view of the reflector and seedlings. (E) The inner side view of the reflector and seedlings.

DETAILED DESCRIPTION

Embodiments of the present invention provide an adjustable lampshade-type reflector that can reflect light rays that stray away from the shelf of an indoor farm rack, whereby the light source is placed directly above the shelf of the rack, hence preventing the loss of stray light to the environment. Additionally, embodiments of the present invention can be adjusted to accommodate light sources, such as light tubes, of various dimensions. This maximizes the light distribution on the shelf and increases the light available to plant seedlings that are cultivated on these shelves. The result is enhanced productivity of plant seedlings, more efficient use of electricity and space, and therefore higher profitability due to increased yields.

One example embodiment of the present invention generally comprises a main frame and four reflective boards which are hung via ropes connected to regulative shanks, and whose included angles can be adjusted for maximizing indoor plant seedling productivity through optimising the available light distribution along the shelf of Indoor Farm Rack. The main reflector frame additionally provides tracks for bearing and allowing two movable reflector racks to move back and forward along it for the purpose of making the reflector adaptable to different specifications of lamps such as LED tubes or fluorescent lamps, according to an example embodiment. To create various included angles of the reflective boards for gaining the optimal reflective effect, the four reflective boards are hung via their respective adjusting ropes connected to the regulative shanks. The regulative procedure is therefore achieved through controlling the lengths of ropes to facilitate the reflective boards to hang at desired angles. Advantageously, embodiments of the present invention can optimise the available light distribution area along the shelf of Indoor Farm Rack, thereby enhancing the light conversion efficiency, decreasing the cost of plant cultivation and maximising the production of both biomass and metabolites of plant seedlings.

In one example embodiment, the reflective boards can be adjusted with an included angle that ranges from 0° to 90° . This allows for achieving optimal light distribution on the shelf of indoor farm rack. In addition, the design according to example embodiments allows for different types of light sources/tubes of various specifications to be applied to the Indoor Farm Rack. In doing so, embodiments of the present invention can dramatically enhance the uniform light distribution area on Indoor Farm Racks of a plant factory and simultaneously save electrical energy used for plant cultivation, leading to a significant reduction in the cost of plant/seedling production.

Embodiments of the present invention can provide an economical adjustable lampshade-type reflector that can be conveniently installed on an indoor farm rack. It can be used to improve light distribution throughout the rack, leading to increased plant productivity through retrieving the lost light energy from stray light. In addition, the inclusion of four gaps at the four corners according to an example embodiment of the present invention can reduce heat accumulation by maintaining ventilation along the shelf.

In one example embodiment, an adjustable lampshade-type reflector for improving available light distribution in indoor farm racks is to be employed by firstly confirming the specification and number of light tubes applied in the shelf of the indoor farm rack, and secondly setting, for example, 7 to 13 cm for the width range of the reflective boards, whose exact width is decided by the actual configuration of the indoor farm rack, and thirdly installing the validated reflective boards onto the rack followed by adjusting them to the desired included angle. Alternatively, the adjustable lampshade-type reflector according to an example embodiment can be used by only adjusting the included angle of the reflective board to achieve its optimal fixed-width reflective boards light distribution effect, verifiable by utilising a light meter. By virtue of the adjustable lampshade-type reflector according to example embodiment, the uniform light distribution area on the shelf of indoor farm racks can be significantly enlarged and the light intensity at both edges of a shelf can thereby be remarkably enhanced.

FIG. 1 is a three-dimensional schematic view of an adjustable lampshade-type reflector 100 according to an example embodiment. Four reflective boards e.g. 102, 104 are attached via hinges e.g. 10 to a frame 3, whereby their angles can be adjusted by pivoting around pivot axes defined by the hinges e.g. 10 and held in position. The main frame 3 comprises tracks e.g. 7 that allow for the movement of two reflector boards 102, 104 located at the width-sides of the main frame 3, in order to accommodate different lengths of light tubes adopted.

Specifically, the adjustable lampshade-type reflector 100, whose purpose is to maximise the available light distribution on the shelf of an indoor farm rack by attaching four included-angle-adjustable reflective boards e.g. 102, 104 onto the track-equipped frame 3, is connected by six identical frame mounting legs e.g. 4 located at the four corners of the frame 3 and at both centers of a length-side of the frame 3 and then fastened under an upper shelf of an indoor farm rack, for example by using screws fitted through a hollow structure in the legs e.g. 4, which is for fixation purpose, to provide a reflective effect onto a lower shelf of the indoor farm rack, wherein the included angles of the four reflective boards e.g. 102, 104 can be flexibly adjusted to reach the optimal reflective effect through the adjusting ropes e.g. 6 connected to the regulative nut e.g. 2 and operated by the regulative shank e.g. 1. Two movable reflector racks 103, 105 at the width-sides of the frame 3, designed to move along the frame tracks e.g. 7 located on both length-sides of the frame 3, are responsible for attaining an appropriate reflective region according to the specifications and lengths of light tubes (not shown) applied. In other words, the adjustable lampshade-type reflector 100 can be mounted on the bottom of upper shelf 14 of the indoor farm rack (FIG. 8, 9) to direct otherwise straying light ray/energy emitted by the light tubes onto the lower shelf 15 of the indoor farm rack (FIG. 8, 9) as much as possible for the purpose of maximally offering light energy to support the growth of plant seedlings and avoiding light energy dissipating to the outer environment of the rack.

The adjustable lampshade-type reflector 100 in this example embodiment comprises four rectangular reflective boards, two length-side boards 106, 108 and two width-side boards 102, 104. The length-side reflective boards e.g. 108 are connected by respective attached hinges e.g. 109 that are further fastened to the main reflector frame 3 as well as by respective adjusting ropes e.g. 111 that are linked to each regulative nut e.g. 113 and regulative shank e.g. 115, to ensure that the included angles of the length-side reflective boards e.g. 108 can be freely adjusted at certain degrees, thereby accurately achieving the optimal angles of reflective effects based on the numbers of light tubes applied.

The width-side reflective boards e.g. 102, 104 are connected by respective attached hinges e.g. 10 that are further fastened to moveable reflector racks 103, 105 as well as by respective adjusting ropes e.g. 6 that are linked to each regulative nut e.g. 2 and regulative shank e.g. 1 on the moveable reflector rack e.g. 105, to ensure that the included angles of the width-side reflective boards 102, 104 can be freely adjusted at certain distances from each other and at certain degrees, thereby accurately achieving the optimal angles of reflective effects based on the numbers and lengths of light tubes applied.

In this embodiment, the reflective boards 102, 104, 106, 108 are made of highly reflective material like bright anodised aluminum to guarantee at least 80% of incident light rays emitting towards the outer environment of the rack to be directed back to the shelf. For safety reason, a glass mirror, although its reflectivity can achieve above 95%, is not preferred for manufacturing the reflective boards as it is not only heavy to increase the burden of the whole reflector as well as indoor farm rack, but also fragile and sharp while accidentally broken to easily do harm to the operator.

Bright anodizing of aluminum is characterised as the improved aluminum alloy in an example embodiment that can provide high reflectance similar to that of glass mirror whereas it is light enough to reduce the burden of the reflector frame 3 due to its high metal ductility for producing thinner reflective boards. Furthermore, bright anodizing of aluminum exhibits high tenacity followed by low fragility, which means that it is not as fragile as glass mirror, while its anodic layer is non-conductive, suggesting that it is a fine insulator to be kept insulated and safe to the operators of indoor farms while installed within the rack together with the light tubes which may present certain risk of electric leakage.

The width, W, of the reflective boards 102, 104, 106, 108 is an important aspect that should be considered and preferably optimised, for the reason that too small a width may decrease the reflective effect of the reflector 100 while too large a width may influence the ventilation and heat dissipation in the indoor farm rack. Furthermore, the width of the reflective boards 102, 104, 106, 108 is also subject to the actual configuration of the indoor farm rack due to the variation of storey heights from rack to rack. In order to obtain a reasonable height for guiding the manufacture of reflective boards according to example embodiments, not by limitation, a width range W of 7 cm to 13 cm is thus proposed to fulfill different configurations and storey heights (normally from 14 cm to 26 cm) of indoor farm racks. However, the actual height of reflective board 8 depends on the actual rack applied.

FIG. 2 is a three-dimensional schematic view of the adjustable lampshade-type reflector 100 showing the movements of the two movable reflector racks 103, 105 along the tracks 7 located at the main reflector frame 3.

Specifically, in this example embodiment, the intention is to flexibly achieve the ideal reflective range because not all light tubes applied in the indoor farm racks have identical specifications, meaning that the lengths of various light tubes are different. Therefore, the length-side dimension of the reflective region defined by the reflective boards 102, 104, 106, 108 on the reflector frame 3 for installing the light tubes is advantageously not fixed in the example embodiments. Instead, in the example embodiments, an appropriate reflective region can be adjusted by designing the movable reflector racks 103, 105 on both width-sides of the reflector frame 3 to reach various optimal reflection effects by moving the width-side reflective boards 102, 104 while allowing the application of different standards of light tubes in the indoor farm rack.

In this example embodiment, the maximum length of the reflector frame 3 is determined by the actual length of the upper shelf 14 of the indoor farm rack (FIG. 8, 9) plus the widths of both

movable reflector racks 103, 105. It is noted that multiple adjustable lampshade-type reflectors 100 can be used along the length of the upper shelf in different example embodiments.

5 The maximum width of the reflector frame 3 is determined by the actual width of the upper shelf minus twice the diameter of the supporting legs e.g. 4, to allow that the reflector frame 3 can be installed underneath the upper shelf. The lengths of both length-side reflective boards 106, 108 should be the same as the length of the upper shelf of the indoor farm rack minus twice the diameter of the mounting legs e.g. 4, while the lengths of both width-side reflective boards 102, 104 are the same as those of the two movable reflector racks 103, 105. This setting is to preferably ensure that the included angle of reflective boards can be adjusted from 0° (i.e. vertical orientation) to 90° (i.e. horizontal orientation).
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The material used for fabricating the frame 3 of the reflector 100 in this example embodiment is aluminum alloy that is low in density and approximately one third of that of stainless steel, and high in strength similar to high-quality steel, and cheaper in cost, as compared to that of the reflector being made by stainless steel under the same size in different embodiments.

15 In the example embodiment, a distance between respective pivot axes of the width-side reflective boards 102, 104, defined by the hinges e.g. 10, is adjustable for adjusting a reflective region of the adjustable lampshade-type reflector 100. In this embodiment, while moving the movable reflector racks 103, 105 supported by the frame tracks 7 to adjust the reflective region, they can be slid such that the distance between the two movable reflector racks 103, 105, and hence the distance between respective pivot axes of the width-side reflective boards 102, 104, can be regulated in order to achieve the ideal reflective region depending on the lengths of the light tube applied.
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FIG. 3 is the top view of the adjustable lampshade-type reflector 100 showing the movements of the two movable reflector racks 103, 105 along the tracks 7 located at the main reflector frame 3.
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In the top view of the adjustable lampshade-type reflector 100 in FIG. 3, in addition to illustrating the motion trails of the movable reflector racks 103, 105 along the reflector frame tracks 7, also illustrated is the advantageous design of gaps e.g. 300 in the lampshade-type reflector 100 according to an example embodiment to alleviate the issues on ventilation and heat dissipation within the space of the Indoor Farm Rack.
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Specifically, the movements of two moving reflector racks 103, 105 at any time may not affect them to keep parallel to the movable reflector racks 103, 105 at their original places located at both width-sides of the frame 3, which means that the intention for the regulation of the movable reflector racks 103, 105 is only to parallelly move them to create various rectangular reflective regions on the shelf of the indoor farm rack, according to the example embodiment. Furthermore, the design of frame tracks 7 preferably ensures that the movable reflector racks 103, 105 at any position of tracks 7 can still form an enclosed rectangular reflective region substantially without generating any connecting separation between two length-side reflective
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boards 106, 108 and the two width-side boards 102, 104 in the plane of the frame 3, even when the reflector racks 103, 105 are kept at the far ends of the frame tracks 7.

While viewing the adjustable lampshade-type reflector 100 from the top as shown in FIG. 3, it is noticed that the respective margins of the length-side reflective boards 106, 108 and the width-side reflective boards 102, 104 when projected into the plane of the frame 3 constitute a right angle, defining the gaps e.g. 300. This is to ensure that four gaps e.g. 300 can be formed at the four corners of the adjustable lampshade-type reflector 100 at all the included angles of the reflective boards 102, 104, 106, 108 except for 0° of included angle (i.e. when the boards 102, 104, 106, 108 are vertically oriented). Such design can preferably ensure the ventilation along the space of the indoor farm rack for the benefit of the plants, and for assisting in dissipating the heat accumulating in the indoor farm rack.

In other words, the rotational axes of the first, second, third and fourth reflective boards 102, 104, 106, 108 preferably define a rectangle at various different distances between the respective pivot axes of the first and second reflective boards, so as to provide gaps between edges of the first, second, third and fourth reflective boards 102, 104, 106, 108 when off-vertically oriented. This can improve ventilation in an indoor farm rack where the adjustable lampshade-type reflector is used and/or improve heat dissipation from a light source with which the adjustable lampshade-type reflector is used.

As will be appreciated by a person skilled in the art, photosynthesis of the plants is required to absorb CO₂ while releasing O₂ in the dark reaction phase, hence, a better ventilation environment may help to accelerate such photosynthetic process through providing more CO₂ to the plants and taking away O₂ at the same time. In contrast to the example embodiment described herein, the configuration of existing lampshade-type reflector may impede the circulation of air due to the obstruction of the enclosed reflective surfaces. The described example embodiment overcomes such drawback via reserving four gaps at the four corners of the lampshade-type reflector 100 to allow air passing through. It is noted that the existence of four gaps may not influence the reflective effect of the whole lampshade-type reflector 100 as light distribution at the corners of the lampshade-type reflector 100 is commonly weak and thus less light at these sites will be available to be reflected back to the shelf.

On the other hand, existing lampshade-type reflector may generate the problem of heat accumulation, by not only reflecting light, but also heat, both generated by the light tubes. Excessive heat accumulation in the space of indoor farm rack will result in increased temperature in this area, which may be unsuitable for the growth of seedling/plant. Therefore, the setting of four gaps in the described example embodiment of the present invention may ameliorate this problem by means of the maintained ventilation as mentioned above, to dissipate the heat accumulated in the space of indoor farm rack via guaranteed air circulation.

FIG. 4 is the front, width-length view, partly in cross-section of the adjustable lampshade-type reflector 100.

Specifically, the adjustable lampshade-type reflector 100 according to the example embodiment has the main reflector frame 3, which includes the frame tracks 7 for supporting both movable reflector racks e.g. 103 and for allowing them to be adjusted manually back and forth in order to obtain the best reflective region subject to the specification of light tubes applied and achieve the optimal effect of reflection. For such objective, the cross section of both frame tracks 7 is designed to have a right-angle groove shape. In this embodiment, the height of the outer edge e.g. 402 is designed higher than that of the inner edge 404 for firmly attaching both movable reflector racks e.g. 103 to the frame tracks 7. On the other hand, the height setting of the inner edge 404 is chosen for freely moving the movable reflector racks e.g. 103 without hindrance.

As drawn in FIG. 4, specifically the cross section of the frame tracks 7, the intersecting surface of both ends e.g. 406 of the movable reflector rack e.g. 103 attached along the frame tracks 7, is designed circular for reducing the friction and for easily moving the movable reflector racks e.g. 103. Between the end e.g. 406 and the main body of the movable reflector rack e.g. 103, there is a groove connection 408, which may allow the appropriate height of the inner edge 404 of the frame track 7 to fit in. The inner edge e.g. 404 along with outer edge e.g. 402, respectively, of the frame track 7 contribute to confine both of the movable reflector racks e.g. 103 only to move within the tracks.

It is noted that in a different embodiment, only one of the width-side reflective boards 102, 104 is moveable, for example by implementing only one moveable rack. In such an embodiment, the reflective region is still advantageously adjustable, albeit in a less flexible manner compared to the example embodiment described herein in detail.

FIG. 5 is the left length-side view of the adjustable lampshade-type reflector 100.

The adjustment and control of the included angle of the reflective board e.g. 108 may resort to the assistance of the adjusting rope e.g. 111 of reflective board e.g. 108. The material selected for manufacturing the adjusting rope e.g. 111 of reflective board e.g. 108 in this example embodiment is nylon as the property of this kind of material is tenacious, flexible and not easy to be broken, while in this example embodiment, the material adopted for reflective board e.g. 108 is thin bright anodizing of aluminum that is light enough to be fully supported by such nylon cord. For operating the adjusting function, the adjusting rope e.g. 111 of reflective board e.g. 108 is firstly tied to the hanging ring e.g. 9, which is located at the lower edge of the reflective board e.g. 108, followed by being connected and fastened to the regulative shank e.g. 115 that is attached to the regulative nut e.g. 113 and can be rotated for adjustment. Preferably, the regulative shank e.g. 115 and regulative nut e.g. 113 are designed so that the adjusting rope e.g. 111 can be held in place by frictional forces to set the desired length and hence angle of the reflective board e.g. 108, without requiring additional fasteners, in this embodiment. A screwdriver is used to rotate the regulative shank e.g. 115 for adjustment of the angle, according to an example embodiment.

FIG. 6 is a three-dimensional schematic view of the adjustable lampshade-type reflector 100 with 5 LED tubes placed inside, illustrating its application in an indoor farm rack lighting system.

Specifically, FIG. 6 depicts the three-dimensional schematic view of the combination of the adjustable lampshade-type reflector 100 according to the example embodiment and the light tube e.g. 11 panel in the indoor farm rack. The arrangement of the light tube e.g. 11 panel in the rack and the number of the light tubes e.g. 11 applied are typically subject to the width of the indoor farm rack. In order to acquire the optimal light distribution along the shelf, the light tubes e.g. 11 are arranged at regular intervals along the width of the upper shelf of the indoor farm rack as shown in FIG. 6.

As an example, if the width of the indoor farm rack is set as 60 cm which distance are suitable for accommodating five light tubes 11 in one example, or nine identical light tubes in another example, to generate different intensities of light on the shelf. As shown in FIG. 6, for example five light tubes e.g. 11 are parallelly arranged for installing on the bottom of the upper shelf of the indoor farm rack in a regular interval manner.

FIG. 7 is a three-dimensional schematic view of the adjustable lampshade-type reflector 100 with 5 shorter LED tubes e.g. 700 placed inside when decreasing the distance between two width-side boards 8 to produce an appropriate reflective region, illustrating its advantages for application in an indoor farm rack lighting system.

Specifically, FIG. 7 depicts the three-dimensional schematic view of the use of the adjustable lampshade-type reflector 100 according to the example embodiment with shorter light tubes e.g. 700 (compared to light tubes e.g. 11, see e.g. FIG. 6) panel in an indoor farm rack application, with the shortened distance between the adjusted two width-side boards 102, 104. In order to acquire the optimal light distribution along the shelf, the shorter light tubes e.g. 700 are typically parallelly arranged at regular intervals along the width of the upper shelf of indoor farm rack as shown in FIG. 7. It is noted again that multiple adjustable lampshade-type reflectors 100, one each for each panel of light tubes, can be used along the length of the upper shelf in different example embodiments.

FIG. 8 is the front width-side view of the adjustable lampshade-type reflector 100 installed at the indoor farm rack.

Specifically, the adjustable lampshade-type reflector 100 in accordance with the example embodiment is attached to the upper shelf 14 of indoor farm rack by using six frame mounting legs e.g. 800 located at the four corners of the frame 3 as well as the middle of the length-side of the frame 3 to install. The plane of the reflector frame 3 is typically parallel with that of the upper shelf 14 of the indoor farm rack. Furthermore, the plane of the upper-edges of the four reflective boards e.g. 102 typically overlap the LED light chips or lamp bulbs, indicated at numeral 12, rather than the upper-edges being disposed near the bottom of the LED light chips or lamp bulbs. This can preferably achieve the optimal reflective effect along the lower shelf

15 of the indoor farm rack where the germination tray 16 and the seedlings/plants 17 are located.

FIG. 9 is the left length-side view of the adjustable lampshade-type reflector 100 installed at the indoor farm rack.

- 5 Specifically, FIG. 9 illustrates that the regulative shanks e.g. 1 on the movable reflector racks e.g. 105 toward the light tubes e.g. 11 may be impeded by the dimensions of the upper shelf 14 of the Indoor Farm Rack. However, it has to be noted that this is not the major issue as the specification of the light tubes e.g. 11 length is typically not much shorter than that of the upper shelf 14 of Indoor Farm Rack, meaning that the movable reflector racks 105 just need to move
10 a small distance, yet this adjustment can preferably provide an optimal reflective region for various light source dimensions applied, such as light tubes of different lengths. Alternatively, the design/location of the adjusting mechanism can be varied in different example embodiments to allow movement beneath the upper shelf 14, for example when multiple adjustable lampshade-type reflectors are used along the length of the upper shelf in different
15 example embodiments.

- In the example embodiment described above with reference to Figures 1 to 9, an adjustable lampshade-type reflector for improving available light distribution in an indoor farm rack by means of the flexible regulations of the included angle of reflective board with the help of regulative shank and nut system, as well as the free adjustment of the reflective region by virtue
20 of the frame tracks is provided, in which the reflective boards are attached to the rectangular main frame of reflector by hinges, and which can be installed beneath an upper shelf of the indoor farm rack to reflect the light rays originally emitted out of the range of the indoor farm rack back and received by the lower shelf.

- Two long-side and two short-side reflective boards from four directions were attached to the rectangular main frame of reflector, which is equipped with two tracks as an entire entity, to offer a three-dimensional space for reflecting the light rays emitted by the light tube panel onto the received shelf, where two short-side rectangular reflective boards are particularly connected to both movable reflector racks that are responsible for moving their locations along the frame tracks, in order to achieve the appropriate reflective region subjected to the specifications of
25 light tubes applied, thereby maximally uniforming the light distribution along the shelf of Indoor Farm Rack.
30

The adjustable lampshade-type reflector according to the example embodiment described above further has two long-side and two short-side reflective boards that are rectangular in shape and are oppositely adhered onto the four sides of the rectangular main frame of reflector.

- 35 These four reflective boards are hung by the adjusting ropes of reflective boards, suggested to be made by nylon, to achieve certain optimal included angle by a set of manual regulative system, subjected to the specifications and arrangements of light tubes employed.

In the example embodiment described, each high-reflectance-material-made reflective board such as bright anodizing of aluminum is jointed to respective side of the reflector frame through using hinges, in which the hinges are provided so that the reflective board can be freely rotated.

5 Also, each high-reflectance-material-made reflective board is substantially seamlessly jointed to respective side of the reflector frame to maximally avoid light rays to be emitted from the gaps between the upper-edges of the reflective boards and the main frame and subsequently decrease the reflective effect.

10 In the described example embodiment, the two short-side reflective boards are substantially seamlessly connected to two movable reflector racks supported by the frame tracks, where both movable reflector racks can be smoothly moved back and forth in the defined range of the frame tracks.

Using aluminum alloy rather than stainless steel in the example embodiment is advantageous as the manufacturing material of the reflector main frame for reducing the manufacturing cost of the invention followed by decreasing the weight burden of the whole indoor farm rack.

15 In the example embodiment, the manual regulative system including the regulative shank, regulative nut, adjusting rope of reflective board and hanging rings attached to the reflective board, can preferably be operated smoothly, where the regulative shank can be freely rotated to ensure the accurate adjustment of the included angle of reflective board.

20 The regulative nuts are attached to the extended frame of the main frame in the example embodiment to form the hanging structure for included angle adjustment of reflective board, in which both long-side reflective boards are equipped with two sets of regulative systems to fully support the whole board while only one regulative system is used for each short-side one.

25 In the described example embodiment, the cross section of the frame tracks is designed to be grooved for firmly embracing and supporting both reflective boards within the frame to become an entirety.

30 The adjustable lampshade-type reflector of the example embodiment has at least six mounting legs applied in the main frame for firmly attaching the reflector to the upper shelf of the indoor farm rack, subject to the size of the whole reflector. As described above, the adjustable lampshade-type reflector of the example embodiment can improve available light distribution in the indoor farm rack through employing safe bright anodizing of aluminum as the reflective boards, utilizing suspension mode to achieve various included angles of reflective boards and using frame track manner for regulating the optimal reflective region.

35 The adjustable lampshade-type reflector according to example embodiments may be applied in all indoor farm racks of plant factory involving in the cultivation of plants, whether plant seedlings or high value-added commercial crops, for improving their biomass, by significantly increasing the available light distribution area along the shelf and also remarkably enhancing the light intensity received by the shelf. As is understood by a person skilled in the art, higher light intensity before light saturation point may produce higher plant biomass.

Also, the adjustable lampshade-type reflector according to example embodiments can markedly improve indoor farm rack plant productivity, and further, that of the whole plant factory, by enlarging the available light distribution area and generating higher light intensity along and at the edges of its shelves, meaning that the total plant biomass of each shelf can thus
5 be improved and the higher plant productivity of the whole indoor farm rack/plant factory may therefore be achieved if the height of each shelf in the indoor farm racks is further reduced in order to generate more layers of shelves in the identical indoor farm rack. This is particularly useful for countries such as Singapore and regions like Hong Kong, China, where land is limited, to develop the plant factories. The significant enhancement of plant productivity in the
10 plant factory may concurrently indicate that the utilization efficiency of country/region land is greatly enhanced.

Also, the adjustable lampshade-type reflector according to example embodiments is capable of reducing energy consumption originally applied in indoor farm racks, by reducing the number of light tubes required to achieve the identical light distribution and light intensities along the
15 same shelf, hence playing an active and positive role in decreasing energy loss and supporting a low-carbon concept for improved sustainability.

Also, the adjustable lampshade-type reflector according to example embodiments is designed flexibly and can be universally applied for various specifications of light tubes. A majority of reflectors currently applied in indoor farm racks of plant factory is custom-made with fixed
20 angle of reflection to match specific light tube setting, which may generate the issue of inappropriate or insufficient light reflective effect while light tubes with different specifications are applied. The issue of light reflective effect is closely related to the included angle of reflective board followed by its width. As such, the adjustable lampshade-type reflector according to example embodiments can solve the issue of light reflective effect through flexibly
25 changing the included angle of reflective board along with freely regulating its reflective region to match the lengths of applied light tubes when different specifications of light tubes are employed in the indoor farm rack.

Also, the manufacturing cost of the adjustable lampshade-type reflector according to example embodiments is cost-effective as compared to that of the whole indoor farm rack. Based on the
30 information from the vendors of Singapore in 2018, the manufacturing cost for making each reflector is not higher than \$ 550 of Singapore dollars while that for manufacturing a four shelves indoor farm rack is quoted for not lower than \$ 12,000 of Singapore dollars, revealing that all the reflectors installed only account for approximately 18% invested cost of the whole indoor farm rack if the rack contains four shelves.

35 In one embodiment, there is provided an adjustable lampshade-type reflector comprising:

a main frame having opposing first and second length-sides and opposing first and second width-sides;

first and second reflective boards pivotably coupled to the main frame at the first and second width-sides of the main frame, respectively; and

third and fourth reflective boards pivotably coupled to the main frame at the first and second length-sides of the main frame, respectively;

wherein a distance between respective pivot axes of the first and second reflective boards is adjustable for adjusting a reflective region of the adjustable lampshade-type reflector.

5 Each of the first, second, third and fourth reflective boards may be coupled to one or more manual actuators of the adjustable lampshade-type reflector for adjusting respective angles between the first, second, third and fourth reflective boards and a plane of the main frame. Each manual actuator may comprise a rope coupled to one of the first, second, third and fourth reflective boards. The rope may be made from nylon.

10 The adjustable lampshade-type reflector may comprise a first rack coupled to the first reflective board and the main frame. The first rack may be received in tracks of the main frame extending along the first and second length-sides of the main frame, respectively. The first reflective board may be coupled to the main frame via one or more first hinges connected to the first rack. The first reflective board is preferably substantially seamlessly coupled to the first rack at the
15 pivot axis.

The adjustable lampshade-type reflector may comprise a second rack coupled to the second reflective board and the main frame. The second rack may be received in tracks of the main frame extending along the first and second length-sides of the main frame, respectively. The second reflective board may be coupled to the main frame via one or more second hinges
20 connected to the second rack. The second reflective board is preferably substantially seamlessly coupled to the first rack at the pivot axis.

The third and fourth reflective boards are preferably substantially seamlessly coupled to the main frame at the respective pivot axes.

Each of the first, second, third and fourth reflective boards may be made from a high-reflectance-material such as bright anodized aluminum.
25

The adjustable lampshade-type reflector may comprise at least six mounting legs on the main frame for firmly attaching the adjustable lampshade-type reflector to an upper shelf of an Indoor Farm Rack.

30 The rotational axes of the first, second, third and fourth reflective boards preferably define a rectangle at various different distances between the respective pivot axes of the first and second reflective boards, so as to provide gaps between edges of the first, second, third and fourth reflective boards when off-vertically oriented. This can maintain ventilation in an indoor farm rack where the adjustable lampshade-type reflector is used and/or improve heat dissipation from a light source with which the adjustable lampshade-type reflector is used.

35 In one embodiment, a method of illuminating an indoor farm rack using the adjustable lampshade-type reflector according to an example embodiment is provided.

Embodiments of the present invention can have one or more of the following features and associated benefits/advantages:

Feature	Benefit/Advantage
Reflective boards whose angle can be adjusted easily.	The optimal reflection angle can be selected in order to maximise light distribution on the shelf of an Indoor Farm Rack.
Movable reflective racks	Movable racks allow for the precise regulation of the reflective region to accommodate different specifications of LED light tubes.
Gap between any two adjacent reflective boards	The designed gaps decrease heat accumulation and maintain the ventilation in the reflector system and on the shelf of Indoor Farm Rack.
Higher reflection efficiency	The light intensity at the edge of the shelf can be significantly enhanced.

- 5 Embodiments of the present invention can provide a cost-effective solution to the problem of energy wastage by reflecting stray light rays back towards the shelf of an indoor farm rack, hence resulting in an improved distribution of light available for indoor plant seedling cultivation. Embodiments of the present invention can be readily adjusted to accommodate light tubes of various dimensions, and the inclusion of gaps allow for better ventilation through
- 10 the rack. These features confer versatility to the embodiments of the present invention and allow them to be installed onto most indoor farm racks used in indoor farms, thereby enhance light conversion efficiency, improve biomass and metabolite accumulation in plant seedlings, and decrease the cost of plant cultivation.

15 **The performance evaluation of the adjustable lampshade-type reflector according to an example embodiment using choy sum (*Brassica rapa* var. *parachinensis*)**

- By using the professional Tracepro software, the simulation for the optimal included angle and width of the reflective board of an adjustable lampshade-type reflector according to an example embodiment was carried out, the results showed that at the fixed distance of 12 cm counting from the surface of the germination tray to the LED tubes, the combination of 32° of included
- 20 angle and 10 cm of reflective board width could achieve an optimal reflective effect, by overall consideration of various factors including available light distribution area, ventilation and the cost of reflective board materials.

FIG. 10(A) shows erected and FIG.10(B) inverted schematic views of the three-dimensional simulative model of an adjustable lampshade-type reflector according to an example

embodiment designed by the light simulative software TracePro. Indicated are the lambertian diffuser board 1000, the long-side simulative reflective boards e.g. 1002, the short-side simulative reflective boards e.g. 1004 and the absorber board 1006. The lambertian diffuser board 1000 and absorber board 1006 work together to simulate the light distribution along the absorber board 1006, where the tray(s) with seedlings are located. FIG. 10(C) shows a schematic width-side view of the adjustable lampshade-type reflector 100 according to an example embodiment illustrating the definition of the included angle of reflective board.

FIG. 11(A) shows the arrangement of germination trays on the shelf of indoor farm rack. The sketchy screening of the appropriate included angles for the optimization of simulated light intensity distribution along the rack shelf with the application of an adjustable lampshade-type reflector according to an example embodiment is shown in the FIG. 11(B)-(H), specifically the screened included angles are (B) 90°, (C) 75°, (D) 60°, (E) 45°, (F) 30°, (G) 15° and (H) 0°. The width of reflective board is set as 10 cm. The scale unit on the figures is cm.

FIG. 12 shows the fine screening of the appropriate included angles for the optimization of simulated light intensity distribution along the rack shelf with the application of an adjustable lampshade-type reflector according to an example embodiment. The screened included angles are (A) 24°, (B) 25°, (C) 26°, (D) 27°, (E) 28°, (F) 29°, (G) 30°, (H) 31°, (I) 32°, (J) 33°, (K) 34° and (L) 35°. The width of reflective board is set as 10 cm. The scale unit on the figure is cm.

FIG. 13 show the screening of the appropriate width of reflective board under the optimal included angle (32°) for the optimization of simulated light intensity distribution along the rack shelf with the application of an adjustable lampshade-type reflector according to an example embodiment. The screened widths are (A) 13 cm, (B) 12 cm, (C) 11 cm, (D) 10 cm, (E) 9 cm, (F) 8 cm, (G) 7 cm and (H) 6 cm. The scale unit on the figure is cm.

Table 1. The parameter configuration of TracePro software for the simulation of an adjustable lampshade-type reflector according to an example embodiment

Parameters	Configuration
Size of the lambertian diffuser board acting as the upper shelf of Indoor Farm Rack for installing the simulated LED (light-emitting diode) light tubes [Length (mm) × Width (mm)]	1200 × 450
Size of the absorber board acting as the lower shelf of Indoor Farm Rack [Length (mm) × Width (mm)]	1200 × 600
Distance between lambertian diffuser board and the absorber board (mm)	120
Size of the long-side reflective board [Length (mm) × Width (mm)]	1130 × 100

Size of the short-side reflective board [Length (mm) × Width (mm)]	444 × 100
<u>Parameters for the reflective board</u>	
Scatter	ABg
Absorptance	0.2
Specular reflection	0.8
Number of simulated LED light tubes (No.)	5
Distance between two simulated LED light tubes (mm)	110
Number of simulated LED drips in per tube (No.)	96
Distance between two simulated LED drips in per tube (mm)	11.7
Type of simulated LED drip	5730
Size of simulated LED drip [Length (mm) × Width (mm) × Height (mm)]	5.7 × 3.0 × 0.9
<u>Parameters for simulated LED drip</u>	
Emission type	Flux
Units	Photometric
Angular distribution	Lambertian
Flux (lumens)	27
Average wavelength (nm)	555
Simulated rays for per LED drip	2000

Table 2. The optimization of the included angles and widths of the four reflective boards of the patented reflector (based on 5-LED-tube panel)

Condition	Included angle	Width (cm)	Highest light intensity [$\mu\text{mol}/(\text{m}^2 \cdot \text{s})$]	Within 10% deviation of light intensity distribution			Within 15% deviation of light intensity distribution		
				Area (cm^2)	Percentage (%)	Average light intensity [$\mu\text{mol}/(\text{m}^2 \cdot \text{s})$]	Area (cm^2)	Percentage (%)	Average light intensity [$\mu\text{mol}/(\text{m}^2 \cdot \text{s})$]
(1)	90°	10	253	3406	47.31	227	4369	60.68	215
(2)	75°	10	253	3407	47.32	227	4370	60.69	215
(3)	60°	10	253	3409	47.35	227	4371	60.71	215
(4)	45°	10	254	3426	47.58	228	4858	67.47	216
(5)	35°	10	253	4763	66.15	227	5476	76.06	215
(6)	34°	10	253	4801	66.68	227	5480	76.11	215
(7)	33°	10	253	4817	66.90	227	5481	76.13	215
(8)	32°	10	253	4830	67.08	227	5496	76.33	215
(9)	31°	10	256	4808	66.78	231	5481	76.13	218
(10)	30°	10	256	4694	65.19	231	5365	74.51	218
(11)	29°	10	263	4598	63.86	236	5349	74.29	223
(12)	28°	10	265	4472	62.11	239	5277	73.20	226
(13)	27°	10	269	4347	60.38	242	5210	72.36	229
(14)	26°	10	273	4275	59.38	246	5185	72.01	232
(15)	25°	10	276	4173	57.86	248	5142	71.42	234
(16)	24°	10	279	4044	56.17	251	5049	70.13	238
(17)	15°	10	308	2823	39.21	277	4827	67.04	261
(18)	0°	10	320	4108	57.06	288	4439	61.65	272
(19)	32°	13	253	4822	68.36	227	5565	77.29	215
(20)	32°	12	253	4895	67.99	227	5533	76.85	215
(21)	32°	11	253	4875	67.71	227	5520	76.67	215
(22)	32°	9	253	4785	66.46	227	5440	75.56	215
(23)	32°	8	253	4751	65.99	227	5417	75.24	215
(24)	32°	7	253	4697	65.24	227	5385	74.79	215
(25)	32°	6	253	4626	64.25	227	5327	73.99	215

FIG. 14 shows the heat maps of (A) temperature, (B) relative humidity, (C) light intensity (380 – 780 nm) and (D) PAR Energy (400 – 700 nm) along the shelf of Indoor Farm Rack under different included angles of an adjustable lampshade-type reflector according to an example embodiment. PAR, photosynthetically active radiation.

FIG. 15 shows the comparisons of (A) temperature, (B) relative humidity, (C) light intensity (380 – 780 nm) and (D) PAR energy (400 – 700 nm) in different shelf zones of indoor farm rack under different included angles of an adjustable lampshade-type reflector according to an example embodiment, as well as available shelf area percentages within different deviations of light intensity distribution under (E) light-intensity-based and (F) PAR-energy-based manners. PAR, photosynthetically active radiation. In the graphs, different upper-case letters (A, B, C) indicate significant differences among different included angles in respective zones, different lower-case letters (a, b, c, d, x, y, z) and Greek alphabets (α , β , γ) indicate significant differences among all the zones under respective included angles, different upper-case letters (R, S, T) and lower-case letter (r, s, t) indicate significant differences among different included angles within 10% and 15% deviations of light intensity distribution along the whole shelf, respectively ($N_{\text{zone1}} = 56$, $N_{\text{zone2}} = 48$, $N_{\text{zone3}} = 40$, $N_{\text{zone4}} = 32$, $N_{\text{zone5}} = 24$, $N_{\text{total}} = 200$, one-way ANOVA; Tukey multiple comparison; $p < 0.05$).

FIG. 16 shows the comparison on the fresh weights of (A) seedling, (B) shoot, (C) root and (D) total leaf, as well as (E) FW-based harvest index and (F) FW-based shoot root ratio of choy sum grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment. In the graphs, FW, fresh weight, the asterisk (*) indicate significant differences found between the control and treatment (Student's *t*-test (i.e. the statistical approach to find whether there is a significant difference between two

groups of data from two independent treatment conditions); $p < 0.05$), different Greek alphabets (α , β , χ) and the lower-case letters (a, b, c) indicate significant differences among all the zones with or without the application of reflector ($N_{\text{zone1}} = 45$, $N_{\text{zone2}} = 38$, $N_{\text{zone3}} = 32$, $N_{\text{zone4}} = 26$, $N_{\text{zone5}} = 19$, one-way ANOVA; Tukey multiple comparison; $p < 0.05$).

5 FIG. 17 shows the comparison on the dry weights of (A) seedling, (B) shoot, (C) root and (D) total leaf, as well as (E) DW-based harvest index and (F) DW-based shoot root ratio of choy sum grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment. In the graphs, DW, dry weight, the asterisk (*) indicate significant differences found between the control and treatment (Student's t -test; $p < 0.05$), the only Greek alphabets (α) indicates that there is not significant difference found among all the zones with the application of reflector, the lower-case letters (a, b, c) indicate significant differences among all the zones without the application of reflector ($N_{\text{zone1}} = 45$, $N_{\text{zone2}} = 38$, $N_{\text{zone3}} = 32$, $N_{\text{zone4}} = 26$, $N_{\text{zone5}} = 19$, one-way ANOVA; Tukey multiple comparison; $p < 0.05$).

15 FIG. 18 shows the comparisons on the (A) total leaf area, (B) hypocotyl length, (C) hypocotyl diameter and (D) root length of choy sum grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment. In the graphs, the asterisks (*) indicate significant differences found between the control and treatment (Student's t -test; $p < 0.05$), different Greek alphabets (α , β , χ) and the lower-case letters (a, b, c) indicate significant differences among all the zones with or without the application of reflector ($N_{\text{zone1}} = 45$, $N_{\text{zone2}} = 38$, $N_{\text{zone3}} = 32$, $N_{\text{zone4}} = 26$, $N_{\text{zone5}} = 19$, one-way ANOVA; Tukey multiple comparison; $p < 0.05$).

FIG. 19 shows the comparisons on the moistures of (A) seedling, (B) shoot and (C) root, as well as (D) photosynthetic efficiency of choy sum grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment. In the graphs, the asterisks (*) indicate significant differences found between the control and treatment (Student's t -test; $p < 0.05$), the only Greek alphabets (α) and lower-case letter (a) indicate that there are no significant differences found among all the zones with or without the application of reflector ($N_{\text{zone1}} = 45$, $N_{\text{zone2}} = 38$, $N_{\text{zone3}} = 32$, $N_{\text{zone4}} = 26$, $N_{\text{zone5}} = 19$, one-way ANOVA; Tukey multiple comparison; $p < 0.05$).

FIG. 20 shows the comparison on the concentrations of (A) total chlorophylls, (B) chlorophyll a , (C) chlorophyll b and (D) total carotenoids, as well as (E) chlorophyll a/b ratio and (F) total carotenoids/chlorophyll a ratio of choy sum shoots grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment. In the graphs, DW, dry weight, the asterisks (*) indicate significant differences found between the control and treatment (Student's t -test; $p < 0.05$), the only lower-case letter (a) indicates that there is not significant difference found among all the zones without the application of reflector, different Greek alphabets (α , β , χ , δ) indicate significant differences found among all the zones with the application of reflector ($N_{\text{zone1}} = 6$, $N_{\text{zone2}} = 6$, $N_{\text{zone3}} = 6$, $N_{\text{zone4}} = 6$, $N_{\text{zone5}} = 6$, one-way ANOVA; Tukey multiple comparison; $p < 0.05$).

FIG. 21 shows the comparison on the (A) total phenolic content and (B) DPPH of choy sum shoots grown in indoor farm rack with or without the application of an adjustable lampshade-type reflector according to an example embodiment. In the graphs, DW, dry weight, different Greek alphabets (α , β) and the lower-case letters (a, b, c) indicate significant differences among all the zones with or without the application of reflector ($N_{\text{zone1}} = 6$, $N_{\text{zone2}} = 6$, $N_{\text{zone3}} = 6$, $N_{\text{zone4}} = 6$, $N_{\text{zone5}} = 6$, one-way ANOVA; Tukey multiple comparison; $p < 0.05$).

The determination on the actual distributions of various environmental factors including total light intensity, photosynthetically active radiation (PAR) light energy, temperature and relative humidity, along the shelf of the indoor farm rack by using a lighting passport (a kind of light meter), showed that an adjustable lampshade-type reflector according to an example embodiment could effectively uniform the distribution of light intensity and accumulate more PAR light energy onto the working (lower) shelf where the plants grow, meanwhile, it could uniform the distributions of temperature and relative humidity and remarkably reduce their differences along the shelf.

The actual performance evaluation on an adjustable lampshade-type reflector according to an example embodiment by using choy sum (*Brassica rapa* var. *parachinensis*) showed that the shoot biomass and morphological characteristics of choy sum seedling grown on the shelf of the indoor farm rack with the application of an adjustable lampshade-type reflector according to an example embodiment (32° of included angle and 10 cm of reflective board width) were significantly higher and more uniform, respectively, as compared to the control without the application of an adjustable lampshade-type reflector according to an example embodiment. With the application of an adjustable lampshade-type reflector according to an example embodiment, the average fresh weight of choy sum shoot could be achieved by up to 1.13- and 1.14-fold of increase, compared with the control, while the average dry weight of shoot and total leaf biomass were up to 1.18-fold and 1.24-fold, respectively, significantly higher than their respective controls.

The nutritional value and quality evaluations of choy sum shoot showed that the level of chlorophyll *b* in choy sum shoot was significantly decreased, while that of the total carotenoids was remarkably increased instead, with the application of an adjustable lampshade-type reflector according to an example embodiment, however, no effect on the levels of total chlorophylls and chlorophyll *a* was found under the same treatment. In addition, two essential parameters such as chlorophyll *a/b* ratio and total carotenoids/chlorophyll *a* ratios were found to significantly increase, with the application of an adjustable lampshade-type reflector according to an example embodiment. There was no significant difference found on the level variations of total phenolic and antioxidant capacities of choy sum shoot, under with or without the application of an adjustable lampshade-type reflector according to an example embodiment.

The application of an adjustable lampshade-type reflector according to an example embodiment could, indeed, significantly improve the distribution of light intensity, PAR energy, temperature and relative humidity, along the shelf of the indoor farm rack, by which

the biomass followed by the bioactive metabolites such as total carotenoids in choy sum shoot could be significantly enhanced.

FIG. 22 shows the comparison on the light distributions along the shelf of indoor farm rack under different specifications of 5-LED-tube panel with or without the application of adjustable lampshade-type reflector according to an example embodiment. (A) 96-chip of LED tubes with reflector; (B) 96-chip of LED tubes without reflector; (C) 72-chip of LED tubes with reflector; (D) 72-chip of LED tubes without reflector; (E) 48-chip of LED tubes with reflector; (F) 48-chip of LED tubes without reflector; (G) 24-chip of LED tubes with reflector; (H) 24-chip of LED tubes without reflector.

Table 3. The comparison on the light distributions under different specifications of 5-LED-tube panel with or without the application of reflector

Condition	Included angle	Width (cm)	Chips applied	Highest light intensity [$\mu\text{mol}/(\text{m}^2\cdot\text{s})$]	Within 10% deviation of light intensity distribution			Within 15% deviation of light intensity distribution		
					Area (cm^2)	Percentage (%) ^a	Average light intensity [$\mu\text{mol}/(\text{m}^2\cdot\text{s})$]	Area (cm^2)	Percentage (%)	Average light intensity [$\mu\text{mol}/(\text{m}^2\cdot\text{s})$]
(A)	32°	10	96	253	4839	67.08	237	5496	76.33	215
(B)	-	-	96	253	3406	47.31	227	4369	60.68	215
(C)	32°	10	72	253	3348	46.47	227	3945	54.79	215
(D)	-	-	72	247	2453	34.07	222	3182	44.19	210
(E)	32°	10	48	241	2623	28.10	217	2544	35.33	205
(F)	-	-	48	238	1514	21.03	214	2021	28.07	202
(G)	32°	10	24	204	957	13.29	184	1443	20.04	173
(H)	-	-	24	202	643	8.93	182	945	13.13	172

^a The total available area per shelf in indoor farm rack is 7200 cm^2 ($120 \text{ cm} \times 60 \text{ cm}$).

FIG. 23 shows the cultivation of choy sum seedlings with the application of the adjustable lampshade-type reflector. (A) The position of the 200 choy sum seedlings along the working shelf of indoor farm rack. (B) The definition of five zones on the working shelf for cultivating choy sum seedlings. (C) The outer view of the reflector. (D) The inner front view of the reflector and seedlings. (E) The inner side view of the reflector and seedlings.

- The above description of illustrated embodiments of the systems and methods is not intended to be exhaustive or to limit the systems and methods to the precise forms disclosed. While specific embodiments of, and examples for, the systems components and methods are described herein for illustrative purposes, various equivalent modifications are possible within the scope of the systems, components and methods, as those skilled in the relevant art will recognize.
- The teachings of the systems and methods provided herein can be applied to other processing systems and methods, not only for the systems and methods described above.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the spirit or scope of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects to be illustrative and not restrictive. Also, the invention includes any combination of features described for different embodiments,

including in the summary section, even if the feature or combination of features is not explicitly specified in the claims or the detailed description of the present embodiments.

In general, in the following claims, the terms used should not be construed to limit the systems and methods to the specific embodiments disclosed in the specification and the claims, but
5 should be construed to include all processing systems that operate under the claims. Accordingly, the systems and methods are not limited by the disclosure, but instead the scope of the systems and methods is to be determined entirely by the claims.

Unless the context clearly requires otherwise, throughout the description and the claims, the words "comprise," "comprising," and the like are to be construed in an inclusive sense as
10 opposed to an exclusive or exhaustive sense; that is to say, in a sense of "including, but not limited to." Words using the singular or plural number also include the plural or singular number respectively. Additionally, the words "herein," "hereunder," "above," "below," and words of similar import refer to this application as a whole and not to any particular portions of this application. When the word "or" is used in reference to a list of two or more items, that
15 word covers all of the following interpretations of the word: any of the items in the list, all of the items in the list and any combination of the items in the list.

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