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CONCEPT OF GLOWING PLANTS: FUTURE POSSIBILITY OF SUSTAINABLE DEVELOPMENT OF SOCIETY

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ABSTRACT

Bioluminescence is a very common physical phenomenon to generate emit light in the presence of oxygen. Bioluminescence plants represent a novel frontier in sustainable biotechnology, offering a unique convergence of natural illumination and synthetic biology. There have been transformed with bioluminescence gene to originate in living organism or plants so far – from bacteria, fungi, insects, firefly, marine organism, algae, dinoflagellate, jellyfish, earthworm, and sea star fish into plant genomes, researchers are developing self-sustaining, light-emitting plants that require no external electricity. During the past years, it was found that bioluminescence system such as the luciferase-luciferin system, PBIN technique, bacterial bioluminescence system, caffeic acid cycle (CAC), and fluorescent proteins (FPs) are generating glowing plants in the dark area and can be easily seen by our naked eyes. Here, we summarized the review of literatures rebuilding bioluminescent system to development of auto luminescence in plant cells. In future possibilities, bioluminescence plants can be used not only in scientific research area, but also a capable of alternative option as formation of artificial light source of lighting. As the next generation of society seeks innovative solutions to climate and energy challenges, bioluminescent plants offer a promising and symbolic step toward a more regenerative and ecologically integrated future.

KEYWORDS: Bioluminescent system; Genetic engineering; Sustainable development

1. INTRODUCTION

Bioluminescence reaction is most of the production of light in living organism, which was discovered among more than 10,000 species from 800 genera (Haddock *et al.*, 2010). They perform a special chemical reaction to produce emit visible light. Bioluminescence considered as a special kind of chemical signals for the living organisms. Basically, bioluminescence word is defined as the general term of a chemical compound that is biosynthesized is a luminous organism to provide energy for emission light by being oxidized by catalysis of a luciferase gene in the presence of oxygen. It is the very natural phenomenon to glow up the living organism with its secret behaviour (Shimomura 2006). Bioluminescence, the biochemical formation of light by a luciferase-luciferin chemical reaction within living organism. It is a natural phenomenon to generate by different type of proteins called luciferases that makes easy to the oxidation of substrates called luciferins. The most relatable review, focuses on the apart of scientists to perform a special role - in the region of glowing plants (Li *et al.*, 2021).

Recently; discovered some new genus of bioluminescence species in the forest of Meghalaya, India (Karunarathna *et al.*, 2020). Bioluminescence is also performed by the photoluminescent activity that glow continuously for a short or long period of time in the absence of light. The alternative strategy to develop novel bioluminescence system is emerging. Many species of fungi naturally produce light, a term known as bioluminescence or fluorescence. During the past some years, found the fluorescent gene in the protein and bioluminescence system are responsible for encourage of most native luminescence gene (Kim and Paulmurugan 2021). The presence of bioluminescent system to change the mechanism of living organisms with a physical advantage in certain ecological situations. Bioluminescence jellyfish *Ae666quorea Victoria* to expresses the green fluorescent protein (GFP) along with the photoprotein aequorin (Morise *et al.*, 1974). Bioluminescence gene was synthesized by fungal, bacteria, insects, fire fly, marine organisms, algae, dinoflagellate, jellyfish, worms, and sea star fish (John 2008).

Most of cases, light emission results from the chemical oxidation. Bioluminescence gene produce cold light in the presence of oxygen but not in higher plant on the Earth. Recently - a few plants have developed, converted using bioluminescence system such as the caffeic acid cycle, bacterial bioluminescence system, luciferase-luciferin system that allow them to glowing the darkness and can be easily seen by our naked eyes giving a clear lighting advantage, through bio-techniques, it is possible to introduce luminescence system into living plant cells as biomarkers (Mitiouchkina *et al.*, 2020). Some plants transformed with luminescence systems for example – Arugula (*Eruca sativa*), Kale (*Brassica oleracea*), Spinach (*Spinacia oleracea*), Watercress (*Nasturtium officinale*), and Tobacco (*Nicotiana tabacum*) plants using the bioluminescent system to produce glowing light (Kwak *et al.*, 2017 and Mitiouchkina *et al.*, 2020). Engineered biolumeneting plant ATP-powered genetically encoded high autoluminescent light source as sustainable alternatives (Gordiichuk *et al*., 2021). Might be useful not only for basic plant research but also for ornamental purpose as a novel property of glowing flower and plant cells. Development a plant with self-sustain bioluminescence gene. Autoluminescent plants engineered to express a fungal, bacterial bioluminescence system that converts caffeic acid into luciferin and report self-sustain bioluminescence that is visible to produce sufficient light. Bioluminescence results from a biochemical reaction involving a luciferase enzyme and a luciferin substrate often requiring molecular oxygen or cofactors such as ATP and NADH catalysed by the specific enzyme, luciferase (Fleiss and Sakisyan 2019). Bioluminescent plants developed through the integration of bioluminescent gene pathways from fungi, bacteria or marine organisms represent a novel and promising tool for advancing sustainable development in modern society. These genetically engineered organisms can emit visible light autonomously without requiring external energy sources making them potential alternative to conventional lighting system. Their application extends beyond aesthetic or ornamental use, offering benefits such as reduced electricity consumption, lower carbon emission, and innovative green infrastructure solutions in urban planning. Furthermore, bioluminescent plants may serve as biosensors for environmental monitoring and contributing to ecological awareness and resource management. Current advancements in synthetic biology including successful expression of fungal bioluminescent in plants (Mitiouchkina *et al*., 2020).

Mechanism of Bioluminescence: Bioluminescence typically involves the oxidation of a substrate (luciferin), catalysed by an enzyme (luciferase), resulting in light emission. In some marine species, luciferase and luciferin are part of a single complex known as a photoprotein which requires additional cofactors to function. The colour of the emitted light depends on the specific luciferin-luciferase system and can range from blue to red (Duchatelet and Dupont 2024).
Some basic principal behind the light emission is as follows -

- **Reaction 1:** A chemical reaction produce bioluminescence activity, which is a sort autoluminescence in which light is emitted. The reaction rate for the luciferin is controlled by a luciferase enzyme and luciferin convert into oxyluciferin and generate glowing light. Luciferin is the main component in bioluminescence reaction. Luciferin from the oxidised (oxyluciferin), ATP and NADH catalysed by the specific enzyme luciferase.

$$\text{Luciferin} + \text{Oxygen} \xrightarrow{\text{Luciferase}} \text{Oxyluciferin} + \text{Light}$$

- **Reaction 2:** The bioluminescence chemical reaction in the firefly is the enzymes called luciferin and luciferase. Luciferin was converted to luciferyladenylate by ATP in the presence of Mg2+. Mg2+, ATP are required for the reaction, while adenosine monophosphate (AMP) and pyrophosphate (PP) are waste product. Luciferin

$$\text{Luciferase} + \text{D-luciferin} + \text{ATP} + Mg^{2+} \longrightarrow \text{Luciferase-D-luciferyl-adenylate} + \text{Pyro-phosphate} + Mg^{2+}$$

- **Reaction 3:** Bioluminescence is due to oxygenation reactions – oxygen reacts with substances called luciferin, producing energy in the form of light. The component Luciferase-D-luciferyladenylate was oxidised by molecular oxygen and produce photons of Luciferase-oxyluciferin and light. In this process the luciferase become oxygenated to from oxyluciferin.

$$\text{Luciferase-D-luciferyladenylate} + O_2 \longrightarrow \text{Luciferase-Oxyluciferin} + CO_2 + \text{AMP} + \text{Light}$$

- **Reaction 4:** At the core of all bioluminescent systems lies a reaction between luciferin (substrate) and luciferase (enzyme). The reaction typically involve – Oxidation of luciferin, emission of a photon (visible light), and regeneration of substrate in firefly bioluminescence operating system.

$$\text{Luciferin} + \text{ATP} + O_2 \longrightarrow \text{Oxyluciferin} + CO_2 + \text{Light}$$

- **Reaction 5:** In some cases, additional cofactors such as FMNH2 (bacteria) are required. *Aliivibrio fischeri* is a marine bacterium that produces light through a luciferase-catalyzed reaction involving FMNH2, oxygen, and a long chain aldehyde. This bacterium often forms symbiotic relationship with marine animals such as the Hawaiian bobtail squid providing camouflage through counter-illumination.

$$FMNH_2 + RCHO + O_2 \longrightarrow FMN + RCOOH + H_2O + \text{Light}$$

  - **Luciferin :** The light-emitting substrate
  - **Luciferase :** The enzyme that catalyzes the reaction
  - **ATP :** Provides energy and activates luciferin
  - **Mg^{2+} :** Essential cofactor for luciferase activity
  - **O2 :** Required for oxidation
  - **RCHO :** Long-chain aliphatic aldehyde (tetradecanal)

- **RCOOH :** Long-chain fatty acid (tetradecanoic acid or myristic acid)
- **FMN :** Oxidized flavin
- **FMNH2 :** Reduced flavin mononucleotide

In the present review highlights the progress report on the bioluminescent systems in plants cell and various scientist contribution to the success of glowing plants to produced emit light using the different bioluminescence system were presented.

Table 1: Different scientist contribution by the glowing plants development

Luminescence gene source	Engineered plants	Derived from	Gene introduces	References
Firefly	*Nicotiana tabacum*	*Photinus pyralis*	Firefly luciferase	Ow *et al.*, (1986)
Firefly	*Daucus carota*	*Photinus pyralis*	Firefly luciferase	Ow *et al.*, (1986)
Bacterium	*Nicotiana tabacum*	Photobacterium leiognathid	luxCDABEG	Krichevsky *et al.*, (2010)
Nano-lantern	*Nicotinan benthamiana*	Artificial nano-lantern	pH2GW7-CT nano-lantern	Saito *et al.*, (2012)
Fluorescent protein	*Torenia fournieri*	*Chiridius poppei*	CpYGFP	Sasaki *et al.*, (2014)
N. tabacum	*Neonothopanus nambi*	H3H, Hisps, Luz and CPH	Fungus luciferase	Mitiouchkina *et al.*, (2020)
Firefly	*Brassica oleracea*	*Photinus pyralis*	Firefly luciferase	Kwak *et al.*, (2017)
Firefly	*Spinacia oleracea*	*Photinus pyralis*	Firefly luciferase, luciferin and CoA	Kwak *et al.*, (2017)
Fluorescent protein	*Chrysanthemum morifolium*	*Chiridius poppei*	CpYGFP	Kishi-Kaboshi *et al.*, (2017)
Fluorescent protein	*Petunia hybrida*	*Chiridius poppei*	eYGPuv	Chin *et al.*, (2018)
Fungi	*Petunia hybrida*	Aspergillus nidulans and Neonothopanus nambi	NPGA, H3H, Hisps, Luz, and CPH	Khakhar *et al.*, (2020)
Fungi	*Nicotiana benthamiana*	Aspergillus nidulans and Neonothopanus nambi	NPGA, H3H, Hisps, Luz, and CPH	Khakhar *et al.*, (2020)
Fungi	*Catharathus roseus*	Aspergillus nidulans and neonothopanus nambi	NPGA, H3H, Hisps, Luz, and CPH	Khakhar *et al.*, (2020)
Rosa rubiginosa	*Aspergillus nidulans* and *Neonothopanus nambi*	NPGA, H3H, Hisps, Luz and CPH	Fungus luciferase	Khakhar *et al.*, (2020)
Nano-lantern	*Arabidopsis thaliana*	Artificial nano-lantern	Green enhanced nano-lantern (GeNL)	Furunata *et al.*, (2020)

Glowing plants with bioluminescent system

Bioluminescent system is very largely understudied, it's very widely use to research area. Various techniques have been developed and use to achieve this goal. Include the techniques like – microinjection, gene gun technique, liposome-mediated, electroporation technique, PBIN, spray method, and *Agrobacterium tumefaciens* method.

Up to now, five Natural bioluminescent system that origin from fireflies, bacteria, fungi, protein have been reconstructed in plants and also used by chemically reaction for glowing plants. The chemically reaction that generates emit light happens within a living organism. Plants can produce a special chemical reaction to generating light, scientists have found way to artificially replicate the phenomena.

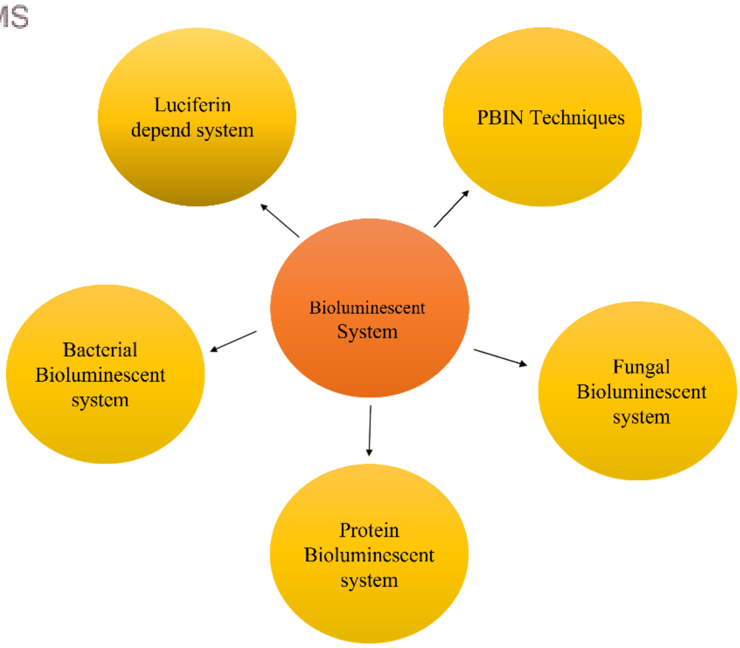


Figure 1: Five types of natural bioluminescent system

2. NATURAL BIOLUMINESCENT SYSTEM

I. D-Luciferase depend system

In fireflies, first-time bioluminescent system that was introduced the *Photinus pyralis* luciferase gene into *Daucus carota* and *N. tabacum* plants is firefly luciferase-luciferin system (Ow *et al*., 1986). Luciferin-Luciferase system (i.e., bacterial, fungal, firefly, coelenterazine-based) have inherently different emission spectra. D-luciferase depend system is luciferase-luciferin system belong to one of the most practically important and most commonly collections of bioluminescence reaction. The most widely studied one, has advanced in several lineages of beetle's species and Coleoptera families including fireflies (*Lampyridae*). The beetle's species (*Elateridae*) and railroad worms (*Phengodidae*) to create a glowing emitting light with 540-640nm wavelength ranging from a green to red fluorescent light. These chemical reactions utilise a stable and non-toxic compound (Tiffen *et al*., 2010, Viviani *et al*., 2011, Kotlobay *et al*., 2020).

Firefly luciferase can be expressed self-sufficiently or fused with proteins of interest in several plant organs, for example roots, stems, and leaves, during the advance transgenic plant development in the area of research (Li *et al*., 2021). Affords a useful tool to study protein expression and localization, and protein-protein interaction (PPIs). Firefly luciferin catalyzing firefly luciferase gene in the occurrence of magnesium (Mg^{2+}), oxygen (O_2), and ATPs, and produce by the yellow-green luminescence. Coenzyme A (CoA) could be used to deoxidize the oxidized light emitting compound found in living organism that generate bioluminescence (Gosset *et al*., 2020).

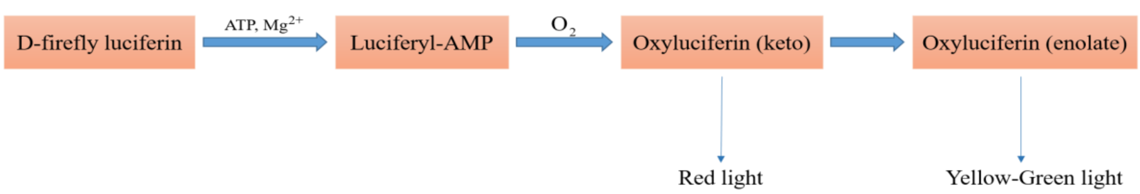


Figure 2: The firefly luciferase bioluminescent rection

II. Glowing plant in Pressurized bath infusion of nanoparticles (PBIN)

In 2017, a novel nano-technique called pressurized bath infusion of nanoparticles (PBIN) techniques. PBIN method works by supplying an external pressure against the internal microchannels with in the leaf mesophyll cells. In this technique, to introduce the firefly luciferin and Coenzyme A (CoA) into two separate nano capsules, and luciferase connected onto the outer layer of silica-PEG nanocarriers. These nanoparticles could decrease luciferin toxicity and artificial denaturation of luciferase, producing a long light-emitting degeneration ratio of up to 8 hours in plant cells.

In this work, to insert the nanoparticles mixture into the entire plant cells, the additional advance development a process of infusion using stomatal pores within the leaves. To develop a nano bionic plant with four separates nanoparticles types containing the protein and development necessary for self-sustaining photonic sources for direct and indirect light source. These different chemically interacting nanoparticles target the plant mesophyll cell and stomata guard cell, which is normally high for ATP. The preparation of nanoparticle system for producing light as per the following: (1) an immobilized silica nanoparticle (SNP-Luc) formed to a poly (ethylene glycol) bis (amine) (NH_2-PGE-NH_2, Mw 2,000, Sigma), (2) D-luciferin releasing poly (lactic-co-glycolic acid) (PLGA-LH_2) was synthesized the light-emitting compound luciferin, (3) Chitosan nanoparticles (medium Mw, Sigma) was added Coenzyme-A (CS-CoA) and CS-CoA was slowly added tripolyphosphate (TPP, Sigma). CoA is capable of release the light emission by regenerating firefly luciferase, reaction with dehydroluciferyl-adenylate, and (4) a silica nanoparticle labeled with Alexa Fluor 488-cadaverine (SNP-AF) and silane to confirm uptake and localized information of nanoparticles. To introduce the nanoparticle mixture into the entire plant cell via a Pressurized Bath Infusion of Nanoparticles (PBIN) technique. Here, the whole plant is briefly merged in a pressured aqueous chamber. PBIN was successfully applied in saturation pressure of 1.8 bar without any membrane damage (Kwak *et al.*, 2017).

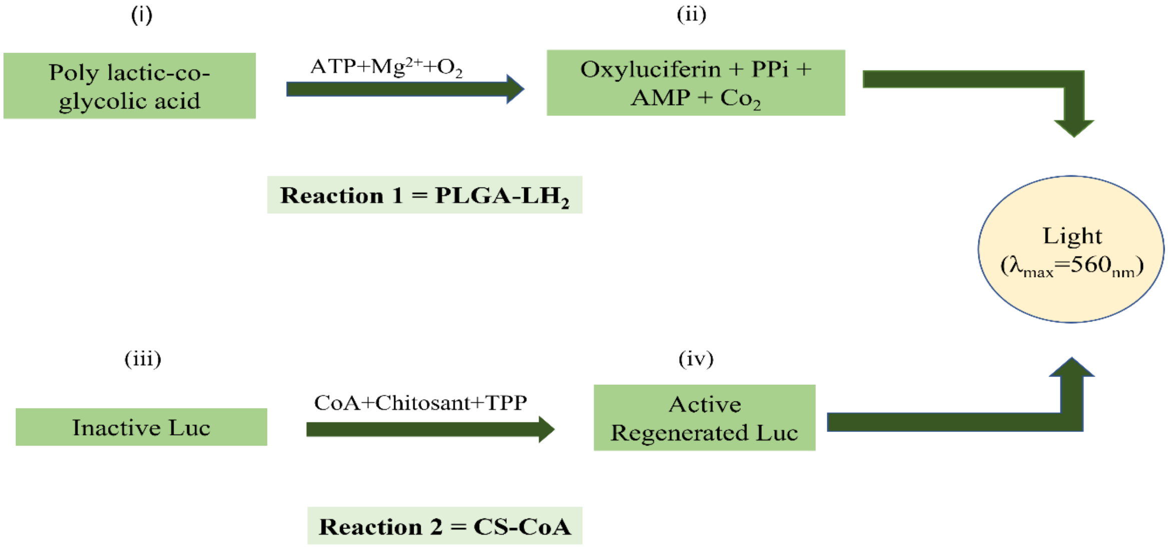


Figure 3: Reaction mechanism of light production by firefly luciferase using Nanoparticles

III. Bacterial bioluminescence system

First bacterial bioluminescent system was reported in *Nicotiana tabacum*, only few bacterial luciferase-luciferin pairs were reported in other transgenic plants (Krichevsky *et al.*, 2010). All bioluminescence bacteria present the same type of mechanism for creating luminating brighter light, where photons are produced in a set of biochemical reactions utilizes flavin mononucleotide FMN and long chain aldehyde group derivative. Although bacterial bioluminescent genes can be target into plastids to engineer autoluminescence plant. This bacterial bioluminescence system is originated from the three gram-negative motile rods luminescent bacterium that is *Photobacterium, Vibrio and Xenorhabdus* (Piyush *et al*., 2022). Luminous bacterial light-emission enzymatic catalyzing luciferin biosynthesis system is encoded by the *lux* operon. The highly conservative *lux* operons (*lux*CDABEG) are utilising the some unique and highly conserved among various species of all luminous bacteria, which encode the complete bacterial bioluminescent system (Close *et al*., 2009). Gene *lux*A and *lux*B encode α and β subunits of the bacterial luciferase, and *lux*CDE are encode enzymes involved in the synthesis of aldehyde substrate utilized in the bioluminescence reaction and *lux*G encode for flavin reductase. Transfer the whole *Photobacterium leiognathi lux* operon into tobacco leaves chloroplast and fined the first auto-luminescent plant (Krichevsky *et al*., 2010). Bacterial DNA gel blot analysis confirms integration of aadA and the *lux* operon in the *LUX*-rps12/TrnV. Total cellular DNA isolated from transplastomic leaves, the TrnA and TrnI plasmid geans aadA and selective spectinomycin resistance gene (Krichevsky *et al*., 2010).

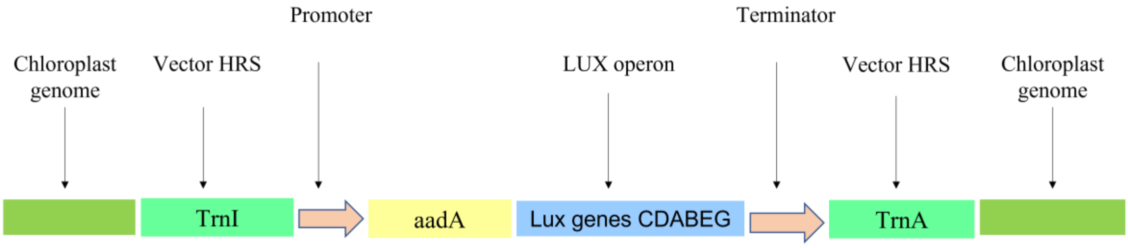


Figure 4: LUX-TrnI/TrnA transplastomic chloroplast genome

IV. Fungal bioluminescent system

Recently; the fourth bioluminescent system originated by bioluminescence fungi has been describe to produce strong self-sustain glowing plant, providing the first genetically encodable pathway from eukaryotes. The fungal bioluminescent system produces emitting light and shows no cytotoxicity and growth inhibition in plant cells. (Kotlobay *et al*., 2018). It is a unique and genetically encodable eukaryotic luciferase-luciferin system, it was introduced into plant cell (Khakhar *et al*., 2020; Mitiouchkina *et al*., 2020). The biosynthetic pathway of fungal luciferin is called caffeic acid cycle (present in all plants) and report self-sustain bioluminescence that is visible to the naked eyes giving a clear lighting asset. Caffeic acid cycle is a metabolic pathway responsible for luminescence in fungi.

To develop transgenic tobacco plants (*Nicotiana benthamiana)* with advance features were performed continuously expressing fungal caffeic acid cycle and taken from the luminescent fungus *Neonothopanus nambi*. The process followed by four types of important enzymes that catalyse the caffeic acid cycle derivative pathways: fungal luciferase (Luz), hispidin synthase (HispS), and hispidin-3-hydroxylase (H3H), and caffeylpyruvate hydrolase (CPH). Another enzyme is NPGA (4'-phosphopantetheinyl transferase), initiates HispS post-translationally (Ke and Tsai 2022). Tree fungus Omphalotus olearius produce a bright glow at night (Farusi and Watt 2016). Glowing plant expressing emitting light for these genes during all developmental stages and the most important think is – no need for any type of external substrates to express enough brightness to be easily visible light. The self-luminescent tobacco plant was brighter than other reported self-light-emitting plants (Khakhar *et al*., 2020).

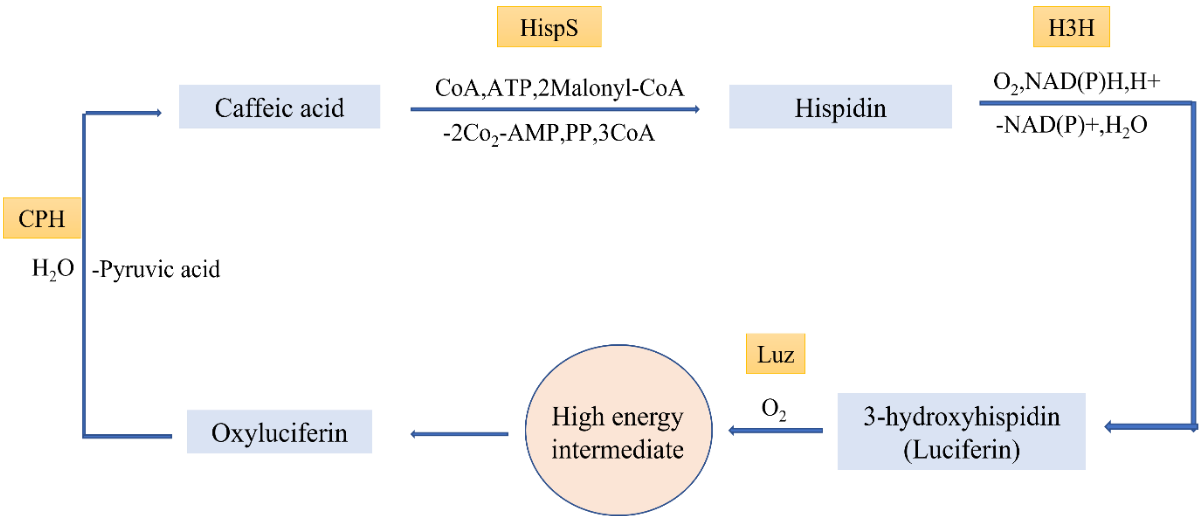


Figure 5: Fungal luciferin biosynthetic bioluminescence pathway

Working on caffeic acid cycle (CAC): The caffeic acid cycle is a native biosynthetic pathway in all plants, and does not appear to harm the plant. Caffeic acid cycle generally present in all plant cell. Fungal bioluminescence system, expression of Caffeic acid cycle is not toxic in plants. Mainly it is a metabolic process for the fungus luciferin. Fungal luciferin is converted into 3-hydroxyhispidin. Luz oxidises luciferin to produce photons and caffelpyruvic acid to hydrolyzed and produce caffeic acid and pyruvic acid. HispS (hispidin synthase) post-translationally can recycle caffeic acid to make hispidin by Hips (Purtov *et al*., 2015 and Oba *et al*., 2017). Three intermediary metabolites lignins, flavonoid anthocyanins condensed tannins, and shikimate produced by the fungal caffeic acid cycle (Mitiouchkina *et al*., 2020 and Li *et al*., 2021).

V. Protein bioluminescent system

In 1995, green fluorescent protein (GFP) gene isolate from jellyfish *Aequorea Victoria* was expressed in *Arabidopsis*, novel research in living glowing plant cell (Hu and Cheng 1995). Protein modification change into amino acid sequences of luciferase can lead to significant shifts in emission wavelength. The photoprotein present in them is called GFP. Fluorescent protein (FPs) is covering various type of fluorescent range (i.e., yellow, blue, green, red, and cyan,) have been modified for plant cells (Blatt and Grefen 2014). Another practically significant group of bioluminescent reactions. A few plants have recently been converted using bioluminescence systems such as the FPs are responsible for induction of most native luminescence (Kim and Paulmurugan 2021). FPs produce photoluminescence that allow them to glow without consumption of ATP (Chudakov *et al*., 2010). Bioluminescent system glowing light by oxidation of a specific substrate, luciferin, with co-factors, i.e. ATP and NADH and catalyzed by the specific enzymes, luciferase (Fleiss and Sarkisyan 2019). Biolumminescent system and FPs required a powerful toolkit as biomarkers and biosensors in living plants cell metabolism. *Aequorea Victoria* uses the bioluminescent protein aequorin to excite GFP. The electrons of FPs are promoted into electronic excited state by a radiation less energy transfer and then relax with they emit light production (Rowe *et al*., 2009).

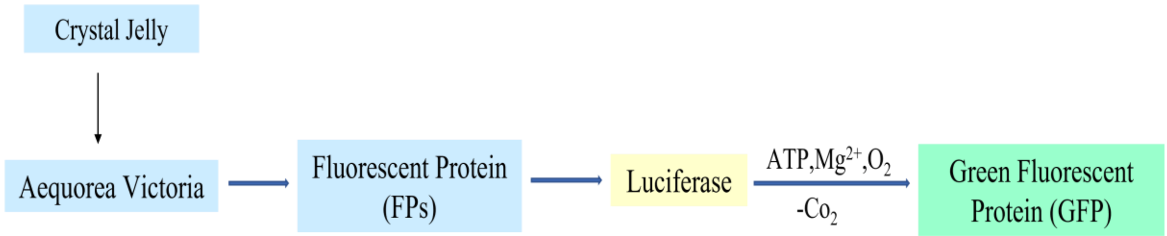
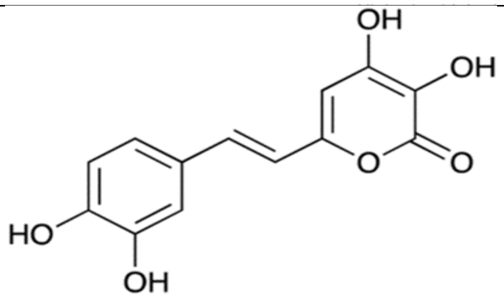
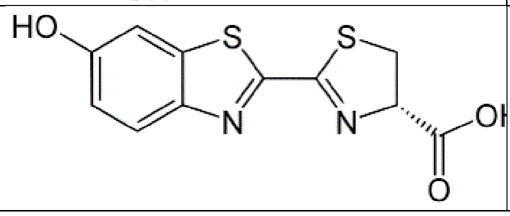
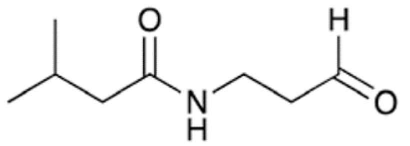
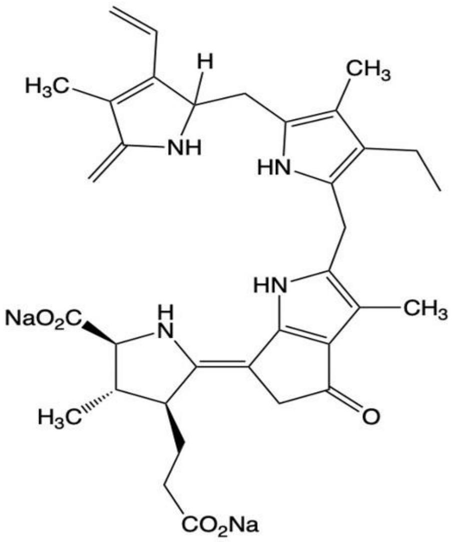
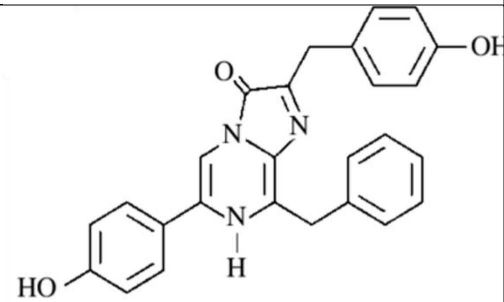
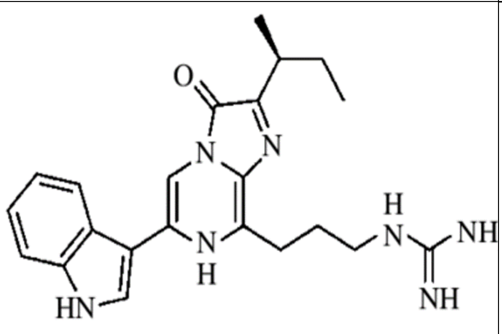
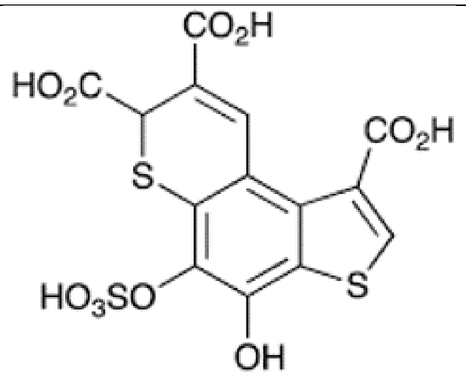


Figure 6: The mechanism of protein bioluminescent system

Protein bioluminescent system provide two representatives system – nano luciferase (NanoLuc) (England *et al*., 2016) and nano lantern (Doerr, 2013). Nano luciferase isolate from shrimp *Oplophorous gracilirotris* luciferase (Hall *et al*., 2012). Nano lantern is an artificial luminescent protein molecule fused with enhanced *Renilla reniformis* luciferase (Saito *et al*., 2012). Recently, green enhance fluorescence nano-lantern gene was introduce into *A. thaliana*, Luminescence became outstanding brighter than suitable substrate furimazine (Furuhata *et al*., 2020).

Table 2: Molecular structure of the known Luciferins gene

Bioluminescence Species	Luciferin	Luciferase Size	Wavelength
Bacterial luciferin		~ 75 kDa	490 nm
Fungal luciferin		~ 29 kDa	520 nm
D - luciferin		~ 280 kDa	560 nm

Diplocardia luciferin		~ 300 kDa	500–530 nm
Dinoflagellate luciferin		~ 135 kDa	476 nm
Marine luciferin		~ 20 kDa	480 nm
Cypridina luciferin		~ 61 kDa	452 nm
Odontosyllis luciferin		~ 35 kDa	510 nm

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Diversity of Bioluminescent Systems: bioluminescence has independently evolved over 40 times in nature (Haddock *et al*., 2010), resulting in varied chemical systems and colours of emitted light. The diversity and mechanisms of bioluminescence systems across various organisms:

Table 3: Variety of Bioluminescence Organisms and Mechanisms

Organism Type	Example Species	Emission Colour	System Type
Bacteria	*Vibrio fischeri*	Blue-Green	FMNH2-dependent
Fungi	*Neonothopanus nambi*	Green	ATP-independent
Insects	*Photinus pyralis (firefly)*	Green-Yellow	ATP-dependent luciferase
Marine organisms	*Aequorea victoria*	Blue	Photoproteins (i.e. aequorin)
Dinoflagellates	*Noctiluca scintillans*	Blue	Luciferin-binding proteins

Colours of Bioluminescence: In nature, bioluminescence produces different colours of light – mainly blue, green, red, yellow, orange, turquoise, and purple. Blue emission is most common bioluminescent colour, especially prevalent in marine organisms such as jellyfish, dinoflagellates, and deep-sea fish. Blue light penetrates water effectively, making it ideal for communication and predation in oceanic environments. Green emission found in some beetles and fungi. Green bioluminescence is often associated with terrestrial organisms, such as *Mycena chlorophos* and *Panellus stipticus*, or engineered systems expressing GFP (green fluorescent protein). Yellow to Orange emission observed in some fireflies and other insects. Variations in the luciferase structure among firefly species cause emission shifts from green to orange. Red emission light is extremely rare in nature. One notable example is the deep-sea dragonfish (*Malacosteus niger*), which can emit and detect red bioluminescence, giving it a stealth advantage in the deep ocean. Turquoise bioluminescence characterized by light emission in the 475-495nm wavelength range is a captivating phenomenon with significant applications in bioimaging optogenetics and synthetic biology. Purple bioluminescence emitting light in the 400-420nm range is relatively rare in nature. This emission is typically achieved through specific luciferase-luciferin system, engineered photoproteins or synthetic substrates.

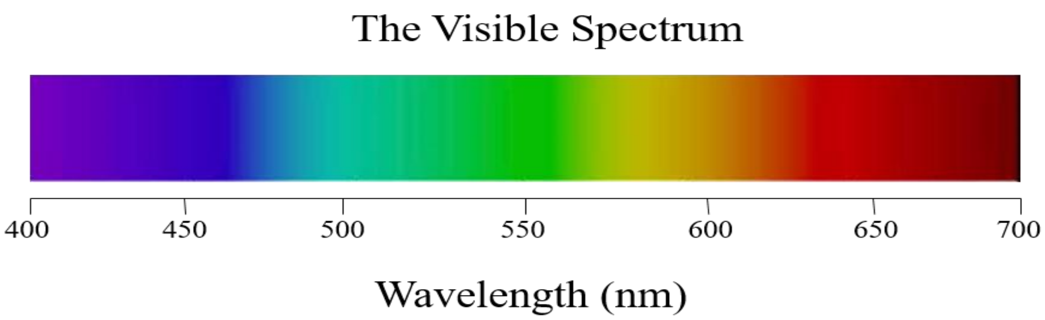
Table 4: Emission Wavelengths of Bioluminescence in Various Organisms

Luciferin	Luminescence maximum (nm)	Approximate colour
Coelenterazine	400 nm	Purple
	450-480 nm	Blue to Turquoise
Dinoflagellate luciferin	474 nm	Blue
Bacterial luciferin	490 nm	Turquoise
Fungus luciferin	520-530 nm	Yellow
Firefly luciferin	560 nm	Green
	615 nm	Orange
Deep sea dragonfish	750 nm	Red

In India, over 100 species across various taxa exhibit bioluminescence including fireflies (*Lampyridae*), click beetles (*Elateridae*), and certain fungi. These organisms utilize bioluminescence for purposes such as mating communication and predation. Despite their ecological significance studies on their distribution and applications in India are limited highlighting the need for further research in biodiversity and conservation (Chatragadda 2020). Certain fungi such as Armillaria mellea and Mycena chlorophose exhibit bioluminescence. The light emission is believed to attract insects aiding in spore dispersal (Duchatelet and Dupont 2024).

Table 5: Some Example of bioluminescent organisms

Organism	Common Name	Wavelength range of light emission
Aequorea aequorea	Jelly fish	~ 500-523nm
Aequorea victoria	Jelly fish	~ 520nm
Diplocardia longa	Earthworm	~ 500-530nm
Gonyulax polyedra	Dinoflagellate	~ 479nm
Mycena mushroom	Fungal	~ 520-530nm
Odontosyllis luciferin	Fireworm	~ 510nm
Photinus pyralis	Firefly	~ 530-590nm
Pleurotus japonicus	Moon night mushroom	~ 524nm
Vibrio fischeri	Marine bacterium	~ 489nm
Malacosteus niger	Deep sea dragonfish	~ 750nm



Applications of Bioluminescence Systems

1. **Biomedical Imaging =>** luciferase reporters are widely used in non-invasive in vivo imaging to track gene expression, cancer progression, and infection dynamic. Bioluminescence imaging (BLI) is a powerful technique used to monitor cellular and molecular processes in living animals. Luciferase-expressing cells or tissues can be tracked over time (Greer and Szalay 2002).
2. **Biosensing =>** bioluminescent systems are applied in environmental monitoring for detecting toxins, heavy metals, and pollutants. Whole-cell biosensors expressing luciferase genes respond to specific analytes with a light signal. Engineered microorganisms expressing bioluminescent gene can detect and respond to environmental contaminants including – Heavy metals (i.e. mercury, cadmium), Organic pollutants (i.e. toluene, pesticides), and Antibiotics in water sources (Van der Meer and Belkin 2010).
3. **Synthetic Biology =>** engineered systems using fungal or bacterial bioluminescence have been incorporated into plants, bacteria, and mammalian cells for real-time biological feedback and smart biosystems (Mitiouchkina *et al*., 2020).
4. **Sustainable Technologies =>** bioluminescent systems are being explored for use in eco-friendly lighting especially in genetically engineered plants or algae as alternative to electricity-based lights in public spaces (Escher *et al*., 2020).
5. **Ecological Monitoring =>** natural or synthetic bioluminescent organisms can be used to: Monitor ecosystem health and Track biogeochemical cycles in marine environments (Haddock *et al*., 2010).
6. **Engineered bioluminescence Plants and Algae =>** recent innovations have enabled genetically engineered plants and algae to autonomously glow, potentially serving as: Living lights for sustainable urban design (Escher *et al*., 2020) and Biosensore for plant health or environmental stress (Mitiouchkina *et al*., 2020).

Use of Bioluminescence plant in society

The most important applications of this system are living bacteria, fungi, insects, firefly, are utilised as a light source. The main applications of the bioluminescence system are the studies of antimicrobial drugs, bacterial infections, and environmental monitoring (Bjorkman and Karl 2001). Fluorescent Protein can provide the fluorescent flowers and fluorescent plant specimens. Fluorescent plants utilized as alternative light source for desk lamp or street bulb in decorative area (Dunuweera *et al*., 2024). It is not only to produce a glowing street bulb, but the fluorescent plant will also play a major role in this solar energy. Transgenic plants are capable to produce auto luminescence light with new technology will allow researchers can study environmental stress in bioluminescence plant metabolism. Glowing plant can be supplied in the market, so that electricity will work for it and it will also be helpful in the economy. Indoor lighting; we can’t live without it, on the one hand light is becoming very expensive and it is also bad for the environment.

Use as a sustainable light source in the future prospective

In future possibilities; production of transgenic bioluminescence plant can be an alternative option as decorative stuff for buildings and areas. Engineered bioluminescence plants through synthetic biology to autonomously emit light without external energy input, offer a promising, nature-based alternative for low-energy lighting. Also, create ornamental glowing plant as a street or reading lamp, which doesn't use any electrical energy. Glowing light will produce automatically by the metabolism activities of living plant leaf. The innovation will lead to low intensity indoor lighting and also transformation into these plants or trees into self-made light and all the streetlights and pole lights. Somehow this alternative source of lighting will also help to conserve lights on large or small scale. These glowing plants are very useful to promoting substitutes of artificial light to light up the night sky in the future.

In this article, we provide an intentionally brief overview of emitting light reaction. Thus, they have done with many plants like kale, spinach, arugula, and watercress can be used as the illumination for reading and writing.

Sustainable development in the next generation of society

In the future; sustainable development has evolved from a concept into imperative for global well-being. Defined by the Brundtland Commission as development that ‘‘meets the needs of the present without compromising the ability of future generations to meet their own needs’’ it emphasizes the balanced integration of economic growth, environmental protection, and social equity. Farmers can cultivate this plant, which will be a good source of income. These bioluminescence plants can also be used as ornamentals, which are largely for decoration purpose. This glowing plant will prove to be a good and beautiful result of the research area and will also provide an advantage field of research. These bioluminescence plants will be very attractive and will prove to be a good example of novel research, so they will also be expensive. If this is an ornamental plant – then its price will also be high, which will prove beneficial for the economy condition and farmers will also get benefit. This bioluminescent plant will prove to be helpful in the economy as will as it will save some amount of electricity, which is also good for our environment. As the next generation faces intensifying challenges – climate change, resource depletion, biodiversity loss, and social inequalities – sustainable development must transform from policy to practice across all sectors of society.

3. CONCLUSION

The concept of bioluminescence plants represents a visionary intersection of synthetic biology, environmental design, and sustainable innovation. Bioluminescence is a simple technique for generating emitted light that produces light in the presence of oxygen. Light can also be generated in living organisms by transferring the bioluminescence gene. Light is produced by transferring the genes of many types of bacteria, fungi, insects, firefly, marine organism, algae, dinoflagellate, jellyfish, earthworm, and sea star fish to the living organism. By integrating natural light-producing pathways into plant systems, researchers are exploring the possibility of creating living, self-sustaining sources of light that operate without the need for external electricity or chemical inputs. These genetically engineered organisms could significantly contribute to energy-efficient urban lighting, eco-friendly interior design and real-time environmental monitoring, aligning closely with the core principles of sustainable development. In the last several years many types of luminescence systems have been discovered such as – the luciferase-luciferin system, PBIN technique, bacterial bioluminescence system, caffeic acid cycle (CAC) and fluorescent proteins (FPs), all these techniques can convert normal plant into glowing plant which can be seen with naked eyes. In this review, attention the focuses will be the roll of bioluminescent system. In this review paper; a brief summary of almost all the techniques used to make a bioluminescent plant has been written, so that it will be convenient for new researchers. As genetic engineering advances bioluminescence system will likely play an increasingly prominent role in next-generation bio-integrated technologies.

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