Biophoton interaction in biological systems: evidence of photonic info-energy transfer?

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ABSTRACT

Photons are continuously absorbed and emitted by all living cells. A possible means of releasing energy when an electron changes energy states during a biochemical reaction is via biophoton emission. An example of energy transfer in biological systems is the process of photosynthesis. Biophoton emission has also been proposed as one possible mechanism responsible for intra- and intercellular communication (information transfer) as well as for regulation of biological and biochemical functions within cells and living systems. Measurements by other researchers of this emission have shown it has the properties of coherent light and is measurable from the UV through the near IR. Experimental evidence gathered by various researchers since the 1920’s indicates that light plays an important role in certain biological functions and processes. Through a series of experiments we have observed resonance effects between plant parts measured using a highly sensitive, low noise, cooled CCD in total darkness in a light-tight chamber. Dynamical systems theory offers a plausible explanation for resonance effects we have observed. The role of photonic interaction at the systemic level in biological systems has received relatively little attention. Yet, a better understanding of these processes would help us in deciphering the nature and role of light in biological systems.

Keywords: biophoton emission, biophoton imaging, biological chemiluminescence, bio-communication

1. INTRODUCTION

Biophoton emission (BE) is a type of biological chemiluminescence where photons are emitted as part of chemical reactions occurring during metabolic processes. This radiation is not stimulated by chemical or optical markers and is distinctly different from luciferin/luciferase reactions used in screening of gene mutants¹ and tumor detection² through the expression of the luciferase “firefly” gene.³ BE exists in all living organisms and persists at a steady state level as part of living metabolic processes. Its amplitude can be orders of magnitude below that of luciferin/luciferase reactions and has been measured in all types of plant, animal and human cells. This radiation is strongly correlated with cellular function (as first noted by Gurwitsch)⁴ and state of health.⁵⁻¹⁶ Hundreds of studies have looked at properties of this radiation.

A review by VanWijk ¹⁷ points out that as early as the studies by Gurwitsch in the 1920’s researchers have been testing the bio-communication aspects of photonic emission from cells. Gurwitsch put forth the idea that “radiation generates cell division” as early as 1911.¹⁷,¹⁸ His studies utilized onion roots as both radiation emitters and biological detectors. He noted that the cellular division increased exponentially on the sides of the roots facing one another while in shadow areas the cellular division rate was less.¹⁹ To show that it was due to effects of radiation rather than chemical, quartz plates were placed between the roots. In later studies it was shown that the radiation passed through quartz plates and not through glass indicating that the stimulating radiation was in the UV portion of the spectrum.¹⁷,²⁰

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These studies were performed before sensitive photon detectors existed. Many years later these and other studies utilizing biological detectors were corroborated using photomultiplier tubes (PMTs).\textsuperscript{21,22} With the development of PMTs in the late 1940’s research concentrated on quantifying weak luminescence from plants and determining its spectral qualities.\textsuperscript{23,24} Emission in the UV was correlated with cell division\textsuperscript{21,25} and emission in the red was found to be related to photosynthetic, chlorophyll\textsuperscript{23} and other oxidative metabolism.\textsuperscript{26-28} These studies focused much more on the mechanisms generating the light than on the informational or functional aspects of the light.\textsuperscript{17} Van Wijk points out that most biochemists considered photon emission as a waste product of the chemical reaction that didn’t serve another purpose.\textsuperscript{17} He also asks how could Gurwitsch have seen variations in cell division rates if there wasn’t some informational or functional aspect to the emission? Gurwitsch was looking at effects that were large enough to be seen with the naked eye. Sensitive photon detectors were not available when Gurwitsch reported his findings.

In the last 30 years a number of different researchers have begun to more fully investigate the information aspects of biophoton emission. Much of this research has been has been led by Fritz-Albert Popp at the International Institute of Biophysics in Neuss, Germany.\textsuperscript{29-33} Popp is the one who coined the modern usage of the word “biophoton” to refer to biological chemiluminescence emitted by cells as part of metabolic processes. When looking at a system as a whole, if there are informational aspects to the radiation there should be some correlation between processes and BE. Van Wijk and co-workers have shown that there is a difference in BE for increasing number of cells and whether they are normal cells or tumor cells.\textsuperscript{5,34} Normal cells show a decreasing emission with increasing number of cells, while tumor cells show increasing emission with an increasing number of cells.\textsuperscript{17} Furthermore this emission is dependent on cell type and the decay of illumination with time depends upon whether the cells are normal or tumor. The difference in the decay law has been attributed to the coherence of the radiation by applying the coherence theory of Dicke.\textsuperscript{17,35} Normal cells have greater coherence in their emission than do tumor cells. These theories have led to more studies of the quantum properties of biophoton emission including theoretical properties and energy states.\textsuperscript{30,32,33,36,37}

Up until a few years ago it was not possible to create images of BE from a biological system. The first images presented in the literature utilized multichannel PMTs or multianode PMTs and only had a few pixels of resolution in each direction.\textsuperscript{38-42} Only recently have high-resolution low-noise super-cooled CCD arrays been available at a reasonable price. Cameras originally developed 10-20 years ago for long exposure images through telescopes have proven to be very useful in studying biophoton emission.\textsuperscript{43-46} The system used for these studies will be described in the next section.

Over the past 2-1/2 years we have observed variations in BE patterns produced by various plant parts such as leaves and vegetables as a function of time and noted that injury (such as cutting) and unhealthy tissue is associated with clearly visible increased biophoton emission.\textsuperscript{43-46} As we studied the thousands of images we recorded, we began to observe there were also patterns in the “noise” surrounding the plant parts. It appears as if not only did the biophoton patterns extended beyond the plants, but that patterns were strengthened between plants when they were in close proximity. In this paper we will present some of these images and point out the patterns surrounding plant parts creating “auras” as well as those between plant parts that fall off with distance. We will also describe the imaging system and present ways in which these patterns can be enhanced. In our discussion we will present a dynamical systems explanation for the patterns we are observing.

### 2. BIOPHOTON IMAGING

The imaging system used for these studies was a Princeton Instruments VersArray 1300B low-noise high-performance CCD with cryogenic cooler, manufactured by Roper Scientific.\textsuperscript{47} The system includes a camera head containing the sensor and readout electronics along with electronics to get images into a computer, a CryoTiger cryogenic cooler and software for controlling the camera and acquiring images. The camera is mounted on top of a dark box that is as light tight as possible (see Figure 1). The sensor is a back-illuminated silicon CCD with 20μm x 20μm pixels (E2V CCD36-40, grade 1) digitized to 16 bits yielding 65,536 grey scale levels (GSLs). It is cooled to reduce thermal and readout noise. For optimal exposures, the sensor is cooled to a temperature of –80 to –100°C using the CryoTiger. The response of this sensor spans from 350-1000 nm with the maximum response in the 400-800 nm wavelength range.
Much of what this sensor detects is in the range of human vision; however, it is much more sensitive to low light levels than human vision, and can see things that the human eye cannot. The output of this sensor is directly proportional to the number of photons incident at each pixel. Using the specifications provided by Roper Scientific\textsuperscript{47} when operating the camera in low-noise mode with a gain of 4x and assuming an average quantum efficiency of 0.8 as outlined in the specification sheet for the sensor, there are approximately 1.6 photons per GSL. This camera is essentially close to counting photons.

A standard Nikon F/1.2 50mm lens set at F/1.2 is used to image the plant parts. The field of view (FOV) at the closest focal distance (CFD) is 220 mm wide. Objects to be imaged are placed on a black or non-fluorescing piece of paper on top of a focusing stage at the CFD. Because nothing is truly light tight and there are always some ambient photons present even in the darkest room and the darkest enclosure, the imaging system is placed within a darkened room and baseline images are monitored before and after each imaging session to determine if there has been a light leak. Baseline images are taken without the presence of objects and have the same exposure time as the regular images so that we may determine noise background levels.

The necessary operating temperature of the sensor was determined by taking images at different sensor temperatures with no object present. As shown in Fig. 2(A) the background noise minimizes when operating the CryoTiger at least as cold as \textdegree{80}C with 1-minute exposure times. The background levels are shown as number of GSLs. 1x1 refers to reading out every pixel, while 3x3 is the binning of groups of 3 pixels wide and 3 pixels high in hardware and reading out this 9-pixel unit as a single pixel. When hardware binning is used the resolution of the sensor is decreased. For 3x3 binning each image element is now 60x60\textmu{}m instead of the 20x20\textmu{}m for 1x1 binning. Binning effectively enables increasing the signal-to-noise level (SNL) because the system is essentially background limited. Figure 2(B) shows signals from plant leaves compared to background levels with no object present for different settings of hardware binning. Figure 2(C) shows how binning can help increase the signal level as a function of time. Most of the measurements taken for this study utilize 2x2 binning, which increases the SNL by a factor of four, but only decreases the image resolution by a factor of two.
Figure 2. (A) Mean grey-scale level (GSL) for different operating temperatures and hardware binning levels for 1-minute exposures. (B) Relative GSLs for signal from a geranium leaf and background with no object as a function of hardware binning level. (C) Mean GSLs as a function of exposure time for two different hardware binning levels.

Figure 3 shows examples of images taken with this system. Figure 3(A) is a 100ms white light image of a group of different plant leaves. When the white light is turned off and the chamber is sealed no image can be seen in this light-tight chamber with a 100ms exposure (Fig. 3(B)). A one-minute exposure in the dark taken immediately after turning off the light and closing the chamber is shown in Fig. 3(C). This image illustrates the fluorescence of chlorophyll that will decay over 10-20 minutes. After the chlorophyll fluorescence has decayed there remains a persistent ultraweak biological chemiluminescence generally referred to as biophoton emission (Fig. 3(D)).

The chlorophyll fluorescence is many times brighter than the biophoton emission as can be seen in Figure 4(A). This plot shows the mean levels averaged over areas of geranium leaves with 1-minute exposures taken over a 3-hour long time period. Once the initial fluorescence has decayed, the biophoton emission persists and even slightly increases as time as the leaves are drying out. The emission from geranium leaves is predominantly in the red and near-infrared parts of the spectrum (see Fig. 4(B)). Further analysis of the data show that approximately 89% of the emission we detect from plant leaves is between 600-1000 nm. In plants, it is well-known that reactions relating to chlorophyll are a major contributor to emission in the red and near IR. This affirms the published experimental evidence pointing to chemical reactions involved in the production of singlet oxygen and other oxygen derivatives (free radicals) as the source of this emission. The work of Hideg and colleagues also points to similar reactions in mitochondria as another mechanism for emission peaking in the red and near IR present after many hours in darkness. Both chlorophyll and mitochondria are fundamental to cellular energy metabolism in plants.

Biophoton imaging can reveal information about the state of health of a biological object. When plant parts are used as objects, unhealthy and injured (cut) areas will have more emission than healthy and uninjured (uncut) areas. However,
there is a point where a portion of the plant part may be unable to emit biophotons when it no longer has metabolic processes functioning such as in a brown spot on a leaf.

Figure 4. (A) Average biophoton emission for geranium leaves with 1-minute exposures with background signal subtracted. (B) Emission of geranium leaves as a function of time with visible pass (380-670nm) and IR pass (>720nm) filters on camera lens. Scales of (A) and (B) are relative and of different sets of leaves and therefore cannot be directly compared to one another.

Figure 5. Cut geranium leaf on black stage platform. (A) White light image. (B) Chlorophyll fluorescence image. 1-minute exposure in total darkness. (C) Two-hour biophoton image after five hours in total darkness, Bright spots are high-energy “cosmic” ray hits. (D) Biophoton image (C) after a 5x5 median filter to remove cosmic rays.
Figure 5(A) shows a cut and slightly wilted geranium leaf with browned edges taken in white light with a conventional digital camera. Figure 5(B) shows a one-minute chlorophyll fluorescence image immediately after the light-tight chamber is darkened. Figure 5(C) shows a two-hour long biophoton emission image begun after the leaf had been in total darkness for 5 hours. Note that the biophoton emission persists and that some areas are brighter than other areas. Also note that details in the leaf such as veins are easily visible. The bright spots all over the image are due to high-energy rays such as stray gamma rays and other “cosmic” rays or particles that expose pixels of the array. These spots have much higher values than the surrounding pixels and can be removed using a median filter as shown in Fig. 5(D) that utilized a 5x5 median filter. Removing these “cosmic” rays enables more precise determination of biophoton emission in areas of plant parts. The downside of median filtering is that it reduces the resolution of the image (smears it) so that the details are not as visible.

3. BIOPHOTON INTERACTION

In our experiments, initially we placed the plant parts on a black background that absorbs light. To look more closely at the patterns around and between plant parts, we found that placing the plants on a white background (that did not itself fluoresce and glow in the dark) could enhance the ability to detect light patterns around the plants and potentially between them. Since the white background reflected and scattered light emitted from the plant parts, we were able to see more emission around the edges and between plant parts. This is analogous to energy workers who often report that they see human aura’s more readily when people are near white walls.

Figure 6(A) shows a two-hour biophoton image of geranium leaves with the gray scale scaled as a photograph. The leaves on the left side of the image are on non-fluorescing white paper to enhance the light around and between the leaves while those on the right side of the image are on black paper. The white paper reflects and scatters the biophotons emitted from the leaves so we can more easily see what is in the areas around and between the leaves. Figure 6(B) was enhanced in software by stretching the gray scale. This enables seeing areas between and around the leaves more clearly. This scaling shows that more light can be seen in the areas between and around the leaves on the white paper than those on the black paper. Figure 6(C) is an enlargement of the lower left quadrant of the middle image. Close inspection of this image shows a “halo-like” pattern around the leaves (i.e. an “aura”). Furthermore there is noticeably more light between adjacent leaves than around leaf edges without an adjacent leaf and this signal is stronger when leaves are closer together.

![Figure 6](image6.png)

Figure 6. (A): Biophoton image of geranium leaves taken as a two-hour exposure in total darkness inside a light-tight chamber. Leaves on the left side of the image are on non-fluorescing white paper and those on the right are on black paper. (B): Same biophoton image rescaled in software to enhance the area between the leaves. (C): Enlargement of lower left quadrant of (B).

Figure 7 shows one-hour biophoton images of string beans taken on white paper ((A) and (B)) and black paper ((C) and (D)). Figure 7(A) on white paper is noticeably hazier around the beans than Figure 7(C) on black paper. Both images have gray scales covering the entire range of the image as you would scale a photograph. The differences become more striking when comparing the software enhanced gray scales of Figure 7(B) on white paper and Figure 7(D) on black paper. Although it is obvious that there is light between the beans even on the black paper, it is much easier to see biophoton emission between the beans on the white paper.
Figures 8(A) and (B) show two images from an experiment we performed studying effects of distance between plant parts. Sections of string beans were pinned in place a known distance apart in millimeters on non-fluorescing paper and a series of one-hour biophoton images were taken. As expected, the bean sections were brighter in the first hour than in the fourth hour. When the gray scales are enhanced as shown in Figures 8(C) and (D) the amount of light between the sections falls off with their separation and as a function of time. It can be seen that the closer the cut pieces of beans are, the brighter the emission between them.
4. DISCUSSION

The images in Figures 6-8 show that we can see light emission beyond the edges of the plant parts. More light is seen when the plant parts are on a white non-fluorescing background than when they are on a black background. The white background enables scattering and reflecting of the light emitted from the edges as well as the unseen portions of the plant parts. This scattered and reflected light around the edges is analogous to what often is called an “aura.” It should be noted that this effect can also be seen on black backgrounds but it is more often than not much closer to the background noise level than it is with a white background.

Another aspect of the effects we are seeing is that when the plant parts are on a white background there is more light surrounding the plant part that can be absorbed as well as reflected from an adjacent plant part. We know we can only see photons that get into the camera lens. Those that are going at larger angles than the field of view are not visible in these images. Having a white textured background such as paper scatters and reflects many more photons into the lens’ field of view.

When plant parts are closer together they are receiving more photons from other plant parts. These photons can be absorbed by the adjacent plant parts and cause areas closer to other plant parts to glow more. Because each plant part glows a different amount depending upon its current state of health and hydration, we can only make relative comparisons of outputs of adjacent plant parts. We can infer and hypothesize from the images shown that there is some type of dynamic feedback mechanism at work as the plant parts interact with one another over time. This dynamic feedback appears to be stronger when the plant parts are closer together. It’s a process where plant part A illuminates plant part B which absorbs and re-emits a portion of the light back to A creating a mutual positive feedback loop. Photons passed back and forth between plant parts will pass energy back and forth as well as biophotonic information.

5. CONCLUSIONS

These images, and thousands of others recorded in our laboratory, reveal not only that plants “glow in the dark” but that the patterns of light emitted by the plants extend beyond them creating “aura-like” structures around them. Moreover, the patterns appear stronger when the plant parts are closer together, suggesting a dynamic feedback communication process involving mutual absorption and re-emission.

Whether or not the biophoton emission between and around plant parts we have observed has a functional purpose remains to be further tested. As stated in the introduction many researchers have been studying the properties of this light, however there remains much research to do to determine what functionality and informational aspects the emission may have. As more research on the bio-informational aspects of light in biological systems unfolds, we will gain a better understanding of the role the photon plays in biological functioning and a greater insight into the nature of light.

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