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Bioluminescence experience in the holistic cuisine: Making contact through living light and sound

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ABSTRACT

The holistic cuisine is an interdisciplinary work in gastronomy to understand food and gastronomic experiences in different ways. It encompasses different fields and knowledge from natural to social science. This concept created by Rasmus Munk, the chef from Alchemist restaurant in Copenhagen, shows how different fields can work together. Inspired in the concept of alchemy, the chef brings a new vision of gastronomy, understanding the world holistically. Since alchemists tried out to distill light from fireflies, the chemiluminescence phenomenon has been intensively studied by scientist nowadays. It can be defined as the emission of light resulting by chemical reaction between a protein called luciferin and an enzyme called luciferase. Many different microorganisms have the capacity to produce light, like the Dinoflagellates, *Pyrocistys lunula* (algae). This study measured the capacity of this algae to grow at two different temperatures. It was found that at 21 °C, pH 7 and 35% of salinity was the optimum conditions for the highest growth. Searching for the highest luminosity of the algae by acoustic wave stimulation, it was found that at 18 Hz, algae showed the most. Curiously, 18 Hz appears to be one of the frequencies in which the musical note G is emitted. To see the effect of the blue bioluminescence emitted by applying the musical note G, it was measured the emotional response of a bioluminescent experience. The sensory analysis showed how the blue light evoke curiosity, expectancy, interest, surprise, or admiration. Blue light might be used in a gastronomic experience due to the emotions that evoke, but also in other applications in order to handle emotional challenges and regulate mood over time.

1. Introduction

Holistic cuisine is a concept that considers many different elements as a whole to create a perfect culinary experience at the restaurant (Brønnum and Munk, 2019). By using interdisciplinary work, holistic cuisine integrates different fields of knowledge from natural sciences to social sciences, as well as philosophy, art, design, music, or literature (Korsmeyer, 2002) in an attempt to really understand gastronomy as a whole.

This synergy of knowledge, developed in a multidisciplinary space like gastronomy, opens new windows for food research and development and sensory sciences. A good combination between social, cultural, ethical, aesthetical and scientific factors can bring a more integrated and global understanding of the food and the gastronomic world. With this complex combination, holistic cuisine can be used as a tool to generate changes both on an individual and global level (Brønnum and Munk, 2019): a "human transmutation", according to the chef Rasmus Munk from Alchemist restaurant (Copenhagen). It clearly seems that this chef makes an intimate relation between holistic cuisine and the name of his restaurant. As alchemy was considered the precursor of the modern sciences by having a broad vision of nature, holistic cuisine might be the inspiration of a new vision of gastronomy.

Digging deeper into the ancient practice, alchemy developed a symbolic language that was used to explore the world from a scientific, spiritual, and philosophical vision (Íñigo Fernández, 2010). This multifaceted understanding of the reality was based mainly on observation (a crucial factor also for modern science). Describing the phenomena of nature and its link with the human being, the alchemist analyzed the qualities of substances: color, smell, texture, and reciprocal interactions (Pariente Pérez, 2016). The light was one of the elements

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studied and was commonly represented as a symbol of the spirit. In 1602, the alchemist Vincenzo Casciarolo accidently discovered Bologna phosphorus, known today as barium sulfate. He obtained a luminous powder, the so-called Lapis Solaris (the solar stone), able to accumulate light when exposed to the sun and to emit light into the darkness (Aldo Roda, 2008). This discovery created great interest in the alchemist community as it provided a direct link between matter and light (Ware, 2002).

After the systematic observation and deep understanding of nature, alchemists conceived that there was a strong relationship between the simple metals, the visible planets, the days of the week, the colors, and the musical scale. For example, the relationship between tin, with the planet Jupiter, the day Thursday, the blue color, and the musical note G (Huidobro Moya, 2007) as interesting factors to reach the peace of mind.

Under the observation of light, alchemists tried to "distill" light from fireflies and find a relation with blue color (Aldo Roda, 2008). They did not understand yet that nature could explain chemiluminescence phenomena, the emission of light resulting from a chemical reaction that produces photons in the visible light spectrum and requires around 40–70 kcal/mol (Zomer, 2010). Many different luminous species have been characterized such as bacteria, fungi, dinoflagellates, cypridinids, among others (Hastings, 2010). When chemiluminescence takes place in living organisms, such us insects or algae, the phenomenon is called bioluminescence. This natural reaction is produced by the oxidation of the protein, luciferin, and catalyzed by the enzyme called luciferase (Haddock et al., 2010; Pieribone, Vincent; Gruber, David F.; Nasar, 2007). The energy released from the reaction in the form of photons is at a wavelength around 470–490 nm in the blue part of the visible light spectrum.

The Dinoflagellates responsible for many spectacular displays of coastal bioluminescence are indeed interesting either from a scientific and an aesthetical perspective (M. I. Latz, 2017). These wavelengths in bioluminescence travel longer distances in marine environments (Latz and Rohr, 2005). According to Baker et al. (2008) there are at least 18 luminous species like the dinoflagellate *Pyrocystis lunula*. This microorganism produces the photosynthetic phenomenon by the organelles called "scintillons" (flash units) containing the luminescent chemicals (Seo and Fritz, 2000) with a diameter between 0.5 and 0.9 μm (Valiadi and Iglesias-Rodriguez, 2013). Dinoflagellates emit light due to pressure changes in the medium or stimulation by mechanical disturbance (M. I. Latz, 2017). This phenomenon has been interesting for the science community as well as for the artistic community (Video 1), including the culinary field. An example of this interest is the work done by scientists of the University of Cádez in collaboration with the chef Angel Leon, who was the first chef introducing bioluminescence in his restaurant as a cocktail (Pérez-Lloréns, 2019).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.ijgfs.2022.100641

Getting back to the alchemist belief about the strong relationship between the blue color and the musical note G, a nice mischief from a restaurant called Alchemist would be to find whether the musical note G (a mechanical force) could have an effect on the characteristics of the bioluminescence emission. And above all, could the emitted light have an effect on the guest's mood? Many different researchers have been studying the impact of light in human being-enhancing performance and mood in individuals who has mild sleep restriction (Gabel et al., 2013). Furthermore, the blue light enhances speed of information processing, so it is beneficial for learning process (Lehrl et al., 2007).

An enhanced speed of information processing after blue light but not after yellow light exposure.

Under a holistic perspective, it is important to revisit ancient knowledge as it can bring interesting inputs to be applied and to reinterpret by modern science. According to the holistic cuisine concept, the aim of this research was to understand bioluminescence in order to introduce it as a gastronomic experience in a restaurant. Specific objectives were focused on the growth study of the dinoflagellates *Pyrocystis lunula* at two different temperatures. Bioluminescence intensity made by the grown dinoflagellates was also studied when acoustic waves stimulation made by the application of the musical note G was applied into these microorganisms. Finally, the emotional response from consumers exposed to the emission of bioluminescence and musical note G was also studied.

2. Materials and methods

2.1. Growing of algae

Dinoflagellates of the *Pyrocystis lunula* strain were purchased from BioGlow Bioluminescence, a company located in Westfalen 47–3524 KE Utrecht, The Netherlands. The dinoflagellates were grown in seawater enriched with F/2 culture medium (Guillard and Ryther, 1962) in two growth chambers at controlled temperatures of 21 ± 2 °C and 27 ± 2 °C respectively. The temperature was continuously monitored through a digital thermometer (Inkbird Wireless Bluetooth Thermometer & Hygrometer Smart Sensor IBS-TH1). The pH was recorded through a pH meter (Thermo Scientific - Eutech Expert pH). The cultures were exposed to artificial light, provided by a flexible LED light strip (PEREL-Flexible LED strip, cold White), a constant luminous flux per meter (206.64 lm) in periods of 14 h of light and 10 h of darkness (Guillard, R., & Keller, 1984). The day was programmed to start at 22:00 h and the night at 14:00 h. The seawater used in the culture was initially sterilized by maintaining a temperature of 95 °C for a period of 30 min. Subsequently, 5 mL of F/2 medium was added to 10,000 mL of seawater. The dinoflagellates were diluted by a factor of 10% (300 mL seawater – 30 mL Dinoflagellates) (Guillard, R., & Keller, 1984) and maintained in sterilized 500 mL Erlenmeyer vessels. The cell density of the *Pyrocystis lunula* strain was determined through the Sedgwick-Rafter cell counting chamber (50 mm long by 20 mm wide and 1 mm deep for a total area of 1000 mm2 and internal volume of 1 mL). The stereo microscopy was used for the cell counting which model is ZEISS Stemi 305, with a built-in camera model Axiocam 208 color. Samples of cell growth, pH and salinity, which were taken per triplicate, were recorded every third day at 15:00 h. A total of 15 samples were taken over a period of 48 days. Both samples were done by triplicate.

2.2. Acoustic waves stimulation

The stimulation of algae was measured by an apparatus built for this experiment. The apparatus consists of an 8″ diameter subwoofer (Fenton SHFS08B). Attached to the speaker membrane, a 50 mm high x 60 mm diameter PVC tube was placed to settle a 170 mm diameter x 1 mm thick metal plate. Attached to this surface, a polypropylene (PP) container measuring 195 × 195 × 51 mm with a total volume of 1300 mL was placed. A digital frequency generator was used by (Szynalski, n.d.). Acoustic stimulation was performed on *Pyrocystis lunula* algae by putting the samples into the container from frequencies ranging between 10 Hz and 100 Hz. It was also performed at sound frequencies in the musical note G (Huidobro Moya, 2007): 12.25 Hz (G-1), 24.5 Hz (G0), 48.9 Hz (G1), 97.99 Hz (G2) (LuxDeLux, 2020). The illumination peak emitted by the bioluminescent algae was recorded for each experiment. For the photographic record, a camera (Canon EOS - 5D Mark IV) with a lens (50 mm 1:1.8 ST) suspended at 30 cm height from the polypropylene container containing the *Pyrocystis lunula* algae was used. For each photographic record, the camera was set as follows: ISO: 8000, shutter speed: 1″, F: 4.0. The sound stimulation interval was 3 s and 5 min rest between photos. For each sound frequency, the photographic record was replicated 5 times, obtaining 50 photos for the sound stimulation between 10 Hz and 100 Hz, 20 photos for the four frequencies used in the musical note G, and 60 photos for the sound stimulation between 18 Hz and 29 Hz. A total of 120 photographs were obtained. The numerical values of each photograph were provided by Adobe Photoshop 2020) (Adobe Inc., 2020).

2.3. Sensory analysis

The study was performed with 73 people from Basque Culinary Center, San Sebastian, in a gender ratio of female (65.75%) and male (34.25%). The range of age has been from 20 to 58 years old (averaging 28 years old). The sensory analysis was performed in two different parts. The first part had the objective to measure the emotional response of bioluminescent experience according to Plutchnik's wheel of emotions (Plutchik, 1980), shown in Table 1. The algae were stimulated under the sound created by musicians according to a range of frequencies between 20 Hz and 30 Hz obtained in this research, for 3 min. The second part of the sensory analysis was conducted by consumer testing of a cocktail under the effect of bioluminescence, and one with non-natural illumination (fluorescent). It used a 9-points hedonic scale (1 = extremely dislike, 9 = extremely like). Both cocktails were served to 30 mL in a plastic and transparent glass. The sensory analysis room was kept at 21 ± 2 °C and none of the consumers had taste disorders. The samples were served from nonnatural illumination to bioluminescence illumination, and the consumers had to rinse their mouths between samples.

The cocktail was made with 27.78% of melon juice, coconut water and gin, 0.28% of xanthan gum in water. To make the foam 0.22% of gelatine was dissolved in water (3.58%) at 50 °C. The egg white powder (0.22%) was dissolved in 41.39%, next 11.63% of lime juice, 15.88% of lemon juice, 27.07% of simple syrup (1:1 water and sugar and reduced) were mixed with the rest of the ingredients (Adriá et al., 2014).

2.4. Data analysis

The Wilcoxon test (non-parametric test), for two independent samples, was conducted using sample 1 and sample 2, setting up at 21 °C and 27 °C, respectively, to analyze the algae growth, pH and salinity, over the time. The Shapiro-Wilk test was conducted before the non-parametric test, to study the normal distribution. The sensory analysis data was analyzed in two different parts. In order to study the emotional response of bioluminescent experiences, variance analysis and F-test for one sample was conducted, to analyze which attributes were more chosen. Hedonic test was conducted using t-student to study the differences between illumination exposition and gender. Results were considered significant when $p < 0.05$. All data analyses were conducted using the statistical package XLSTAT Version 2020.4.01 (Addinsoft, USA) (Addinsoft, 2021).

3. Results and discussion

3.1. Growing algae at two different controlled temperatures

As explained in the methodology section, dinoflagellates (*Pyrocystis lunula*) were grown in seawater at two different temperatures (21 °C and 27 °C) in order to observe the effect of temperature on microbial growth. Growth of the Dinoflagellate, *Pyrocystis lunula* was very sensitive to temperature and pH, whereas salinity showed almost constant values between 35% and 37%. Table 2 shows significant difference between 21 °C and 27 °C samples.

The maximum growth for the samples was produced in day 36 at 27 °C and day 32 at 21 °C with a microbiological growth of 435 and 8675 cell count respectively. With the 27 °C sample, microbiological population immediately decreased showing complete algae death from day 28. From this day, it was noticeable a contamination of the sample by another microorganism which could produce a pH increase (from 7.07 to 9.73) (Table 2) and final microbiological death (Rastogi et al., 2015). At 21 °C, microbiological growth slightly decreased from day 32 (8675 cell count) to the day 51 (8000 cell count) but keeping a considerable number on microbiological population. The three days after the maximum growth, the pH slightly increased, the same as salinity (Table 2), therefore the division of cells decreased.

Table 1
Plutchnick's Wheel of emotions used in the sensory analysis study.

TRUST	GRIEF	ASTONISHMENT	INTEREST
BOREDOM	HOSTILITY	SADNESS	ANTICIPATION
ANGER	CURIOSITY	TOLERANCE	TERROR
ECSTASY	JOY	TIMIDITY	SERENITY
DISLIKE	LOATHING	SURPRISE	FEAR
ADMIRATION	DISGUST	DISTRACTION	EXPECTANCY
DEJECTION	CHEERFULNESS	ANNOYANCE	ACCEPTANCE
RAGE	PANIC	AMAZEMENT	SORROW

Table 2
Wilcoxon test (non-parametric) between samples from different temperatures (21- 27 °C) to pH, salinity (%) and microbiological growth (Cell count). The means, standard deviation, and p-value are shown.

Day	pH	±SD	Salinity (ppt)	±SD	Cell counts	±SD
Microbiological growth at 21°C						
0	7.25	0,07	36,00	0,00	110,50	20,51
3	8	0,14	36,00	0,00	217,50	95,46
6	8,15	0,07	36,00	0,00	475,00	84,85
10	8	0,14	35,00	0,00	677,50	10,61
13	8,2	0,00	35,00	0,00	1172,50	180,31
17	8,25	0,21	35,00	0,00	2100,00	212,13
20	8,15	0,07	36,00	0,00	2580,00	325,27
24	8,3	0,14	36,00	0,00	2475,00	1378,86
28	8,3	0,00	35,00	0,00	4230,00	622,25
32	**8,5**	**0,00**	**36,00**	**0,00**	**8675,00**	**1166,73**
36	8,8	0,14	36,00	0,00	7050,00	424,26
41	8,85	0,07	39,00	0,00	8050,00	70,71
45	8,75	0,07	35,00	0,00	8025,00	318,2
48	8,75	0,07	35,00	0,00	5900,00	1272,79
51	8,85	0,07	37,00	0,00	8000,00	2828,43
Microbiological growth at 27°C						
0	7,07	0,06	36,00	0,00	12,00	15,72
3	8,03	0,15	36,00	0,00	36,33	35,92
6	7,97	0,15	36,00	0,00	118,33	52,52
10	8,3	0,00	35,33	0,01	151,67	10,41
13	8,07	0,06	35,00	0,00	160,00	18,03
17	8,3	0,10	35,00	0,00	208,33	20,21
20	8,13	0,06	36,00	0,00	178,33	47,26
24	8,67	0,06	36,00	0,00	305,00	253,43
28	**8,67**	**0,12**	**35,00**	**0,00**	**435,00**	**235,64**
32	8,93	0,23	36,00	0,00	0,00	0,00
36	8,97	0,46	36,00	0,00	0,00	0,00
41	9,3	0,17	39,00	0,00	0,00	0,00
45	9,57	0,06	35,00	0,00	0,00	0,00
48	9,47	0,06	35,00	0,00	0,00	0,00
51	9,73	0,15	37,00	0,00	0,00	0,00
P-value	**0,017**		0,317		**<0.0001**	
Significant	**Yes**		No		**Yes**	

Previous results (Kim et al., 2004) showed that maximum growth rate was obtained at 25 °C and 34 ppt of salinity. Although the present study showed similar values than in previous results in salinity for optimal growth rate, optimum temperature was slightly different, showing a tenfold increase in algae growth at 21 °C compared with the sample growth at 27 °C (Fig. 1) and a fivefold increase compared with the sample at 25 °C (data not shown).

pH plays an important role to produce the reaction between luciferase and luciferin. The activity is optimum between 6 and 6.5 of pH and decreases notably after pH 8 (Hastings, 2010). The biological activity, due to the temperature, increases the photosynthetic activity and consequently increase the pH of the water caused by releasing OH-, which removes CO_2. Due to the availability of CO_2 in water decrease and the limitation of nutrients might explain the collapse of the crops, especially for that which was at 27 °C, which the algae died after 28 days (Fig. 1). In addition, none of the flasks were not shaken, so the layer surrounding the cells prevents the renewal of the water, and thus access to the nutrients. In consequence of the algae death, the biological activity increased and the water was contaminated by another microorganisms, complicating the growth of the rest of the algae, till the crops collapsed.

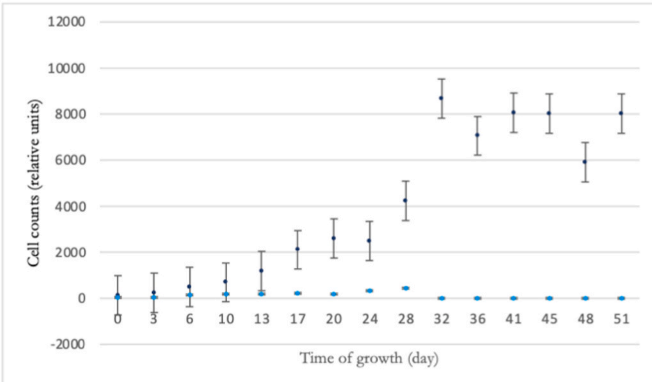

Fig. 1. The microbial growth (cell counts, relative units) to both sample at 27 °C (grey) and sample at 21 °C (black), per days.

3.2. The study of bioluminescence and frequency

According to the previous results, the second part of the studio was focused on stimulation of algae through different frequency ranges of note G to test alchemist beliefs (Huidobro Moya, 2007). The stimulation of frequencies was done from 10 Hz to 100 Hz (Fig. 2), chosen by a previously swept range of frequency (Sengpiel, n.d.) five times per measurements. In that range of frequency is localized G-1 at 12.25 Hz (*subsubcontra*), G0 at 24.50 Hz (*subcontra*), G1 at 48.99 Hz (*contra*) and finally G2 at 97.99 Hz (*great*) (Sengpiel, n.d.). This light needs to be induced by an action potential, triggered by a mechanical stimulus of the cell, in a specific proton channel into the vacuole. The mechanical stimulus is normally produced by the waves in the ocean or even waves produced by mammals such as dolphins among others (Fajardo et al., 2020). By stimulation of algae through different frequencies, it was obtained that at 24.5 Hz (G0), algae luminescence showed the maximum emission with a value of 53.9 units of luminosity intensity (Fig. 2). From this clear peak at note G0, light insensitivity decreased as frequency increased. Lower than 10 Hz and higher than 100 Hz, the algae did not have the capacity to produce the light through the reaction, not having the energy necessary to trigger it. The oxidation of luciferin by molecular oxygen origins an electronically excited oxyluciferin that emits blue light at λ-max of 480 nm (Fajardo et al., 2020). It was visually observed how the light is produced between 18 and 100 Hz, being the energy required to trigger the enzymatic reaction into the cell. The data was analyzed by using the histogram-luminosity tool. The following constant values provided by the program were considered: average, standard deviation, and pixels. It was also visually observed the much higher luminosity of algae when G0 was applied (Fig. 3) These measurements

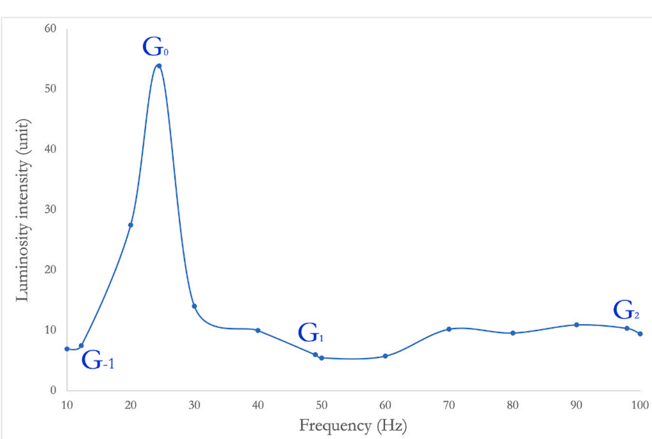

Fig. 2. The frequency (Hz) and luminosity intensity to the algae stimulation.

might confirm that the empirical approach of alchemists was right between the relation of colour and note G, although the references are very scarce.

4. Sensory analysis

Having clear that at G0, blue bioluminescence of algae showed a maximum luminosity, to follow "*alchemist path*", next step of this research was focused on people's response. Could the emitted light have an effect on the guest's mood?

According to previous results, a song was composed to stimulate the algae during the sensory analysis (track 1). Music for glowing things is written in the key off G, with the main component being a synthesizer sub bass, playing a rhythmical combination off two sine waves vibrating at 24.5hz (G0) and 49hz (G1). In this way the low frequency material of the music vibrates at an optimal frequency for stimulating bioluminescence.

The results showed (Table 3 and Fig. 4) that the bioluminescence evoked mainly curiosity, followed by expectancy, serenity, interest, and admiration for consumers. Joy and astonishment have been evoked by bioluminescence for 15 and 12 people, as Table 4 shows. In contrast, emotions such as rage, loathing have not been chosen by any consumers. The p-value is below to 0.05, thus the attributes have differences between them.

The curiosity, expectancy, interest, surprise, or admiration are feelings that might be explained by the neuroimaging effects. The neuroimaging effects of light on non-visual brain functions was more intense to blue colour than green colour, that is humans are more sensitive to shorter wavelength light (at around 460–480 nm; blue light). The molecule in charge of that is called melanopsin ipRGCs, a photoreceptor (protein) involved in non-image forming responses to light, including suppression of melatonin release, circadian rhythms, or even masking and induction of sleep (Hughes et al., 2012). Thus, the blue colour ($\lambda =$ 480 nm) can suppress melatonin secretion and is related with body temperature increase, heart rate and to shift circadian phase (Vandewalle and Dijk, 2013). Blue light stimulates connections between areas of the brain that process emotion, improving the speed of information processing. Furthermore, it improves the night-time sleep quality and duration, therefore is related with serenity (Table 3) (Gomes and Preto, 2015).

The second part of the sensory analysis, the bioluminescence was used to analyze how the light can influence the liking of a cocktail. Two samples were analyzed, sample one (without the presence of bioluminescence stimulation) and sample two (under the presence of bioluminescence stimulation). In general, there no differences between gender and samples, so the consumers liked the cocktail influenced by the bioluminescence and fluorescent light. These results might explain how the bioluminescence does not change the taste perception of food but evoke different emotions that improve a culinary experience.

5. Conclusion

The Dinoflagellates, *Pyrocystis lunula* are very sensitive to pH, salinity, and temperature. The optimum parameter to grow the algae and production of the bioluminescence reaction might be established at 7.5 pH (but no more than 8), 35 of salinity and 21 °C. In addiction it needs to be considered to shake the vessel to increase the renewal of the surrounding water fill in the cell to increase the access of the nutrients. Furthermore, the mechanical stimulation necessary of triggering the bioluminescent reaction is optimum at 18 Hz but might be possible in a range from 10 to 100 Hz. Blue light might be used in a gastronomy experience due to the emotions that evoke, but also in other fields in order to handle emotional challenges and regulate mood over time.

This work also intended to embrace another way to approach either gastronomy or science, connecting nodes in a much broader way. This approach tries to generate connections that in our current way of

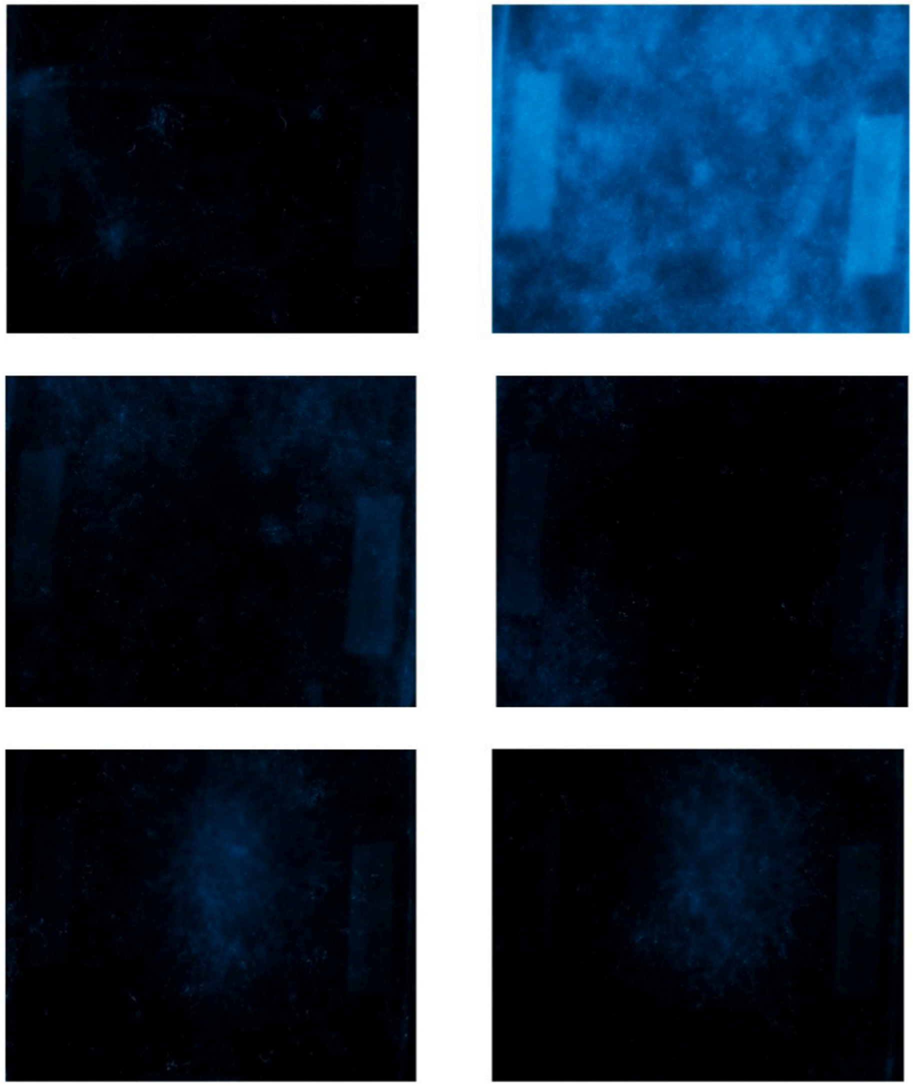

Fig. 3. Fig. 3. Bioluminescence produced by different intensity 12.25 Hz (G-1), 24.5 Hz (G0), 48.9 Hz (G1), 60 Hz, 97.99 Hz (G2), 100 Hz.

Table 3
Contingence table of emotions related to bioluminescence effect and F-value. The attributes were considered significantly different F > 0.05.

Attribute	Contingent data	Fisher	Attribute	Contingent data	Fisher
TRUST	5	**<0.0001**	ASTONISHMENT	12	**<0.0001**
BOREDOM	11	**<0.0001**	SADNESS	4	**<0.0001**
ANGER	0	**<0.0001**	TOLERANCE	5	**<0.0001**
ECSTASY	4	**<0.0001**	TIMIDITY	5	**<0.0001**
DISLIKE	3	**<0.0001**	**SURPRISE**	**25**	**<0.0001**
ADMIRATION	**20**	**<0.0001**	DISTRACTION	11	**<0.0001**
DEJECTION	3	**<0.0001**	ANNOYANCE	1	**<0.0001**
RAGE	0	**<0.0001**	AMAZEMENT	13	**<0.0001**
GRIEF	4	**<0.0001**	**INTEREST**	**32**	**<0.0001**
HOSTILITY	6	**<0.0001**	ANTICIPATION	6	**<0.0001**
CURIOSITY	**51**	**<0.0001**	TERROR	2	**<0.0001**
JOY	15	**<0.0001**	**SERENITY**	**35**	**<0.0001**
LOATHING	0	**<0.0001**	FEAR	8	**<0.0001**
DISGUST	2	**<0.0001**	**EXPECTANCY**	**38**	**<0.0001**
CHEERFULNESS	6	**<0.0001**	ACCEPTANCE	11	**<0.0001**
PANIC	2	**<0.0001**	SORROW	4	**<0.0001**

working is not permitted. It is our belief that during a meal experience, multiple elements are likely to overlap and might therefore be too complex to measure separately. Even scientists acknowledge the complexity of the meal, which reaches far beyond what we sense on the plate, or with whom we dine, the room, and the atmosphere.

Considering the complexity of a meal, chefs and other food professionals will benefit greatly from including scientific, cultural, social ethical, and aesthetical factors when designing meal experiences. This enables them to incorporate and communicate food culture, ethical and social perspectives that are embedded in our sense of pleasure.

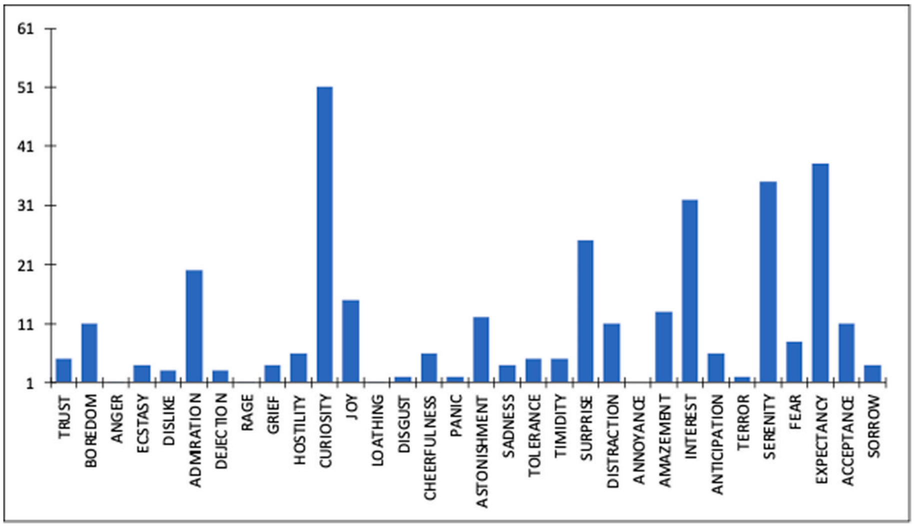

Fig. 4. Emotions related to bioluminescence effects and contingence value per emotions.

Table 4
Results of t-Student analysis. Mean and standard deviation of consumer test (liking) of samples and gender and p-value. The samples were considered significantly different $p < 0.05$.

Interaction	Mean	SD (±)	p-value
Nonnatural illumination (fluorescent)	6507	1386	0,567
Bioluminiscence illumination	6356	1767	
Female	6296	1594	0,140
Male	6708	1543	

Credit author statement

Giordano Espina Rodríguez: Investigation, Methodology, Formal analysis, data curation, writing. Juan Carlos Arboleya: conceptualization, formal analysis, methodology, supervision, writing. Diego Prado: gastronomic applications, investigation. Rasmus Munk: project administration, supervision, resources. Nabila Rodríguez Valerón: conceptualization, formal analysis, investigation, methodology, supervision, writing.

Implications of gastronomy

This work shows how the application of holistic cuisine can help to build interdisciplinary research by using the frame of gastronomy. From the restaurant Alchemist (Copenhagen) it is proposed a specific way of working that permits new findings to be used in the kitchen. Bioluminescence produced by algae can be used in culinary applications to design gastronomic experiences.

Declaration of competing interest

The authors declare no conflicts of interest.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijgfs.2022.100641.

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