No. 1. Patrícia Noronha, yeast biopainting, yeasts grown on watercolor paper, 22 × 41 cm, 2009. (© Patrícia Noronha)

No. 2. Patrícia Noronha, detail of a yeast biopainting, yeasts grown on watercolor paper, 27 × 42 cm, 2009. (© Patrícia Noronha)

ARTIST'S NOTE

Yeast Biopaintings: Biofilms as an Artistic Instrument

Patrícia Noronha

ABSTRACT

The author works with microorganisms that produce colored natural pigments to create *biopaintings* that result from the manipulation of organisms and their specific interactions. The author's biopaintings were obtained by controlling the growth of yeast cells on paper, ensuring the stability of the final results. These biopaintings resulted from the artist's observation and experimentation with evolving patterns of yeast biofilms. The often-unexpected results are part of the creative process and suggest new artistic methodologies to be explored. An overview of the aesthetic manipulation of microorganisms by other artists is briefly presented.

New objects and themes that traditionally belong to the area of science are populating the world of art today. A similar movement took place during the Renaissance. For example, in *The Ambassadors* (1533), Holbein painted two astrolabes, two globes, a sundial and a skull, objects not generally used in painting décor. Thereafter, scientific themes began to appear in paintings representing human activity, as in *The Anatomy Lesson* by Rembrandt (1632) and the *Portrait of Pasteur* by Edelfelt (1885). More recently, the now-defunct science culture journal *The Sciences* illustrated all its articles with paintings from the world of art. In recent decades, scientific research institutes have begun to open their doors to artists. Genetics, robotics and computers are the main attractions, and several projects have been created as a result of the interaction between artists and scientists [1–4].

Nowadays artists can work with traditional painting materials or use other methods, for example, exploring the pictorial activity of a robot [5], a computer program [6] or microbial cells [7,8].

The State of the Art in Biopaintings

Nobel Prize winner Alexander Fleming developed a procedure for growing microorganisms on paper that he called "germ paintings." He used a wide collection of bacteria and molds to draw images directly on paper soaked in a culture medium and grew the organisms in an incubator [9]. Although the final result was microbial paintings on paper, they were produced and preserved for scientific and not artistic purposes.

In 1988, Peter Gerwin Hoffman removed bacteria from Wassily Kandinsky's painting *Parties diverses* (1940) and created a new artwork in the laboratory entitled *Microorganisms by Kandinsky*. The bacteria were grown in a culture medium and were then used to compose a picture formed by petri dishes containing those microorganisms. Kandinsky's painting was selected because the Russian artist had often postulated that abstract art creates a new world, which on the surface has nothing to do with "reality," and that this new world will one day be just as concrete as the "real" world [10].

In the early 1990s, David Kremers genetically altered *E. coli* bacteria so they would produce colored enzymes. He used those strains in paintings on agar plates; the growth was then arrested by removing moisture from the plate, and the plates containing the bacteria were sealed out with a synthetic resin, leaving the work in a state of suspended animation. The work was neither "dead" nor finished, and the resin could be removed to supply the bacteria with fresh nutrients [11–13]. Marc Quinn constructed *Sir John Sulston: A Genomic Portrait* (2001) using bacteria containing DNA fragments from Sulston's sperm. The *E. coli* recombinant cells containing Sulton's DNA fragments were suspended in a culture medium in a mirror-like frame [14].

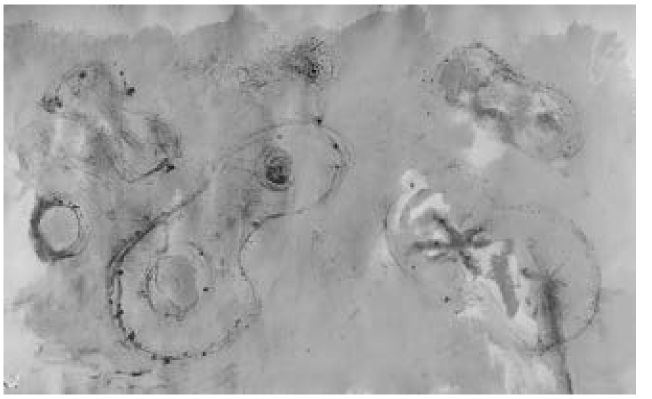
In his transgenic artwork *Genesis* (1999), Eduardo Kac created a synthetic gene by translating the sentence "*Let man*

Patrícia Noronha (researcher, visual artist), Instituto de Tecnologia Química e Biológica (ITQB), Universidade Nova de Lisboa (UNL), Av. da República—EAN. 2780-157, Oeiras, Portugal. E-mail: <pnoronha@itqb.unl.pt>, <pnoronha69@gmail.com>.

See <www.mitpressjournals.org/toc/leon/44/1> for supplemental files related to this article.

Article Frontispiece. Yeast biopainting, yeasts grown on watercolor paper, 28 × 18.8 cm, 2009. (© Patrícia Noronha)

Fig. 1. Yeast biopainting with biologic forms, yeasts grown on watercolor paper, 27 × 42 cm, 2009. (© Patrícia Noronha)



have dominion over the fish of the sea, and over the fowl of the air and over every living thing that moves upon the earth," from the biblical Book of Genesis, into Morse code and converted the Morse code into DNA base pairs. This "*Genesis* gene" was incorporated into bacteria. A culture of these bacteria was displayed in a gallery show, where the public could turn on an ultraviolet light, causing biological mutations. The mutated bacteria DNA was then translated back into Morse code and then back into English. The mutation that took place in the DNA changed the original biblical sentence, and, in the context of the work, the ability to change the sentence is a symbolic gesture [15]. The projection of the bacterial culture on the wall of the gallery was a vivid painting. In *Specimen of Secrecy about Marvelous Discoveries* (2004–2006), Kac again worked with microorganisms creating living images that changed during exhibition in response to internal metabolism and environmental conditions [16].

Artists such as Peta Clancy [17], Edgar Lissel [18], K.D. Thornton [19], Ana Dumitriu [20], Polona Tratnik [21] and Marta de Menezes [22] have used microorganisms to produce bio art works, but in differing contexts and with different purposes. Andre Brodyk uses transgenic *E. coli* transformed with encoded genetic material that enables the production of the proteins responsible for either green fluorescence or red fluorescence. These bacteria were used in numerous bacterial drawings in petri dishes [23].

In 2009, I presented a one-day installation with live biological cultures, titled *World (s) zero-reinvention,* at the Calouste Gulbenkian Foundation Gardens in Lisbon. This site-specific installation was a live biopainting performed with 25 species of microorganisms (yeasts, filamentous fungi and a *cyanobacterium*) in 157 petri dishes (each 15 cm in diameter). This work was a reflection on the frailty of life and the need to reinvent our world [24].

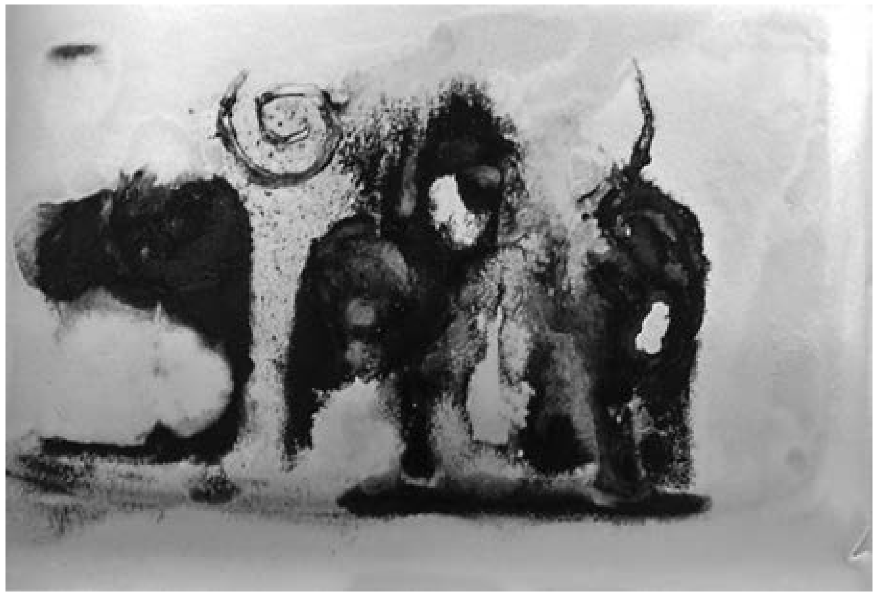


Fig. 2. Yeast biopainting, yeasts grown on watercolor paper, 20 × 28 cm, 2009. (© Patrícia Noronha)

Fig. 3. Yeast biopainting, yeasts grown on watercolor paper, 15 × 24.5 cm, 2009. (© Patrícia Noronha)

Yeast Biopaintings

Until the end of the 18th century, artists ground and mixed their own pigments, which were mostly of mineral origin. They had a special relationship with the materials they used and possessed considerable skills as practical chemists. With the birth of chemical technology in the early 19th century, artists began to use industrially produced synthetic colors [25,26].

A variety of pigments, such as flavins [27], carotenoids [28] and melanins [29], are known to be produced by the cells of various yeast species. I am exploring the possibility of using yeast microorganisms as pigments on paper to produce art for what is to my knowledge the first time. Biopainting production and its durable fixation to paper is an original way of painting that can bring up a series of questions about the use of living organisms to produce artworks.

Yeast biofilms can be used as pigments to produce bio art. Biofilms are thin films composed of millions of cells stuck together like a tissue. I selected a collection of yeast cells (unicellular fungi) based on their color and texture characteristics (*e.g. Rhodotorula spp.*, *Bullera spp.*, *Cryptococcus spp.* and *Rhodosporidium spp.,* from the Portuguese Yeast Culture Collection [PYCC]). I then manipulated them in such a way that they could be used as materials to produce biopaintings.

Yeast colonies have a limited variety of colors: white, black, yellow, magenta, orange and pink. I have produced blue and green yeast colonies by growing some species in a culture medium (Color Plate D No. 2) [30], in the presence of methylene blue, which, in some cases, can be absorbed by the cells. I have isolated a new black yeast species from cork and have explored it according to its capacity to grow on paper. This black yeast is as intrinsic a part of this art project as was the vibrant ultramarine blue developed by Yves Klein in 1955 and patented by him as a new color [31]. The new black yeast species found during the development of this work has been taxonomically identified and deposited at Centraalbureau voor Shimmelcultures (CBS).

I inoculated the yeast cells onto sterilized watercolor paper soaked with culture medium and placed on a sterilized tray containing appropriated solid culture medium. The activity of painting is initiated by the inoculation of yeasts on the paper medium. Then I incubated the cultured microorganisms in the watercolor paper at 25°C. At this stage, the different strains of yeast cells begin to grow, invading the whole paper. During the growth process, biofilms and co-aggregates of cells belonging to different species appear, undergoing competition-cooperation relationships [32,33]. When I consider the painting complete, the microorganisms are killed by ultraviolet light, leaving their print on the surface of the paper (see Article Frontispiece, Figs 1–4 and Color Plate D Nos. 1 and 2). This last step is an important part of the creative process, since it is the artist, through intuition, who decides when the work is finished, as has always been the case in art. This decision transcends the field of bio art and shares commonality with all artistic activity.

During the production of biopaintings, the yeast cells undergo all stages of life processes: growth, maturation, decay and death [34]. The initial orientation is set by "painting" the regions where the yeast cell growth is to begin. After that, the biopainting process is autonomous and depends on the relationship between microorganisms and their growth conditions. The artist interferes in the biopainting by inoculating the paper with more yeast cells and/or by changing the growth conditions (e.g. by adding fresh culture medium). This is part of the creative process.

In some cases, the initial drawing can be detected by some "defined" lines or dots in the final painting (as in the case of Fig. 1). However, in most biopaintings, the cell growth completely covers the paper surface, and only a residual trace of the initial drawing remains (Figs 2–4, Color Plate D Nos. 1 and 2).

The blue biopainting in Fig. 4 was made using three distinct yeast species on a culture medium dyed with methylene blue: a black yeast (a new species still to be classified by CBS, black in color after it is fully grown under appropriate conditions), *Rhodotorula glutinis* (original color orange; turns to green when grown with this dye) and *Sterigmastosporidium polymorphum* (originally a white yeast that becomes blue when it absorbs methylene blue). This orange *Rhodotorula glutinis* and the white *Sterigmastosporidium polymorphum* easily absorb the methylene blue, while the black yeast is not very tolerant to this compound and does not grow in these conditions. As a consequence, we only see a faint trace of the initial drawing made with the black yeast cells (see the black lines), as its subsequent growth is inhibited. The black/grey image that we see is almost solely the result of growing the species *Rhodotorula glutinis* and *Sterigmastosporidium polymorphum* colored by a blue dye.

Due to interactions of cooperation/competition and reaction to the environment [35,36], the microorganisms grow and reorganize themselves on the paper, often changing the initial drawing completely. The final pictures are the result of the growth of biological patterns and do not present similarities with recognizable images. Biopaintings result from the artist's observation of the interactions between the cells and from experimentation with their evolving patterns. The often unexpected results are part of the creative process and suggest new methods to be explored.

I am still experimenting with this methodology in order to improve the stability of the colors and the adherence of the biomaterial to the surface. So far, the biopaintings presented here have remained stable for 6–12 months when covered with a commercial varnish. I selected and tested all the materials and technical procedures to obtain the desired performance. Using this technique of painting with microorganisms in a strictly controlled scientific laboratory, the artist recovers the craftsmanship of pigments. However, the fact that yeasts are microorganisms and the growth is in a way without control adds an unexpected artistic dimension to biopaintings. This predicted under-control has formal similarities with Jackson Pollock's work.

This dialog between art and science constitutes a new trend in contemporary art, as did the motifs of Holbein's painting. The use of new developments of science to produce art contributes to the creation of new forms of expression and to the dissemination of new technological concepts, bringing to the public a deeper understanding of the technological achievements of the modern world.

Fig. 4. Blue yeast biopainting, yeasts grown on watercolor paper, 19 × 28 cm, 2009. (© Patrícia Noronha)

Acknowledgments

This work was developed at Instituto de Tecnologia Química e Biológica (ITQB/UNL) under a post-doctoral grant in artistic studies (SFRH/BPD/44351/2008) and has been funded by Fundação para a Ciência e Tecnologia (FCT). I would like to thank T. Barreto Crespo for advice and scientific support; I. Ritto, V. San Romão and Carmo Basílio for advice; and A. Fonseca (UNL) for providing samples from the PYCC. Finally, I am grateful to the *Leonardo* referees and editor for their comments on the manuscript.

References and Notes

1. S. Wilson, *Information Arts: Intersections of Art, Science, and Technology* (The MIT Press, Cambridge, MA, 2002).

2. B. Arends and D. Thackara (Ed.), *Experiment: Conversations in Art and Science* (Wellcome Trust, 2002).

3. For art and science more generally see E. Strosberg, *Art and Science* (Abbeville Press, 2001).

4. S. Ede, *Art & Science* (I.B. Tauris, 2005).

5. L. Moura, *RAP, Robotic Action Painter* (Catalogue, Palace Galery, Municipal Museum of Tavira, 2009).

6. L. Moura, ed. Inside: Arte E Ciencia (Art and Science) (Catalogue, Ed. LXXL, Lisbon, 2009) pp. 102–109.

7. <www.microbialart.com/2009/11/biopaintings/>

8. <www.itqb.unl.pt>

9. E. Kac (Ed.), *Signs of Life, Bio Art and Beyond* (MIT Press, 2007) pp. 22–23, 345–346.

10. I. Reichle, *Art in the Age of Technoscience. Genetic Engineering, Robotics, and Artificial Life in Contemporary Art* (SpringerWienNewYork, 2009) p. 65.

11. Wilson [1].

12. Kac [9] pp. 295–297.

13. Reichle [10] pp. 65–66, 283.

14. S. Anker and D. Nelkin, *The Molecular Gaze. Art in the Genetic Age* (Cold Spring Harbor Laboratory Press, 2004) pp. 9–10.

15. E. Kac [9] p. 164 includes details on the show; the mutated sentence read: "Let aan have dominion over the fish of the sea and over the fowl of the air and over every living thing that ioves ua eon the earth."

16. Reichle [10] p. 131.

17. Reichle [10] pp. 284–285.

18. Reichle [10] pp. 286–293; Edgar Lissel, "The Return of Images: Photographic Inquiries into the Interaction of Light," *Leonardo* **41**, No. 5, 438–445 (2008).

19. Reichle [10] pp. 294–295.

20. <web.mac.com/annadumitriu/iweh/NF/homo.html>

21. <www.ars-tratnik.si/Microcosmos.htm>; Polona Tratnik, "37<deg>C: From the Inside of a Being to the Thin Line of Life," *Leonardo* **38**, No. 2, 102–108 (2005).

22. <www.martademenezes.com>

23. <eaf.asn.aw/biotech/brodyk.html>

24. See Ref. [8].

25. R. Mayer, *The Artist's Handbook of Materials and Techniques* (5th ed. Penguin Books, 1985).

26. P. Ball, *Bright Earth, Art and the Invention of Color* (Chicago, 2001).

27. B. Yongsmith, W. Tabloka, W. Yongmanitchai and R. Bavavoda, "Culture Conditions for Yellow Pigment Formation by *Monascus spp.* KB10 grown on cassava medium," *World Journal of Microbiology and Biotechnology* Vol. 9, No. 1, pp. 85–90 (1993).

28. P. Davoli and R.W.S. Weber, "Carotenoid pigments from the red mirror yeast, *Sporobolomyces roseus*," *Mycologist* Vol. 16, pp. 102–108 (2002).

29. T.W. Flegel, V. Meevootisom, Y. Thebataranoyh, Z. Qi-Tau and J. Clardy, "A New Naphthaquinone Antibiotic from a New Species of Yeast," *The Journal of Antibiotics*, Vol. XXXVII, No. 4 (1984).

30. G. Acuff, C.R. Vanderzant and D.F. Splittstoesser (Ed.), Compendium of methods for the microbiological examination of foods (3rd ed., 1992) pp. 1145 and 1165.

31. R. Mayer [25].

32. G.A. O'Toole and M.E. Davey, "Microbial Biofilms: From Ecology to Molecular Genetics," *Microbiology and Molecular Biology Reviews* Vol. 64, No. 4, pp. 847–867 (2000).

33. P. Watnick and R. Kolter, "Biofilm, City of Microbes" (2000).

34. A.H. Rickard et al. 2003, "Bacterial Coaggregation: An Integral Process in the Development of Multi-Species Biofilms," *TRENDS in Microbiology* Vol. 11, No. 2, p. 94 (2003).

35. Watnick and Kolter [33].

36. Rickard et al. [34].

Manuscript received 15 December 2009.

Patrícia Noronha has a Ph.D. in biology and works as a visual artist in a microbiology laboratory at a scientific research institute (Instituto de Tecnologia Química e Biológica, Oeiras, Portugal). She is interested in exploring the use of biological materials to produce art, in particular the use of microbial patterns as a form of art, and also in investigating new ways to preserve these artworks.