Women in Engineering and Science

Laura S. Privalle *Editor*

Women in Sustainable Agriculture and Food Biotechnology

Key Advances and Perspectives on Emerging Topics

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Pioneering Women in Sustainable Agriculture and Food Biotechnology

Jill S. Tietjen and Laura S. Privalle

The original plant breeders were women. When humans moved from the hunter/gatherer phase into the cultivation phase, the women kept the seeds from those plants that grew to be the biggest and the strongest for use the following season. These were not the only traits for which the women were looking. Domestication of wild plants required many generations of those plants and fostered traits that included more robust plants, plants with non-shattering seed pods, seeds that did not become dormant, blooms that flowered synchronously across the population, and larger fruits and grains (Flint-Garcia 2015).

As we think of sustainable agriculture and food biotechnology today, many branches of science have been tapped for the advances that we have experienced. Women contributed to each of these sciences as they evolved and led to plant biology and biotechnology. Let's learn about some of those pioneering women through the ages.

Tapputi (Also Tapputi-Belatekallim)—Perfumist (Second Century BC)

Considered the world's first chemist, Tapputi made perfume and is mentioned on a cuneiform tablet from the second millennium BC in Babylonia. Her perfume contained flowers, oil, calamus, cyperus, myrrh and balsam to which she added water. This mixture was then distilled and filtered in her still; the oldest referenced

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still of which we are aware. Women perfumers used the chemical techniques of distillation, extraction and sublimation to create their perfumes, which were important in medicines and religion as well as for cosmetics (Alic 1986).

Miriam the Alchemist (1st or 2nd Century AD)

Born in Alexandria, Egypt, Miriam was also known as Mary, Maria, and Miriam the Prophetess or the Jewess. Her major inventions and improvements included the three-armed still or *tribikos*, the *kerotakis*, and the water bath. Although the purpose of the inventions was to accelerate the process of metals transmuting into gold, they are used extensively in modern science and contemporary households. The *tribikos* was an apparatus for distillation, a process of heating and cooling that imitated processes in nature. Sponges formed a part of the mechanism and served as coolers. The *kerotakis* was an apparatus named for the triangular palette used by artists to keep their mixtures of wax and pigment hot. The water bath, also known as Marie's bath (*bain-marie*), is similar to the present-day double boiler (B.F. Shearer and B.S Shearer 1997).

Hildegard of Bingen—Natural Philosopher (1098–1179)

A Benedictine abbess known as "the Sibyl of the Rhine," Hildegard wrote music as well as treatises on science including cosmology, medicine, botany, zoology, and geology. Two of her manuscripts, *Causae et curae* (*Causes and Cures* or *Book of Compound Medicine*) and *Physica* (*Natural History* or *Book of Simple Medicine*) are considered among the greatest scientific works of the Middle Ages and have survived intact. *Physica* is her natural history textbook and included descriptions of nearly 500 plants, metals, stones and animals, and explains their medicinal value to humans. The book became a medical school text. In *Causae et curae*, Hildegard describes the relationships between the macrocosm and specific diseases of the microcosm, the human body, and prescribed medicinal remedies. Hildegard was the first medical writer to stress the importance of boiling drinking water (Ambrose et al. 1997; Proffitt 1999; B.F. Shearer and B.S Shearer 1996).

Marie Meurdrac—Alchemist (C. 1610–1680)

Marie Meurdrac was not aware of Miriam the Alchemist's chemistry work when she wrote a six-part chemistry treatise. Meurdrac covered laboratory principles, apparatus and techniques, animals, metals, the properties and preparation of medicinal simple and compound medicines, and cosmetics. Her work included a

table of weights as well as 106 alchemical symbols. Her work titled *La Chymie charitable et facile en faveur des dames* was first published in Paris in 1666. Later editions were issued in 1680 and 1711. Her foreword to her book contained the following thought: … *that minds have no sex and that if the minds of women were cultivated like those of men, and if as much time and energy were used to instruct the minds of the former, they would equal those of the latter* (Alic 1986).

Jane Colden—Botanist (1724–1766)

By 1757, Jane Colden (later Farquhar), the first woman botanist in the U.S., had prepared a catalog of over 300 local species of flora and had exchanged specimens and seeds with several colonial and European botanists. Under the tutelage of her father, Cadwallader Colden, a New York botanist and government leader, Jane Colden mastered the Linnaean classification system and wrote a paper for a publication by the Edinburgh Philosophical Society. She is best known for her identification and description of the gardenia, which she was the first to identify. Her botanical work ceased after her marriage in 1759 (Ambrose et al. 1997; Bailey 1994; Rossiter 1992; Ogilvie 1993).

Marie Anne Pierrette Paulze Lavoisier—Chemist (1758–1836)

Antoine and Marie Lavoisier established chemistry as a modern scientific discipline. Their discoveries included the identification of oxygen and the nature of combustion, oxidation, and respiration. In addition, they established the law of conservation of matter as a principle for experimental design. It is impossible to separate Marie's contributions from Antoine's although she is known to have assisted with experiments and kept all of the laboratory records and notes. She edited and illustrated her husband's treatise *Elements of Chemistry* (1789) and translated and wrote commentaries on scientific papers, including Richards Kirwan's 1787 *Essay on Phlogiston* (Proffitt 1999; Ogilvie 1993).

Jane Haldimand Marcet—Science Popularizer (1769–1858)

Remembered particularly for the impact her *Conversations in Chemistry* had on influencing future scientist Michael Faraday, Jane Marcet wrote books to popularize science, especially intended for women and young people. Marcet was encouraged to begin a writing career by her husband, physician Dr. Alexander Marcet, whose passion for

chemistry exceeded his interest in practicing as a physician. *Conversations in Chemistry* (1806) was very popular and went through numerous editions, including 15 American editions titled *Mrs. Bryan's Conversations*. Marcet believed that the information presented in a conversational format was more readily comprehended by the audience, as she was better able to understand chemistry after conversing with a friend. Her other books included *Conversations on Botany*, *Conversations on Natural Philosophy, Conversations on Political Economy,* and *Conversations on Vegetable Physiology* (Proffitt 1999; Ogilvie 1993; Ronan 1982; Suplee 2000; A dictionary of scientists 1999).

Josephine Ettel Kablick (Josefina Kabliková)—Botanist and Paleontologist (1787–1863)

An intrepid Czech botanist and paleontologist, Josephine Kablick collected plant and fossil samples. Undeterred by any weather or terrain, she gathered new species in dark forests and on mountains. Her collection gained renown and she gradually collected plants for schools and colleges in her country as well as for museums and learned societies in other parts of Europe. Fittingly, many of the fossils and plants that she collected are named in her honor (Mozans 1913).

Estella Eleanor Carothers—Zoologist and Cytologist (1882–1957)

Eleanor Carothers studied cells and their inner workings. She particularly examined the relationship between cytology and genetics with specific emphasis on the effects that X-rays have on cells. Through her research thoroughness and her emphasis on the genetics of the order Orthoptera (including crickets and grasshoppers), she answered many questions concerning cytological heredity. Considered a primary investigator in the field of genetics, Carothers focused on grasshopper embryos. Her name is starred in the 1926 edition of the *American Men of Science,* meaning that she was considered one of the foremost scientists of the day. Carothers received many honors including the 1921 Ellen Richards Research Prize from the Naples Table Association and election to the National Academy of Sciences (Proffitt 1999; B.F. Shearer and B.S Shearer 1996; Ogilvie 1993).

Gerty Cori—Biochemist (1896–1957)

Nobel Laureate Gerty Cori was the first American woman to win a Nobel Prize in science. She and her husband, Dr. Carl Ferdinand Cori, received the 1947 Nobel Prize in Physiology or Medicine "for their discovery of the course of the catalytic

conversion of glycogen." They explained the physiological process by which the body metabolizes sugar.

Cori was born in Prague where her uncle, a professor in pediatrics, nurtured her interest in mathematics and science and encouraged her to undertake the study necessary to enter a university and study medicine. By age 18, she had passed a very difficult examination and entered the German branch of the medical school at Prague's Carl Ferdinand University. During her first semester anatomy class, she met her husband-to-be. They jointly agreed to pursue medical research, not medical practice, and to jointly attain medical certification (a 6-year process) before marrying.

In 1922, Carl received an offer to work in the U.S. and Gerty, demonstrating significant independence, stayed behind until she too had an offer to work in the U.S. They both worked at the New York State Institute for the Study of Malignant Diseases (later the Roswell Park Memorial Institute) in Buffalo, New York; he as a biochemist, she as an assistant pathologist. Here, Cori experienced resistance to her presence as a woman in science. The director of the institute threatened to fire Gerty if she did not end collaborative work with her husband. Later, a university offered Carl a job—only if he ended working collaboratively with his wife. The rationale for these requests was that not only was it un-American for a man to work with his wife—his wife was standing in the way of his career advancement!

Not everyone believed this however. After becoming naturalized American citizens in 1928, Gerty and Carl received offers to work at Washington University in St. Louis. Carl would become a professor of pharmacology and Gerty was offered the position of research associate in pharmacology. Here, Gerty gave birth to their son, Thomas who eventually became a research chemist himself, following in his parents' footsteps.

Although denied positions and titles that she would have received as a man, Gerty was promoted to associate professor in biochemistry in 1943, the year she and Carl achieved the synthesis of glycogen in a test tube. In 1947, shortly before she was awarded the Nobel Prize, Gerty was promoted to full professor of biochemistry. The Cori's discovery of glycogen led to more effective treatments for diabetes. The relationships between the liver and muscle glycogen, and blood glucose and lactic acid is now known as the Cori cycle. Gerty's other areas of research included hereditary glycogen storage diseases in children and the identification of a new enzyme, amylo-1, 6-glucosidase which helped her identify the structure of glycogen. She became a member of the National Academy of Sciences in 1948 (B.F. Shearer and B.S. Shearer 1997; Proffitt 1999; Bailey 1994; Kass-Simon and Farnes 1990; McGrayne 1993).

Barbara McClintock—Geneticist (1902–1992)

Barbara McClintock received the Nobel Prize in Physiology or Medicine in 1983 for her discovery that genes can move around on the chromosomes (transposable elements)—the so-called "jumping genes." She first published the discovery in

1950, but it was not accepted in the scientific community for many years and she worked on her research for many years alone. Her novel idea took 35 years for the Nobel Prize because it was such a revolutionary concept. In addition, the transposable elements that she had conjectured weren't actually seen until the late 1970s when the science of molecular biology had developed significantly further than it had as of 1950.

McClintock was recognized as one of the brightest geneticists from her graduate school days at Cornell in the 1920s. After serving as an instructor in botany for 5 years and then working in research for 6 years, she left Cornell as they would not appoint women to faculty positions. In the early 1930s, she found chromosomes that formed rings. Later, she found that the ring chromosomes were a special case of broken chromosomes. She predicted the existence of structures, which she named telomeres, that would be found on the ends of normal chromosomes, that maintained a chromosome's stability and integrity but were lost when a chromosome was broken. Telomere research is a rapidly growing area of biology today, with specific implications for cancer and aging. McClintock served as an assistant professor of botany at the University of Missouri for 5 years. In 1942, she began work at the Cold Spring Harbor Laboratory on Long Island, New York where she would spend the rest of her career.

McClintock was recognized for her genetic work, however, even if the Nobel Prize was slow in coming (the general span is 10–15 years after the research or discovery). Her name is starred (indicating eminence as a scientist) in the seventh edition of *American Men of Science*. She was elected the first woman president of the Genetics Society of America in 1945. In 1944, she was elected to the National Academy of Sciences. McClintock received the National Medal of Science in 1970. She also received awards including the Kimber Genetics Award (1967), the Lasker Award (1981), and a MacArthur genius award starting in 1981 (Proffitt 1999; B.F. Shearer and B.S Shearer1996; Bailey 1994; McGrayne 1993).

Rosalind Franklin—Biologist (1920–1958)

Rosalind Franklin made key contributions to the structures of coals and viruses and provided the scientific evidence about the double-helix structure of DNA for which James Watson, Francis Crick, and Maurice Wilkins shared the Nobel Prize in 1962. Although Nobel Prizes are only awarded to living scientists, her contributions to the effort to discover the structure of DNA are thought by some to have been overlooked.

Franklin grew up in London and decided at any early age to pursue a career in science. She graduated from Cambridge in 1941 and after a short-lived research scholarship to study gas-phase chromatography with future Nobel laureate Ronald G.W. Norrish, accepted a job as assistant research officer with the British Coal Utilization Research Association (CURA). At the CURA, she applied her knowledge of physical chemistry to study the microstructures of coal. In 1947, she

moved to Paris where she learned the technique known as X-ray diffraction. In 1951, she left Paris to set up an X-ray diffraction unit in a laboratory at St. John T. Randall's Medical Research Council at Kings' College in London to produce diffraction pictures of DNA.

Here she worked with Maurice Wilkins, who took an intense dislike to her. Wilkins would later show Watson the DNA diffraction pictures that Franklin had amassed (without her permission) and here Watson saw the evidence needed to discern the helical structure of DNA. Franklin had recorded in her laboratory notebook that DNA had a helical structure of two chains prior to the publication by Watson and Crick of their similar analysis.

Franklin left King's College for Birkbeck College where she worked on the tobacco mosaic virus, particularly the RNA structure and the location of protein units. She died at age 37 from ovarian cancer (Proffitt 1999; B.F. Shearer and B.S Shearer 1996; McGrayne 1993).

Indra and Vimla Vasil—Plant Biotechnologists

After obtaining their Ph.Ds. from the University of Delhi in 1958 and 1959, respectively, Indra and Vimla Vasil came to the U.S. on sabbaticals in the early 1960s and worked with A.C. Hildebrant. There, Vimla demonstrated the totipotency of plants cells by regenerating plants from single cells of tobacco. Her husband, Indra, demonstrated that plant species other than carrot could form somatic embryos. These two pioneers were both at the University of Florida from 1967 to 1999 where they worked together on in vitro biology and biotechnology of cereals. Their production of the first detailed account of embryonic cultures of cereals led to successful regeneration in numerous cereals and grasses. The Vasils were the first to obtain transgenic wheat using biolistic technology. In 2007, they jointly received the Society for In Vitro Biology's Lifetime Achievement Award. In their acceptance remarks, the Vasils said, "Based on our own experiences we feel that it is important for senior scientists to provide support and guidance to the next generation of students, and to encourage them to think big, think bold, think different, and not be afraid to challenge conventional wisdom and dogmas" (https://sivb.org/InVitroReport/41-3/lifetime.htm).

Norma Trolinder—Geneticist

A pioneering cotton research geneticist, Norma Trolinder, Ph.D. founded Genes Plus, a research company specializing in genetic engineering work. She was also president and research director of Southplains Biotechnology, Inc. and a research scientist for 8 years at the USDA Cropping Systems Research Lab in Lubbock, Texas. Her work together with her daughter Linda Trolinder (today Head of Trait

Development—Cotton, Corn and Soy for Bayer CropScience) on cotton transformation and regeneration was critical to being able to successfully produce commercial transgenic cotton such at Bt[1] cotton. Upon her receipt of the 2000 Cotton Genetics Research Award, it was said "her diligent efforts in the difficult area of plant regeneration from cotton tissue overcame a major hurdle in cotton biotechnology. Her work was essential to the successful utilization of transgenic cotton in the industry that we are experiencing today." Trolinder's bachelor's, master's and doctorate degrees are from Texas Tech University (http://www.cotton.org/news/releases/2001/cotton-genetics-research-award.cfm).

Mary-Dell Chilton-Plant Biotechnologist (1939–)

In 1983, Mary-Dell Chilton led the research team that produced the first transgenic plants. As such, she is considered one of the founders of modern plant biotechnology and the field of genetic engineering in agriculture. After groundbreaking efforts at the University of Washington and Washington University, she established one of the world's leading industrial biotechnology agricultural programs at Ciba-Geigy (today Syngenta). Her team has worked to produce crops with higher yields, and resistance to pests, disease and adverse environmental conditions (such as drought).

The recipient of numerous awards including the 1985 Rank Prize in Nutrition and the 2013 World Food Prize, Chilton was inducted into the National Inventors Hall of Fame in 2015. Today, Distinguished Science Fellow Chilton works in a building in the Research Triangle Park in North Carolina that bears her name.

Dr. Chilton's B.S. and Ph.D. degrees are in chemistry from the University of Illinois Urbana-Champaign. She said "My career in biotechnology has been an exciting journey and I am amazed to see the progress we have made over the years. My hope is through discoveries like mine and the discoveries to follow, we will be able to provide a brighter and better future for the generations that follow us" (Lacapra 2015; http://invent.org/inductees/chilton-mary-dell/; http://www.worldfoodprize.org/index.cfm/24667/35489/syngenta_scientist_dr_marydell_chilton_named_2015_national_inventors_hall_of_fame_inductee).

Barbara Hohn—Molecular Biologist (1939–)

Barbara Hohn considers herself privileged to have witnessed and contributed to major steps in the understanding of the molecular basis of life. She was involved in cloning of DNA and transformation of and genetic recombination in plants.

[1]Bt as a modifier before a plant means that the plant has been genetically altered to express proteins from the bacterium *Bacillus thuringiensis*.

Reveling in naiveté and curiosity, her research into basic principles led to the discovery that maize (corn) could be the host for DNA transfer. In addition to working at the FMI Institute for Biomedical Research in Basel Switzerland, Hohn's career included time at Yale, Stanford, and the University of Basel. The recipient of many awards, Hohn studied chemistry and received her Ph.D. in biochemistry (http://www.fmi.ch/about/people/emeriti/emeriti.html?group=14).

Martha Wright—Biologist

Although she entered the Kansas City Science Fair in 1956, Martha Wright's father encouraged her to major in business at then Lindenwood College in St. Charles, Missouri, because she would always be able to get a job as a secretary. A business advisor, noting that Wright was bored, urged her to sign up for an advanced biology course—and she was hooked. Graduating with a biology major (and minors in chemistry, classics, and business), Wright was hired by Monsanto because she had worked with radioactivity while in college (one of her biology professors had worked on the Manhattan Project). Her early projects revolved about insecticides. Then, she became involved in the pioneering work on field crop cell culture, working particularly with soybeans, maize and alfalfa. She published papers on regenerating soybeans from cell culture. After joining what is today Syngenta, her attention turned to corn and pioneering work on that cell culture. Her team produced the event that became the first commercial Bt corn product, Bt 176 (also known as Maximizer Knockout™). Wright says "our work broke the mystique of plant regeneration from cell culture, and ultimately allowed the transformation of recalcitrant crops. Enhanced crops mean more people get to eat and more people are healthy and can devote their energies to improving the world" (Neal Stewart 2008).

Nina Fedoroff—Molecular Biologist (1942–)

The recipient of the National Medal of Science for "pioneering work on plant molecular biology and for her being the first to clone and characterize maize transposons," Nina Fedoroff is Emeritus Professor of Biology at Penn State University. Her research interests include plant stress response, hormone signaling, transposable elements, and epigenetic mechanisms. An expert in the fields of plant genetics and molecular biology, she joined the faculty at UCLA after receiving her Ph.D. in molecular biology where she did research on nuclear RNA. As one of the first plant molecular biologists, Fedoroff pioneered DNA sequencing while working at the Carnegie Institution for Science. Later, she worked on the molecular characterization of jumping genes (transposable elements—for which Barbara McClintock won the Nobel Prize). A member of the National Academy of Sciences, Fedoroff has served on the National Science Board and received many honors (http://bio.psu.edu/news-and-events/

2008; http://bio.psu.edu/directory/nvf1; https://en.wikipedia.org/wiki/Nina_Federoff; http://www.ofwlaw.com/attorneys/dr-nina-v-fedoroff/).

Virginia Walbot—Agriculturist and Botanist (1946–)

Virginia Walbot loved striped flowers at an early age, so it seems not surprising that her career has focused on the characteristics of the striped and speckled seeds of Indian corn. After undergraduate work at Stanford and graduate work at Yale, she spent time as a faculty member at Washington University in St. Louis. There, she began her work with maize, spending time with Nobel Laureate Barbara McClintock at Cold Spring Harbor. Today, Walbot is a Professor of Biology at Stanford University. She is a member of the team that developed a new sweet corn. A Fellow of the American Association for the Advancement of Science, Walbot has received many awards and honors and was the first foreign woman elected as a corresponding member of the Mexican Academy of Sciences (in 2004). Walbot is concerned about scientific literacy and presents many lectures at which she encourages a discussion of the science underlying transgenic food (http://www.k-state.edu/bmb/seminars/hageman/2001-walbot.html; http://web.stanford.edu/~walbot/cv/cv_walbot.pdf; https://profiles.stanford.edu/virginia-walbot).

Lydia Villa-Komaroff—Molecular Biologist (1947–)

The third Mexican-American woman to earn a Ph.D., Villa-Komaroff was part of the research team that discovered insulin could be produced from bacteria. Inspired by her mother's love of nature and plants and her inability to study botany after a bout of rheumatic fever as a child, Villa-Komaroff studied biology at the University of Washington. After graduating with a Ph.D. from MIT, she focused on the synthesis of eggshell proteins using the new technology of recombinant DNA (combining the DNA from one organism to the DNA of bacteria). She used that technique as a member of the team at Harvard that successfully produced insulin from bacteria. This patented process led to almost all commercial insulin today being made from bacteria. Among her many awards, her favorite is "100 Most Influential Hispanics" (Proffitt 1999).

Patricia Zambryski—Plant Biologist

Professor of plant and microbial biology at the University of California, Berkeley, Patricia Zambryski is a pioneer in the development of genetic engineering in plants. Zambryski discovered how the bacterium *Agrobacterium tumefaciens* transfers