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

DNA into the plant that it infects. This discovery and additional investigation into this specific bacterium have led to fundamental insights applicable to numerous areas of bacterial and plant biology. Zambryski grew up in Canada, receiving her B.S. in genetics and later received her Ph.D. in molecular biology. A Fellow of the American Association for the Advancement of Science and a Fellow of the American Society for Microbiology, Zambryski was elected to the National Academy of Sciences in 2001. Her current research focuses on studying the molecular mechanisms of *Agrobacterium* that leads to genetic transformation of plant cells. She and her lab also study how plant cells communicate with one another (http://pmb.berkeley.edu/profile/pzambryski; http://www.usias.fr/en/evenements/visitors/martin-sarter/pat-sambryski/).

Barbara Mazur—Agricultural Biotechnologist (1949–)

Currently the Vice President, Technology Acquisition Strategy for DuPont Pioneer, Barbara Mazur has degrees in microbiology and molecular genetics. A long-time DuPont employee, she began her DuPont career in the Central Research Department. Her primary focus has been on the modification of seed quality traits, crop protection biochemical discovery, and herbicide resistance trait discovery and development. Mazur holds four patents and has served on advisory boards for the National Academy of Sciences and the National Science Foundation. She has been featured as a STEM (science, technology, engineering and mathematics) Women All-Star, where her background is described as "A research leader at DuPont working to increase food production by improving the rate of crop seed genetic gain through biotechnology and advanced breeding technologies" (http://www.kgi.edu/about-kgi/board-of-trustees/barbara-j-mazur; http://www2.dupont.com/Media_Center/en_US/assets/downloads/pdf/DuPont_Speakers_Bureau.pdf; http://the-dupont-challenge.tumblr.com/post/41289108646/our-second-dupont-stem-women-all-star-is-barbara).

Anne Knupp Crossway—Biologist, Geneticist, Business Manager (1953–)

The pioneering developer of a laboratory method called micromanipulation, a technique that is now widely used in transferring genetic materials from one cell to another, Anne Knupp Crossway did her undergraduate work in biology. Her education included a Ph.D. in genetics and an MBA. Crossway holds two patents, one for microassay for detection of DNA and Ribonucleic acid and one for plant cell microinjection technique. Early in her career, she worked in venture capital as well as holding management positions in biotechnology, consumer products, and over-the-counter drug/device companies. Crossway also served as a managing scientist at an early successful

biotechnology company, Calgene, Inc. As a biotechnology consultant she provides services to clients including bioscience companies in early stages of development and non-profit science and technology companies (https://www2.cortland.edu/bulletin/issues/bulletin_05_06/April_17_06.pdf; http://prabook.com/web/person-view.html?profiledId=792869; http://readme.readmedia.com/SUNY-Cortland-To-Hold-12th-Annual-Scholars-Day-April-9/118007).

Elizabeth Hood—Biologist

Currently Distinguished Professor of Agriculture at Arkansas State University, Elizabeth Hood's primary areas of focus are biomass to biobased products (renewable resources), foreign gene expression in transgenic plants, plant cell wall structure and function, and plant cell biology and protein targeting. With three partners, Hood started a company whose purpose is to produce enzymes for biomass conversion from transgenic plants. Her research laboratory at ASU examines plant-based protein production technology and cell wall structure and function. She has previously served as the Program Director at the National Science Foundation and formed a research group at ProdiGene, a plant biotechnology company. At Pioneer Hi-Bred International, Hood served as the director of the cell biology group for plant production of therapeutic proteins. She has many publications, 14 patents and has received numerous honors. Hood has an M.S. in botany from Oklahoma State University and her Ph.D. is in plant biology from Washington University in St. Louis, Missouri (http://biobasedsolutions.org/#!about-us-page).

Ann Depicker—Plant Biologist

The Group Leader of the Vlaams Institute voor Biotechnologies (VIB) at the University of Ghent (Belgium) since 1996, and Division Coordinator since 2003, Ann Depicker leads the group focused on plant-made antibodies and immunogens. A significant breakthrough from her group's work is the simplification of the process for producing biotech medicines—using plant seeds instead of mammalian cells. This effort was undertaken to create an alternative and cost effective system for the production of complex recombinant proteins including antibodies and composite vaccines. Plant seeds can be produced in large quantities in short periods of time as compared to mammalian cells without the need for specialized equipment or expensive media. The technique is called the GlycoDelete technology. Depicker said "the simplicity of the modification makes an industrial approach possible and could lead to the inexpensive large-scale 'pharming' of medicines using plants" (http://www.vib.be/en/research/scientists/Pages/Ann-Depicker-Lab.aspx; http://www.seedquest.com/solutions.php?type=solution&id_article=76572).

Maud Hinchee—Botanist

Maud Hinchee's botany roots go back to her childhood when she made the eggplants in her mother's backyard garden sterile because she hated eggplant. After receiving BS, MS and Ph.D. degrees in botany, Hinchee became involved with protocols for inserting genes into plant cells due to her training as a plant morphogeneticist. At Monsanto, she was able to design methods that allowed successful and reproducible results in soybean plants—and led to the first transgenic soybean containing the Roundup® Ready gene. Hinchee worked on other plants including sugar beet, flax, potato, strawberry, cotton and sweet potato. After time at ArborGen as Chief Technology Officer where she led efforts to genetically improve tree products, Hinchee moved to Agricen Sciences. As Chief Science Officer at Agricen Sciences, Hinchee is striving to develop solutions for increased nutrient availability and uptake, improved sustainability of agriculture, and higher crop yields. The holder of five patents, Hinchee was named a Monsanto Science Fellow in recognition of her scientific achievements (Neal Stewart 2008; http://www.agricensciences.com/about-us/our-team/maud-hinchee/; http://www.genomecanada.ca/en/about/governance/hinchee.aspx).

Pamela Ronald—Plant Pathologist and Geneticist (1961–)

An international advocate for genetic engineering of food crops, Dr. Pam Ronald is a professor at the University of California, Davis as well as the Director of the Institute for Food and Agricultural Literacy located there and the Director of Grass Genetics at the Joint BioEnergy Institute in Emeryville, California. She determined her career focus, rice (the biggest food staple in the world), during her years as a graduate student at the University of California, Berkeley (from which she received her Ph.D.). Her laboratory has developed rice that is disease-resistant and flood-tolerant. Featured in a TED talk in 2015, her topic was how genetic engineering can fight disease, reduce insecticide use, and enhance food security. Her undergraduate degree is from Reed College (Oregon) which afforded her the opportunity to study the recolonization of Mt. St. Helens. She has a master's degree from Stanford as well as from Uppsala University, Sweden (http://biosci3.ucdavis.edu/Faculty/Profile/View/14069; http://en.wikipedia.og/wiki/Pamela_Ronald; https://www.jbei.org/people/directors/pam-ronald/).

Sustainable Agriculture

Sustainable agriculture, of course, relies on more options than just those offered through the application of biotechnology solutions, however in this volume we have chosen to focus on the contributions that biotechnology products bring to the

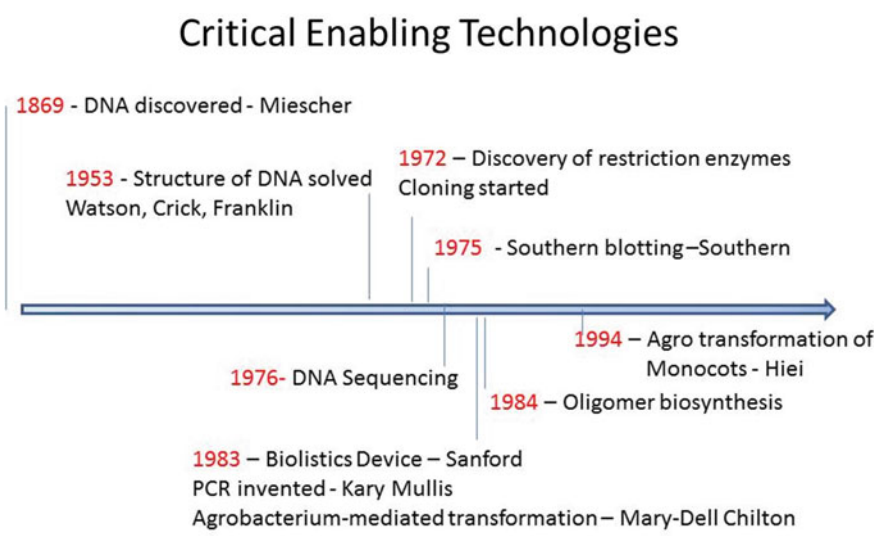

Fig. 1 Key Enabling Technologies. Presented is a time-line with key enabling technologies that were essential to the development of agricultural biotechnology products.

table. These are critical solutions when considering the necessity for sustainable agriculture and the expected population growth the world will see in the next 30 years and beyond. To set the stage, key scientific accomplishments were necessary. A timeline of the critical enabling technologies, as developed by Dr. Privalle, is shown in Fig. 1. All these technologies were necessary to lead to the key early regulatory approvals shown in Table 1, and those of today—but 1983 really stands out. Three food scares occurred in Europe in the 1990s which were key in increasing public mistrust of government agencies as they were used by anti-biotechnology factions to fuel the flames of uncertainty around these technologies. In 1996, the first case of mad cow disease in Europe was reported. In 1999, dioxin contamination was found in animal feed in Belgium and, in 1999, Coca-Cola products were withdrawn in Belgium. These scares resulted in a moratorium (1998–2004) on approvals of biotech products while a new agency was formed for evaluation of not only biotechnology products but also of new products that were entering the market or were associated with food production. To date, only four biotechnology products have been approved for cultivation in Europe: Bt 176, Mon810 and T25, prior to the moratorium; since the moratorium only the Amflora potato has been approved for cultivation. Multiple products have been approved for import into the EU.

Today, biotechnology products are grown in 28 countries around the world with more than 90% of the growers small land holders. (James 2015). Recent approvals show that not only major biotechnology corporations can bring products to market but smaller organizations like EMBRAPA (soybean), Simplot (potato), Okranaga (apple), Mahyco (Bt eggplant) and the USDA (virus resistant plum) are also having

Table 1 Key early US regulatory approvals of biotechnology products (http://cera-gmc.org)

Year	Product	Agency	Registrant
1992	FlavrSavr Tomato (delayed ripening)	FDA	Calgene (now Monsanto)
1994	Bt176 Maize (insect resistant)	EPA (1995, USDA, FDA)	Ciba-Geigy (now Syngenta)
	Bromoxynil Cotton (herbicide tolerant)	USDA, FDA	Calgene (now Monsanto)
	RR Soybean (herbicide tolerant)	USDA (FDA, 1995)	Monsanto
1995	NewLeaf Potato (insect resistant)	USDA, EPA, FDA	Monsanto
	T25 Maize (herbicide tolerant)	USDA	Agrevo (now Bayer)
	RR Canola (herbicide tolerant)	USDA, FDA	Monsanto
	Mon810 (Insect resistant)	EPA (USDA, FDA, 1996)	Monsanto
1996	Virus resistant Papaya	USDA (EPA, FDA 1997)	Cornell University
	InVigor Canola	FDA, USDA	Aventis (now Bayer)
1998	RR sugarbeet	FDA, USDA	Monsanto/Novartis (now Syngenta)

success. The early generation products were virus resistant, herbicide tolerant, and/or insect resistant but now products for drought tolerance, low acrylamide, reduced browning, and golden rice[2] are being developed. Finally products are reaching those areas that most need them like Cameroon, Nigeria, and Kenya. Still there is doubt about the utility, benefits and safety of these products. All the authors in this volume are women who have contributed to or benefited from this technology and have watched its adoption, rejection and debate. Enjoy their stories!

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[2]Golden rice is a genetically modified rice that is golden in color due to the over production of β-carotene, the main precursor of Vitamin A. Consumption of golden rice would greatly reduce Vitamin A deficiency and hence reduce blindness and death in children around the world whose diet currently is insufficient in Vitamin A.

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Authors Biography

Jill S. Tietjen, P.E. entered the University of Virginia in the Fall of 1972 (the third year that women were admitted as undergraduates—under court order) intending to be a mathematics major. But midway through her first semester, she found engineering and made all of the arrangements necessary to transfer. In 1976, she graduated with a B.S. in Applied Mathematics (minor in Electrical Engineering) (Tau Beta Pi, Virginia Alpha) and went to work in the electric utility industry.

Galvanized by the fact that no one, not even her Ph.D. engineer father, had encouraged her to pursue an engineering education and that only after her graduation did she discover that her degree was not ABET-accredited, she joined the Society of Women Engineers and for over 35 years has worked to encourage young women to pursue science, technology, engineering and mathematics (STEM) careers. In 1982, she became licensed as a professional engineer in Colorado.

Tietjen starting working jigsaw puzzles at age two and has always loved to solve problems. She derives tremendous satisfaction seeing the result of her work—the electricity product that is so reliable that most Americans just take its provision for granted. Flying at night and seeing the lights below, she knows that she had a hand in this infrastructure miracle. An expert witness, she works to plan new power plants.

Her efforts to nominate women for awards began in SWE and have progressed to her acknowledgement as one of the top nominators of women in the country. Her nominees have received the National Medal of Technology and the Kate Gleason Medal; they have been inducted

into the National Women's Hall and Fame and state Halls including Colorado, Maryland and Delaware; and have received university and professional society recognition. Tietjen believes that it is imperative to nominate women for awards—for the role modeling and knowledge of women's accomplishments that it provides for the youth of our country.

Tietjen received her MBA from the University of North Carolina at Charlotte. She has been the recipient of many awards including the Distinguished Service Award from SWE (of which she has been named a Fellow), the Distinguished Alumna Award from the University of Virginia, and she has been inducted into the Colorado Women's Hall of Fame. Tietjen sits on the boards of Georgia Transmission Corporation and Merrick & Company—of which she is Vice Chair. Her publications include the bestselling and award-winning book *Her Story: A Timeline of the Women Who Changed America* for which she received the Daughters of the American Revolution History Award Medal.

She is delighted to be collaborating with her sister, Laura Privalle.

Laura Privalle received her B. S. in biochemistry from Virginia Tech. Since Jill went to UVA and our parents insisted their four kids stay in-state, Virginia Tech was the obvious choice. During freshman orientation, her father (liberated by Jill's choices) suggested that she not settle for a Master's degree but consider getting a Ph.D. Of course, he would have preferred that she select engineering as her field of study and even on the day she received her diploma, he asked when she was going to switch to chemical engineering! Laura received a M.S. in botany from Virginia Tech where her thesis work was on cellulases from *Achlya bisexualis*, a Phycomycete. She then entered the University of Wisconsin where she received her Ph.D. in biochemistry in 1983. Her major professor was Dr. Robert H. Burris and her dissertation was on nitrogen fixation in *Anabaena* 7120, a cyanobacterium. After a brief post-doctoral fellow position at Duke University working on spinach nitrite reductase, she joined Ciba-Geigy in 1984 as a post-doctoral fellow working on the control of ethylene biosynthesis and became permanent in 1986. Projects at Ciba-Geigy included herbicide detoxification, nitrogen utilization and insect control. In 1992, she joined Regulatory and Government Affairs, tasked to build the Regulatory Science group and was deeply involved in the safety assessment of Bt 176 maize, the first Bt maize product to receive regulatory approval. In 2003, Laura joined BASF to build their regulatory science group where she stayed until 2013 when she joined Bayer as the Global Head, Regulatory Field Studies.

Making the transition from academic research to more applied work and then finally to Regulatory Science allowed Laura to indulge in her passion for the acceptance of biotechnology as a critical component of sustainable agriculture. All her siblings (as well as her kids and nephews) attended Nature Camp for two weeks every summer from the time they had finished 5th grade until after 10th or 11th grades. This was a camp sponsored by the Virginia Garden Clubs with conservation as its theme. There the conservation pledge was recited daily ("I give my pledge as an American to save and faithfully defend from waste the natural resources of my country …"). Camp consisted of classes outside on geology, limnology, botany, herpetology (the favorite of boys), ornithology, astronomy, entomology, and more. This was the highlight of every year and fueled her desire to become a plant scientist and impacted many of her ensuing career decisions. It also helped that her mother was heavy into recycling long before it became common practice (1960s–1970s). Understanding plant biochemistry and being able to relate it and its value to her family certainly pushed her towards a career in biotechnology. Of course, timing is everything. She became employable just at the time when agricultural biotechnology was taking off.

During her 25 years in the Agricultural Biotechnology Regulatory Science area, Laura has participated on many intra-industry organizations as well as global bodies tasked with ensuring the safety of these products. This has led to interactions with regulators from around the world at workshops designed to gather the best scientific minds to consider the most appropriate way to ensure the safety of our food supply. She has gotten to see first-hand how countries interact to make decisions on the global food supply by sitting in on a Codex Alimentarius Commission Ad

Hoc Committee on Allergenicity meeting, She has participated in Scientific Advisory Panel Meetings of the US EPA and has attended workshops at the OECD (Organization for Economic Cooperation and Development), EFSA (European Food Safety Authority), etc. She has participated in workshops on biotechnology regulations in Japan, The Philippines, Korea, China, India, Argentina and Brazil. She has about 50 publications and 4 patents.