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Cary A. Mitchell

Dedication: Cary A. Mitchell

This volume of *Horticultural Reviews* is dedicated to Dr. Cary A. Mitchell, Professor of Horticulture at Purdue University, in recognition of the extraordinary breadth of contributions he has made to horticultural science and technology that span plant physiological research, teaching, mentorship, leadership, and service. In each of these areas, Cary's approach is underpinned by a capacity to express broad visionary goals with clarity, to develop experimental approaches and analyses meticulous in their detail, to communicate with scientific peers with lucidity and precision, and to connect his physiological discoveries to practical and innovative application for the benefit of the broader community of life scientists and horticulturalists.

Cary Mitchell was born in 1943 in Woodstock, Illinois. His interest in horticulture was kindled from an early age through his experiences in 4H and especially through work with his father in the family business, Greenwood Nursery, located northwest of Chicago. His father, Carl, had purchased 52 acres of farmland prior to WWII, which the family used primarily for vegetable production. Two acres had been set aside for greenhouse production, and this provided a practical laboratory for early innovations in bedding plant and hothouse vegetable production. Cary observed that bedding plants stored under a bench in his parents' fiberglass-covered, corrugated greenhouse grew almost as well as those exposed to full light on the benches above. Reinforcing their mutual curiosity, Carl noted that, unlike in shadow-prone glass greenhouses, sunlight passing through the translucent material was scattered and diffused, and the plants under the bench received almost the same amount of light. That was in 1956. Cary was 13 years old, and the Mitchells were the first nursery owners in the Midwest to erect a greenhouse cladded with plastic.

As a young boy in the 1950s, Cary was given responsibility for vegetable sales at the family farm stand, the profits of which provided funds that would later be used to attend college. He also led the family's efforts in perennial ornamental production, and this formed the basis for developing a second business known as Green Thumb Landscaping. Throughout this time, Carl was a key influence on Cary's perpetual curiosity about plants. Cary describes his dad as a "compulsive horticultural inventor." Innovative and progressive, Carl developed customized peat-based growth media, nutritional recipes, wipe-on herbicide applicators, and a host of labor-saving devices. He instilled in Cary a sense of the value of applied science and technology, while challenging him to wonder more deeply about how plants grow and adapt to changing environments.

Cary's natural sense of curiosity was provided a systematic framework and disciplinary context during his undergraduate studies in horticulture at the University of Illinois, Urbana-Champaign. Here, Cary was first exposed to cutting-edge whole-plant biology and plant development through graduate-level courses taught by Profs. Tom Hodges and Leonard Beevers, who sought understanding of plant growth and nutrient uptake at mechanistic and functional scales. Prof. Jack Gartner, head of the Department of Ornamental Horticulture and another guiding influence, recognized Cary's scientific creativity and urged him to attend Cornell University to seek a master's degree. This was a turning point for Cary, where the boundless appeal of advanced graduate study would eventually overshadow earlier goals of returning to the family business. From Cornell, he moved on to pursue a Ph.D. degree in the Department of Botany at the University of California–Davis, where he studied the kinetics and energetics of light-driven chloroplast glutamine synthesis under the guidance of Prof. C. Ralph Stocking, a compelling role model for effective, successful academic life.

Soon after completing his Ph.D., Cary was offered a faculty position in Horticulture at Purdue University, which has been his academic home since 1972. Not one to forget important early influences, encouragements, and special opportunities, Cary remembers the constructive influence of plant developmental physiologist A. Carl Leopold in his early studies of auxin-stimulated growth. The departure of Prof. Leopold in 1975 and the confidence and support of department head Prof. Bruno Moser, opened a career-shifting opportunity for Cary to assume responsibilities of the Plant Growth and Development faculty position that Leopold had held for 25 years. This was a key transition that allowed Cary to pursue lines of research that would fully draw upon his training as a whole-plant and biophysical plant physiologist and to delve deeply into questions of environmental effects on growth and photosynthesis, including those of mechanical stress, hypoxia, UV-B radiation, carbon dioxide and, especially, light spectral composition and photosynthetic photon flux.

PLANT GROWTH & DEVELOPMENT AND MECHANICAL STRESS

Cary's early research on the influence of mechanical stress on plant growth and development began in 1974. This was a pioneering effort that opened many new avenues of discovery in his laboratory and led to new mechanistic understanding of plant responses to a variety of physical stimuli such as touch, vibrational shaking, stem bending or flexing, wind, and gravity. Cary and his students observed that noninjurious mechanical stress inevitably resulted in seedling growth reductions that were manifested in reduced height, internode elongation, leaf area and biomass, relative to undisturbed controls. This mechano-responsivity led also to a wide variety of responses in reproductive as well as vegetative development that were expressed, for example, in changes in chlorophyll synthesis, apical dominance, and net photosynthetic productivity. In short, leaf canopy architecture was significantly remodeled to a more compressed form through which less light penetrated.

The myriad of whole-plant responses elicited by mechanical stress led to literally dozens of testable hypotheses regarding the underlying cellular and molecular changes in cell wall composition, cell elongation, cellular water relations, and plant hormone mediation of stress perception and signal transduction. As broader advancements were made in plant biology and molecular genetics in the 1980s, Mitchell continued astutely to make connections that his students and postdocs could probe at the cutting boundaries of plant physiology and emerging technology. These included, for example, elucidating the role of Ca^{2+} as a second messenger in the biochemical cascade toward seismo- and thigmomorphogenesis as well as efforts to develop effective mass screening procedures to identify T-DNA insertional mutant phenotypes unresponsive to mechano-stimuli in a systematic effort to identify genes mediating the process.

Throughout the research on the underlying physiological bases of plant mechano-responses, Cary Mitchell has communicated broadly with horticultural technologists to increase awareness of the practical applications of mechanical stress in agriculture and horticulture. Examples highlighted by their research included (1) the use of windbreaks and shelterbelts to minimize yield losses under windy conditions, (2) the development of nursery production practices that allowed sapling stems to sway in the wind, thereby yielding sturdier, tapered, more resilient stems, and (3) the use of nonchemical hardening treatments to induce a more favorable root-to-shoot biomass ratio of greenhouse crops prior to shipping as a strategy to improve the survival and field establishment of vegetable transplants or to create a more desirable finished canopy of floral crops. One important practical finding from the laboratory was that sensitivity or responsivity of plants to mechanical stress is inversely proportional to the intensity of light under which they are grown. Thus, plants grown outside under bright summer light can be buffeted about by wind and not suffer in biomass accumulation or productivity, while the same plants grown indoors during the winter or under shade in the summer are very sensitive to even minimal perturbation. This is important ecologically, agriculturally, and experimentally, and is one of the lab's most significant contributions to understanding crop responses to mechanical perturbation.

NASA SPACE BIOLOGY AND CONTROLLED ENVIRONMENT RESEARCH

Cary Mitchell's research on mechanical stress physiology led logically to a keen interest in the development of highly controlled plant-growth environments that could be used to increase the explanatory power of experiments in which multiple environmental variables could be manipulated simultaneously. The concept also appealed to the National Aeronautics and Space Administration (NASA), which recognized the originality of his work on mechanical stress as well as its relevance to the problems of growing plants in microgravity. NASA funded his proposed research through a competitive Space Biology grant in 1976, and thus was initiated a productive and decades-long funding relationship with the agency that grew continually in scope, complexity, and leadership responsibility.

The early focus was on a systems approach to plant production modules in space that would optimize the delivery of water, nutrients, CO_2, and light to ensure a bioregenerative life-support system for human space travel. Known originally as Closed Ecological Life Support Systems (CELSS), the food-production subsystem would need to recapture renewable resources by recycling wastes within a system closed to mass but open with respect to energy. Critical resources would be recycled for reuse in plant production, while providing potable water for humans, oxygen for metabolic consumption, and removal of carbon dioxide from the flight crew cabin air. The design complexity of control systems was a challenge for the Mitchell laboratory that demanded engineering and technology solutions to enable precise resource delivery as well as a strong focus on the horticultural science of growing plants under such conditions. Cary, with his students and postdocs, performed a series of experiments designed to evaluate candidate crop species such as strawberry, cowpea, rice, sweet potato, and lettuce. The cardinal limiting factors of CO_2 level and photosynthetic photon flux (PPF) were varied while simultaneously evaluating, for example, the effects of planting density, canopy management practices, time-to-harvest, light quality, temperature, and photoperiod. This led to in-house creation of the Minitron I and II systems that doubled as small crop-stand gas-exchange cuvettes as well as mini-growth chambers, allowing different CO_2 and light treatments to be applied simultaneously in the same growth room.

The engineering, materials, and dynamic control systems that made these experiments possible were products of exceptional innovation and attention to detail. For example, Mitchell, with postdoctoral associate Changhoo Chun, developed a dynamic system for feedback control of PPF for crop production in CELSS. Using this strategy, setpoints of PPF could be adjusted at different stages of crop development and/or at different times of day to produce a desired amount of O_2, to transpire a desired amount of H_2O, or to produce a desired quantity of edible biomass. Plant productivity was assessed not only as biomass and real-time photosynthesis but also in terms of leaf or fruit nutritional content and availability that could support a balanced human diet. Before LEDs became commercially available, Mitchell and graduate student Jonathan Frantz had evaluated fluorescent intracanopy lighting sources to optimize photosynthesis and productivity within mutually shaded foliar canopies. This experimental approach sought the most effective ways to position light sources for productivity while minimizing electrical energy consumption; the approach became a hallmark of virtually all subsequent studies of crop productivity. In short, the success of these intricately controlled experiments depended on an unusual array of disciplinary talent, drawing upon engineers, physical scientists, computer scientists, food scientists, and statisticians, as well as Cary's core strength as a plant physiologist. He has been an effective convener of multidisciplinary teams to address experimental problems that would otherwise be intractable to plant biologists working in isolation.

The scholarly productivity arising from the initial NASA Space Biology Grant led to increasingly complex funded projects whose successful execution would depend prominently upon multidisciplinary approaches. Cary's earlier roles as scientist and PI grew steadily to include broader program coordination and leadership. His proposal for NASA's Specialized Center of Research and Training (NSCORT) in Bioregenerative Life Support was one of the three established nationally in 1990. He served as Center Director of the project (1990–1996), which included 15 faculty from seven academic departments at Purdue. Numerous graduate students and postdoctoral fellows were an integral component of the Center project whose purpose was to train scientists and engineers in bioregenerative life-support systems relevant to the nation's space program. Because the scope of this project had grown significantly from previous efforts, it was now essential to add molecular biologists, systems analysts, and human nutritionists to the existing array of interdisciplinary talent.

Following the successful NSCORT in Bioregenerative Life Support and a short assignment as Program Scientist in the NASA Gravitational Biology and Ecology Program (1997–1999), Cary's leadership and unfailing personal energy led to another high impact NSCORT proposal with focus on Advanced Life Support (2002–2010). As Center Director, Mitchell had budget authority for 17 research projects at three partner universities and held overall responsibility for direction and conduct of the research program. In addition to the goal of advancing basic understanding of plant gravitational biology using an integrated approach, this NSCORT placed high emphasis on training future leaders in space life-support research as well as on outreach efforts to the public and, especially, to K-16 educators and students.

LED LIGHTING TECHNOLOGIES

The design of Closed Ecological Life Support Systems forced a conceptual framework of rigor and economy with respect to recapture of renewable resources. Mitchell and his colleagues recognized that such systems must be designed to operate stably for long periods of time without resupply from Earth and with minimized costs of energy. They also recognized the close analogy with Earth's biosphere, which likewise is characterized by complex cycles of carbon, oxygen, nitrogen, and mineral elements, although with vastly different rates of element recycling. The lessons learned from CELSS research would have significant carryover and direct relevance for management of horticultural production on Earth. In a paper published in 1996 in *Advances in Space Research* (Vol. 18, No. 4/5:23–31), Mitchell and coauthors observed presciently that the principles of CELSS-based research could lead to Earth benefits that would include, among other benefits:

> "(1) development of active control mechanisms for light, CO_2, and temperature to maximize photosynthesis of crop plants during important phases of crop development, (2) automation of crop culture systems, (3) creation of novel culture systems for optimum productivity, and (4) creation of value-added crops with superior nutritional, yield, and waste-process characteristics."

This vision would inform and motivate Mitchell during the next phase of his research career and would lead directly to a funded USDA NIFA SCRI Project to Develop LED Lighting Technologies for Sustainable Specialty-Crop Production (2010–2015). Ranked the #1 proposal in the 2010 SCRI cycle, the research arising from this project is today changing the paradigm for specialty supplemental lighting of greenhouse crops for propagation, photoperiodic flowering, photomorphogenic development, and yield enhancement of greenhouse-grown specialty crops. Mitchell has been Project Director and responsible for overall conduct of the research and development program, which has included seven projects at four universities and one corporation (University of Arizona, Michigan State University, The Orbital Technologies Corporation, Rutgers University, and Purdue University).

Scholarly, technical, and practical outputs continue to emerge from this highly productive multistate project. One important development has included the use of innovative control systems for LED intracanopy lighting towers that energize sequentially, tracking the vertical shoot growth of high-wire tomatoes and thus reducing electrical energy consumption during the growth cycle. A primary goal was to develop lighting systems that could provide affordable, year-round supplemental lighting in a northern temperate climate. The study has not revealed differences between intracanopy LED *versus* overhead HPS light sources; both treatments consistently stimulated tomato yield (number and mass of fruits) compared to controls. However, the electrical cost of LED-supplied intracanopy lighting ranged from 25% to 50% that of HPS-supplied overhead lighting. This outcome has helped prompt great interest by growers in the use of LEDs, which draw significantly less electrical power and energy than other lamps and are much longer lived. Similarly, neither physicochemical nor organoleptic quality attributes of high-wire tomato fruits differed significantly among these supplemental light treatments; all supplemental sources contributed positively to fruit quality attributes. Thus, the more energy-efficient LED sources can be used confidently by growers without concern about negative effects of LEDs or intracanopy lighting.

TEACHING, TRAINING, AND MENTORING

Cary Mitchell's impact on horticultural science and society extends well beyond the research accomplishments delineated here. In fact, his deepest influence has been on his students and postdoctoral fellows, whose collective accomplishments are astonishing. Since 1974, Cary has mentored 30 graduate students, 12 postdoctoral fellows, and more than 200 undergraduate students. As an assistant professor 30 years ago, I was amazed to see more than a hundred bound theses on his office shelves, each of which represented his fastidiously analytical contributions as an advisory committee member or major professor to a past student's thesis or dissertation. His careful mentorship has been provided in a supportive environment that gently but firmly pushes and challenges students to achieve their best—professionally, scientifically, and personally. He models the value of informed curiosity for his students much as his father, Carl—and his Ph.D. major professor, Ralph Stocking—did for him, often wondering aloud about the possible underlying mechanisms and strategizing about how they could be revealed experimentally. He inspires a lab culture of curiosity and encourages a team approach where more senior members of the lab have the opportunity to become peer-mentors themselves. Student's individual accomplishments as well as their contributions to larger project goals are always recognized with pride.

The Mitchell Lab has functioned as a supportive family, more so than any other I have seen. Undergraduate students are involved in projects every semester, with easy access to mentors and with responsibilities that grow with their experience throughout their college years. Cary's wife, Leticia, is a key partner in that welcoming and supportive environment, and Cary and Letty together have hosted countless gatherings in their home for lab members, sometimes gently guiding conversations along thought-provoking lines. But Cary is not always the model of seriousness and deep intensity. He loves to have fun, and his spontaneous and sometimes wacky sense of humor creates a connection that brings people together.

As a teacher, Cary is prepared to the highest degree imaginable. He never does anything without solid preparation and uncommon attention to detail. Decades before the advent of the "connected" classroom, Cary recorded his lectures in Plant Growth and Development on cassette tapes that were made available for review by students who needed an extra measure of instructional support. The practice communicated the importance of understanding physiological principles in rigorous, quantitative detail as well as his personal concern for their learning.

SERVICE, LEADERSHIP, AND IMPACT

Cary Mitchell has provided extraordinary service and leadership to Purdue University, his professional societies, and to his community.

Important service began with his leadership of Purdue University's interdepartmental graduate program in plant physiology in the 1980s, when he helped forge cross-departmental collaborations in graduate instruction and coordinated significant redesign of the plant biology curriculum. In addition to his many leadership roles at Purdue, Cary has contributed at the highest governance levels within professional societies including: the American Society for Horticultural Science (ASHS), serving as President (2004–2005) and Chair, Board of Directors (2006–2007); the American Society for Gravitational and Space Biology (ASGSB), serving as President (1994–1995) and Member, Board of Directors (2009–2012); the American Society of Plant Biologists (ASPB), serving as Chair of the Committee on the Status of Women in Plant Physiology. His selfless service and leadership have been recognized with honors and awards too numerous to list here. Two are of special note, however: the NASA Space Act Award (2012) for his "*development of high efficiency lighting with integrated adaptive control*" and the American Institute of Aeronautics and Astronautics (AIAA) Jeffries Aerospace Medicine and Life Sciences Research Award (2012) for his "*outstanding contributions to space life sciences through ground-based research and project leadership*." The Jeffries Award is the most prestigious award bestowed by the AIAA, and it reflects Cary's many contributions to understanding the factors influencing plant growth and development in highly controlled environments as well as his leadership within this field.

Given his prominent international stature in the field of gravitational and space biology, Cary often has been called upon by NASA and the U.S. National Academy of Sciences for agency-level reviews of space biology programs and Space Station life sciences utilization. At the level of peer-review and panel deliberations on the merits of particular lines of scholarship, Cary's reviews of manuscripts, proposals, and programs are known for their careful analysis, unfailing attention to detail, and constructive insights. Indeed, a recurring thread that runs through all of Cary Mitchell's contributions is a deep ethic to be thorough, impartial, and helpful, while never losing his pure sense of curiosity or losing sight of the broader vision to serve society through deeper understanding of plant physiology. It is an ethic that has governed his life as a scholar-teacher and that he has instilled in countless students and colleagues.

Cary Mitchell's scientific career has been singularly dedicated to service to society through his unique vision of horticultural science and technology. Like many others who possess multiple gifts of talent and vision, he has been driven to achieve. Yet he has maintained the life of a complete and thoughtful person: scientist, teacher, mentor, and friend, with devotion to community, church, and most especially, to family. Modest and caring, Cary and Letty have raised three children, Carlton, Lesley, and Collin, who are each pursuing successful careers in their own right.

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Identification of Phytomorphs in the Voynich Codex

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ABSTRACT

The Voynich Codex, one of the most fascinating and bizarrely illustrated manuscripts in the world, is preserved in the Beinecke Rare Book and Manuscript Library of Yale University. The descriptive text seems to be an undeciphered writing system. The manuscript has been divided into sections by Voynich commentators, with the major portion of the manuscript depicting plant, animal, and geological images. About 362 phytomorphs, 20 zoomorphs, and 1geomorph are included. In 1944, Hugh O'Neill, a distinguished taxonomic botanist at the Herbarium of the Catholic University of America in Washington, DC, identified two Mesoamerican plants, indicating the possibility that this manuscript is post-Columbian. These identifications were expanded by Tucker and Talbert (2013) to include 37 plants of Colonial New Spain. This paper extends these identifications to 59 phytomorphs, encompassing 55 plant species. Phytomorphs were analyzed by comparing the morphology of the botanical illustrations with herbarium specimens, photographs, and contemporary sources of live plants. The 55 plant species, identified with various levels of certainty, are either circumboreal or indigenous to Colonial New Spain. Most appear to have medicinal uses to improve human health. No European, Asian, or South American plants have been identified other than circumboreal species. This study is consistent with the determination that the Voynich Codex is a herbal written in Colonial New Spain in the 16th century.

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KEYWORDS: Aztec; botany; Colonial New Spain; herbal; Mexico; plant taxonomy; Voynich Manuscript

I. INTRODUCTION AND HISTORICAL CONTEXT

In 1912, the book collector Wilfred M. Voynich discovered a curiously illustrated manuscript written in an unknown symbolic text. Since then, the manuscript has elicited enormous interest resulting in a proliferation of books and web pages with no confirmed resolution concerning the origin or meaning of the text. The U.S. National Security Agency (NSA) has taken cryptological interest (D'Imperio 1978), and Ph.D. theses have been awarded on attempts to decipher the language of the Voynich manuscript (Casanova 1999). Despite claims of the text as a nonsensical hoax (Rugg 2004), the "distribution of words … is compatible with those found in real language sequences" (Montemurro and Zanette 2013) and represents "one single text or as a conglomerate of cryptograms endowed with six separate alphabets" (Casanova 1999). The history of the Voynich manuscript can be easily found elsewhere and need not be repeated here (Brumbaugh 1978; D'Imperio 1978; Kennedy and Churchill 2006; Kircher and Becker 2012). High quality scans of the pages are available, courtesy of the Beinecke Rare Book and Manuscript Library, Yale University (Anon n.d.).

The Voynich Manuscript is numbered with Arabic numerals in a different ink and penmanship from the text. The pages are in pairs ("folios"), with a number on the facing page on the right as *recto*, the reverse unnumbered on the left as *verso* (thus fol. 1r, 1v, to 116v). Fourteen folios are missing (12, 59, 60, 61, 62, 63, 64, 74, 91, 92, 97, 98, 109, and 110). By convention of Voynich researchers, the manuscript includes: "herbal pages" or a "botanical section" (pages with one exception a single type of plant and text); a "pharmaceutical or pharma section" (pages with multiple plant parts and what appears to be apothecary jars or maiolica; "astrological pages" (circular volvelles with nymphs, fol. 70v2–73v that represent the zodiac); "balneological or biological section" (bathing nude nymphs with plumbing fol. 75r–84v), various "magic circle often containing astronomical symbols" (fol. 57v, 67r–69v, 86v), various pages of continuous text that may be recipes or poems (103r–117r), and a last page incomplete (fol. 116v) with some illustrations and text in a different script.

Experts disagree whether this is parchment or vellum. Yale's Beinecke Library terms it parchment, but the report submitted to them by McCrone Associates (2009) calls it vellum. Regardless, while it can be called a manuscript, it is more accurately a codex. A similar shift has been made from the appellation of the Badianus Ms. to the more accurate Codex Cruz-Badianus (Clayton et al. 2009). Henceforth, we will thus refer to this under the more accurate designation of the Voynich Codex.

II. PHYTOMORPH IDENTIFICATION

Although many of the illustrations could be considered bizarre or whimsical, most contain morphological structures which permit botanical identification. Many enthusiasts have attempted to analyze the plants of the Voynich Codex, but only a few are knowledgeable plant taxonomists, despite their large web presence.

Most of the plant identification has been predicated on the conclusion that the Voynich is a 15th century European manuscript (Friedman 1962). The exception to this *zeitgeist* is a short remarkable 1944 paper in *Speculum* (a refereed journal of the Medieval Academy of America) by the distinguished plant taxonomist, the Rev./Dr. Hugh O'Neill (1894–1969), former Director of the Herbarium (official acronym LCU) at the Catholic University of America (CUA) in Washington, DC. From black and white photostats provided by Father Theodore C. Petersen (1883–1966) at CUA, Rev. O'Neill identified two Mesoamerican plants in the Voynich Codex. O'Neill was qualified to make this identification, because he was familiar with the flora of Mexico and allied regions. He collected 8000 herbarium specimens in British Honduras (Belize), Guatemala, and Nicaragua in 1936, and subsequently wrote a paper on the Cyperaceae of the Yucatan Peninsula (O'Neill 1940). Besides acquiring numerous types of Ynes Mexia and other Mexican collectors for the LCU Herbarium, he also directed the dissertation of Brother B. Ayres in 1946 on *Cyperus* in Mexico (Tucker et al. 1989). Rev. O'Neill was so well regarded by his colleagues in plant taxonomy that five species were named after him: *Calyptranthes oneillii* Lundell, *Carex* × *oneillii* Lepage, *Eugenia oneillii* Lundell, *Persicaria oneillii* Brenckle, and *Syngonanthus oneillii* Moldenke.

Despite O'Neill's documented background in plant taxonomy, his expertise was called into question by cryptologist Elizebeth Friedman, who wrote in 1962: "Although a well-known American botanist, Dr. Hugh O'Neill, believes that he has identified two American plants in the illustration, no other scholar has corroborated this, all agreeing that none of the plants depicted is indigenous in America. Sixteen plants, however, have been independently identified as European by the great Dutch botanist Holm." Mysteriously, there was only one mid-20th century plant taxonomist named Holm, Herman Theodor Holm (1854–1932), but he was Danish-American and was only on the faculty of Catholic University of America from July 1932, until he died in December, 1932. This Holm spent almost his entire career on plants of the Arctic and the Rocky Mountains and had no documented expertise in Mesoamerican plants.

O'Neill's discovery had powerful implications for Voynich Codex studies. Tucker and Talbert (2013) identified a New World origin for 37 plants, 9 animals, and at least 1 mineral in the Voynich Codex and concluded that it originated in the 16th century Mexico. In the present paper, identifications are expanded to 59 phytomorphs of the Voynich Codex.

The Voynich Codex contains an estimated 362 plant images or phytomorphs, 132 in the "herbal" section, plus 230 in the "pharma" section. The 132 phytomorphs in the "herbal" section are often quite bizarre and whimsical style that seems to be drawn by the same hand using a pen for outlines and then rather crudely tinting the forms with a few basic mineral pigments: green, brown, blue, or red. The roots are quite stylized and strange, often in the shape of geometric forms or animals. The leaf shapes are clearly exaggerated. The stems often seem to be inserted onto other stems and have been erroneously referred to as "grafted." However, the floral parts are often quite detailed and helpful for identification. The 230 plants in the "pharma" section are reduced, often confined to a single leaf or roots. Furthermore, these images are often associated with names in the Voynich symbolic script. A careful analysis of the images leads us to conclude that the artist was particularly concerned only with certain features significant to identification in their way of thinking.

In the text below, the botanical images of the "herbal" and "pharma" sections of the Voynich Codex are combined by botanical family and species in alphabetical sequence, incorporating the folio number in the Codex. Multiple plants occur on each folio of the "pharma" section. On each page, the plants are numbered from left to right, from top left. Some folios, for example, fol. 101v, are a trifold, so the section of the folio number is indicated in parentheses, for example, fol. 101v (3) is the third section.

Nomenclature below follows a concordance of the cited revisions and/or GRIN (USDA, ARS 2015), and/or the collaboration Royal Botanic Gardens, Kew and Missouri Botanical Garden (Plant List 2013).

A. Fern: Ophioglossaceae

1. Fol. 100v #5. *Ophioglossum palmatum* (Fig. 1.1). O'Neill (1944) identified the eusporangiate fern *Botrychium lunaria* (L.) Sw.,