Nobel Prizes for Research in Plant Science: Past, Present and Future
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ABSTRACT
The Nobel Prizes awarded in two appropriate science categories (chemistry as well as physiology or medicine) and the peace category since 1901 were studied to evaluate the plant science related research that had received recognition. We also checked the Nobel prize nomination database for the two appropriate science categories to verify the number of scientists (with research reputation on plant-based studies) who were nominated, but were unlucky in the eventual selection process. The focus of this review is research on plant materials in a wider sense (including that of photosynthetic bacteria), that received Nobel prize recognition. Until 2017, Nobel Prizes for research in plant sciences have been awarded 17 times to 20 scientists. Pioneering work on five major research themes, namely, (1) chlorophyll and photosynthesis, (2) elucidation of the structure of vitamins (carotene, thiamin, ascorbic acid and vitamin K), (3) use of radioisotopes for metabolism studies, (4) plant natural product chemistry and (5) plant genetics had received Nobel award recognition so far. For future recognition, Nobel laureates such as Melvin Calvin and Barbara McClintock had opined the worth of interdisciplinary teams with expertise in botany for trend-setting new discoveries in plant science research. We predict that pioneering studies along the line of plants that can grow in a desert or sea, plants which can be an enriched source of fuel and hydrocarbon-like materials may have potential to be considered for a Nobel Prize for plant science research.

Keywords: cytogenetics, photosynthesis, plant breeding, plant natural products, vitamins

Introduction
Alfred Nobel (1833-1896) was a Swedish chemist, engineer, inventor, businessman, and philanthropist. His creative productivity includes over three hundred worldwide patents including that of dynamite. According to his famous will of 1895, Nobel’s fortune was to be used to establish the Nobel Prizes for sciences (Chemistry, Physics and Medicine or Physiology), apart from that of Literature and Peace (Sohlman and Schuck, 1929 : Sri Kantha, 1999). These prizes were first bestowed in 1901 and announcement of these prizes in October still continue to be a news-worthy annual event for their merit and glamor (Sohlman, 1983; Garfield and Welljams-Dorof, 1992; Feldman, 2000; Levinovitz and Ringertz, 2001).

Between 1901 and 2017, the Nobel Prizes for chemistry as well as medicine or physiology categories have been awarded to 178 and 214 individuals respectively. Previously, Gresshoff (2002) had expressed an editorial opinion related to research on plant biotechnology that, “There is no Nobel Prize for plant science, preventing the popular press from featuring achievements in this area (NB, since the inception of Nobel Prizes one century ago, only three were awarded for plant-related research).” We presume that Gresshoff’s (2002) count, derives from information scientist Garfield (1987) who had identified three Nobelists (Richard Willstatter, Robert Robinson and Melvin Calvin) as those who had been recognized for research in plant-related sciences. Garfield (1987) did identify a major reason why research on plants receive less recognition and have less visibility; it may be because “they are not perceived as having a direct bearing on human health”. Is this so? How can humans, livestocks and other herbivorous animals survive and lead healthy lives without feeding on plant-based foods?

Stimulated by these thoughts, we studied the Nobel Prizes awarded in two appropriate science categories (chemistry as well as physiology or medicine) and the peace category since 1901 for an alternate count. We also checked the Nobel prize nomination database for the two appropriate science categories to verify the number of scientists (with research reputation on plant-based studies) who were nominated, but were unlucky in the eventual selection process. This derives from the concept of belonging to the ‘Nobel class’ introduced by Garfield (1980) that there are far more scientists whose work is worthy of the Nobel prize than the
highest number (only 3) of prizes awarded each year for a specific category. Thus, to be duly nominated for the Nobel prize deserves recognition because the findings of these scientists were ‘major breakthroughs’ in shaping the advances in science.

Past Record

As presented in Table 1, since 1901, Nobel Prizes for research in plant sciences have been awarded 17 times to 20 scientists. The focus of this review is research on plant materials in a wider sense (including that of photosynthetic bacteria), that received Nobel prize recognition. We disregard specific disciplinary categories such as botany and microbiology. Why? A simple explanation is that scientists frequently switch their research interests depending on factors such as availability of research funding, resources in proximity, collaborators as well as personal preferences. The identifying criterion used for this survey is whether research on plants and plant-derived materials had been mentioned in the laureate’s Nobel award lectures. 18 among the 20 scientists do satisfy this criterion. The sole exceptions were Richard Kuhn and Edward A. Doisy, because they did not deliver their Nobel award lectures.

Nobel Prizes for Chemistry


Richard Willstatter was awarded the Nobel Chemistry Prize for his research on plant pigments in 1915 (Trauner, 2015). It was the first time that Nobel Prize recognition was bestowed for research in plant sciences. Willstatter was an organic chemist who studied chemistry under Adolf von Baeyer. While in his twenties, Willstatter clarified the chemical structure of tropine, atropine and cocaine. (Adams, 1943). Subsequently, he began to focus on chlorophyll and anthocyanin pigments. Willstatter and his team discovered that the chlorophyll of different plant species is the same, but it is a mixture of two different types; chlorophyll a and chlorophyll b. He showed that magnesium is an essential part of chlorophyll’s structure and pointed out chlorophyll’s relationship...
<table>
<thead>
<tr>
<th>Year</th>
<th>Scientist (country)</th>
<th>Field</th>
<th>Research Recognition</th>
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<tbody>
<tr>
<td>1915</td>
<td>Richard Willstatter (Germany)</td>
<td>natural products chemistry</td>
<td>'for his researches on plant pigments, especially chlorophyll’</td>
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<td>1930</td>
<td>Hans Fischer (Germany)</td>
<td>natural products chemistry</td>
<td>'for his researches into the constitution of haemin and Chlorophyll and especially for his synthesis of haemin'</td>
</tr>
<tr>
<td>1937</td>
<td>Paul Karrer (Switzerland)</td>
<td>natural products chemistry</td>
<td>'for his investigations on carotenoids, flavins and vitamins A B C'</td>
</tr>
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<td>1938</td>
<td>Richard Kuhn (Austria)</td>
<td>natural products chemistry</td>
<td>'for his work on carotenoids and vitamins’</td>
</tr>
<tr>
<td>1943</td>
<td>George de Hevesy (Sweden)</td>
<td>nuclear chemistry</td>
<td>'for his work on the use of isotopes as tracers in the study of chemical processes</td>
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<td>1945</td>
<td>Artturi Virtanen (Finland)</td>
<td>agricultural chemistry</td>
<td>'for his research and inventions in agricultural and nutrition chemistry, especially for his fodder preservation method’</td>
</tr>
<tr>
<td>1947</td>
<td>Robert Robinson (UK)</td>
<td>natural products chemistry</td>
<td>'for his investigations on plant products of biological importance, especially the alkaloids’</td>
</tr>
<tr>
<td>1961</td>
<td>Melvin Calvin (USA)</td>
<td>biochemistry</td>
<td>'for his research on the carbon dioxide assimilation in plants’</td>
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<td>1978</td>
<td>Peter Mitchell (UK)</td>
<td>biochemistry</td>
<td>'for his contribution to the understanding of biological energy transfer through the formulation of the chemiosmotic theory’</td>
</tr>
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<td>1988</td>
<td>Johann Deisenhofer (Germany)</td>
<td>biochemistry</td>
<td>'for the determination of the three-dimensional structure of a photosynthetic reaction centre’</td>
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<td></td>
<td>Robert Huber (Germany)</td>
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<td></td>
<td>Hartmut Michel (Germany)</td>
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<td>1929</td>
<td>Christiaan Eijkman (Netherlands)</td>
<td>nutrition, metabolism</td>
<td>'for his discovery of the antineuritic vitamin’</td>
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<td>1937</td>
<td>Albert Szent-Gyorgyi (Hungary)</td>
<td>cell physiology, nutrition</td>
<td>'for his discoveries in connection with the biological combustion process with special reference to vitamin C and the catalysis of fumaric acid’</td>
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<tr>
<td>1943</td>
<td>Henrik Dam (USA)</td>
<td>nutrition</td>
<td>'for his discovery of vitamin K’</td>
</tr>
<tr>
<td></td>
<td>Edward A. Doisy</td>
<td>nutrition</td>
<td>'for his discovery of the chemical nature of vitamin K’</td>
</tr>
<tr>
<td>1950</td>
<td>Tadeus Reichstein (Switzerland)</td>
<td>biochemistry</td>
<td>'for discovery relating to the hormones of the adrenal cortex, their structure and biological effects’</td>
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<tr>
<td>1983</td>
<td>Barbara McClintock (USA)</td>
<td>genetics</td>
<td>'for her discovery of mobile genetic elements’</td>
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<tr>
<td>2015</td>
<td>Youyou Tu (China)</td>
<td>pharmacology</td>
<td>'for her discoveries concerning a novel therapy against malaria’ (artemisinin from Artemisia family of plants)</td>
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**MEDICINE or PHYSIOLOGY**

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<td>1970</td>
<td>Norman Borlaug (USA)</td>
<td>humanitarian work</td>
<td>'developing high yield grains credited with helping to alleviate World hunger’ (contribution to ‘The Green Revolution’ – development of dwarf wheat and rice varieties)</td>
</tr>
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**PEACE**
with the hemoglobin in red blood cells (Willstätter, 1920). Willstatter also pioneered in investigating anthocyanin pigments (Robinson, 1932; Blank, 1947).

In 1930, Hans Fischer received the Nobel Chemistry Prize for his researches into the constitution of hemin and chlorophyll. He studied pigmented substances of biological importance (Fischer, 1930).

In 1937, organic chemist Paul Karrer received recognition with the Nobel Chemistry prize for his investigations on carotenoids, flavins and vitamins A and B, (Karrer, 1937; Wettstein, 1972; Isler, 1978), and for demonstrating that in 1931 that vitamin A (retinol) is related to carotenoids in structure, in resembling half a molecule of a typical carotenoid (Karlson, 1978; Asimov, 1982). Apart from carotenoid research, Karrer also contributed his share to the (1) structural identification of other vitamins such as ascorbic acid (Svirbely and Szent-Gyorgyi, 1933) and vitamin K (Dam, 1940), (2) characterization of anthocyanin pigments (Blank, 1947), and (3) characterization of lichenin from lichens (Perez-Llano, 1944).

The 1938 Nobel chemistry prize was awarded to Richard Kuhn in 1939, ‘for his work on carotenoids and vitamins’. Kuhn received his Ph.D degree under the direction of Richard Willstatter; he subsequently worked on the synthesis of vitamin A, and was the first to isolate vitamin B₆ (pyridoxine) in pure form (Westphal, 1968; Asimov, 1982). Independently of Karrer, Kuhn also distinguished three types of carotenes (β-carotene, α-carotene and γ-carotene) which were identified as the precursors of retinol (Bauernfeind, 1972; Shampoo and Kyle, 2000).

George Hevesy pioneered in introducing radioisotope tracers for the first time to a biological problem (Anon, 1961). Hevesy used thorium B (Pb²¹²) to study the absorption and translocation of lead nitrate in horse bean (Vicia faba) and P³² in maize to study plant metabolism (Hevesy, 1923; Hevesy et al., 1936; Burris, 1950). Though subsequently Hevesy moved on to study the use of radioisotope tracers in animal and human tissues, in his Nobel lecture, he had observed the following: "Ions taken up by the plant can be removed by an exchange process under the action of other ions present in the soil or in the nutrient solution. It was already found in 1923 that minute amount of lead, labelled by the admixture of the lead isotope thorium B, when taken up by the roots of Vicia faba, could to a large extent be removed by an excel of non-labelled lead added to the nutrient solution. Most other ions were found to be much less effective in removing the labelled lead ions from the plant." (Hevesy, 1944).

Artturi Virtanen was awarded the Nobel Chemistry Prize for his research and inventions in agricultural and nutrition - especially for his fodder preservation method (Virtanen, 1945). Virtanen’s focus was on preserving food nutrients in plants of countries with cold winters. Towards this aim, his group studied the chemistry of nutrients in plants and nitrogen fixation by legumes (Virtanen, 1936; Virtanen and Laine, 1936, 1938a, 1938b, 1946; Virtanen and Arhimo, 1939; Virtanen et al., 1938, 1939), including those which contributes to the formation of dairy products and developed a method for better preservation of nutrients in hay. Using hydrochloric and sulfuric acids, Virtanen impeded certain processes, preserving the proteins and vitamins in grass. This helped cows to produce more nutritious milk year round without imported fodder (Miettinen, 1975).

Robert Robinson, honored with the 1947 Nobel chemistry prize, pioneered in ploughing the field of plant alkaloids such as quinine, strychnine, morphine and cocaine (Robinson, 1947; Todd and Cornforth, 1976; Saltzman, 1966); thus, for his times, he became one of the prolific organic chemists (Baglow and Bottle, 1979). Robinson elucidated the structure of morphine in 1925 and strychnine in 1946 (Chakravarti et al., 1947; Openshaw and Robinson, 1946; Pausaker and Robinson, 1947; Robinson, 1947; Asimov, 1982). For 20 years, Robinson had received 51 Nobel chemistry prize nominations cumulatively from 1928 to 1947 (Sir Robert Robinson nominations, 2017). Apart from alkaloids, Robinson also enriched our knowledge on other plant derived compounds like anthocyanins (Robinson, 1936, 1947).

Melvin Calvin was awarded the 1961 Nobel Chemistry Prize for his research on the carbon dioxide assimilation in plants (Moses, 1997; Schulz, 1997). Calvin and his colleagues Andrew Benson and James Bassham traced the path taken by carbon through different stages of photosynthesis using radioactive isotopes in single-cell green algae, Chlorella. They showed that sunlight acts on the chlorophyll in a plant due to the manufacture of organic compounds, rather than on carbon dioxide as was previously believed (Calvin, 1961, 1989; Seaborg and Beson, 1998).

Peter Mitchell received the 1978 Nobel chemistry prize, for his formulation of chemiosmotic theory to explain the biological energy transfer in the cells of green plants, green algae and certain bacteria during photosynthesis and how chlorophyll converts carbon dioxide and water into organic compounds (Mitchell, 1961, 1966, 1967, 1977, 1978; Hinkle and Garlid, 1992). It should be noted that Mitchell had collaborative support from Jennifer Moyle (1921 – 2016) and Peter Scholes. There was initial skepticism for the chemiosmotic hypothesis among peers (Lehninger, 1967; Huszagh and Infante, 1989; Slater, 1994) for the mechanism of
energy conservation during electron transport in the mitochondrion, when the rival chemical coupling hypothesis was supported by other researchers (Slater, 1953; Racker, 1967). But, with the discovery of ATP synthase enzyme by Racker and his colleagues (Kresge et al., 2006) and the finding that a pH difference across the thylakoid membrane in the spinach chloroplasts leads to ATP synthesis (Jagendorf and Uribe, 1966; Jagendorf, 1967), Mitchell’s chemiosmotic theory came to be accepted eventually. In this aspect, thoughts of Mitchell (1970) maybe of some relevance to other researchers, because experimentalists in biosciences have been blamed for their reluctance in advancing plausible hypotheses (Huszagh and Infante, 1989). According to Mitchell (1970), “the practical utility of a concept or of a hypothesis depends, not on the proof of its validity, but on the extent to which it opens up avenues for research and comprehension by providing a basis for the precise formulation of experimentally testable questions.” Mitchell’s success in proving his chemiosmotic hypothesis may be attributed to the tenacity in using many experimental models such as photosynthetic bacteria Rhodospirillum rubrum, Rhodopseudomonas spheroides, Anabaena variabilis and spinach chloroplasts (Mitchell, 1967).

Johann Deisenhofer, Robert Huber and Hartmut Michel received the 1988 Nobel Chemistry prize for the determination of the three-dimensional structure of a photosynthetic reaction center in photosynthetic bacterium (Rhodopseudomonas viridis). A photosynthetic reaction center is a protein-pigment complex from photosynthetic membranes that perform the primary charge of separation. This complex consists of 4 protein subunits, 4 molecules of chlorophyll, 2 molecules of pheophytin and 2 molecules of quinones. For the first time, Michel (1982) succeeded in crystallizing a membrane protein. Among these three laureates, Deisenhofer is a trained physicist, Michel - a molecular biologist and Huber – structural chemist and protein crystallographer. In an unusual pattern rarely seen among Nobel science laureates, Deisenhofer, Huber and Michel had published shared co-author papers (Deisenhofer et al., 1984, 1985a, 1985b), which attest to their collaborative effort in seeking a solution to the mystery behind the “most important chemical reaction on earth”, as touted in the press release of the Royal Swedish Academy of Sciences in announcing the word. The mystery here is, how electrons can be transferred in biological system at a speed of billionth of a second (i.e., 10^{-15} sec). For this Deisenhofer and his two colleagues choose to work with a photosynthetic purple bacterium, a simpler model than that of an algae or higher plant. Combining multiple methods such as picosecond (10^{-12}) absorption spectroscopy, X-ray crystallography and molecular biology from different disciplines proved to be valuable in solving the mystery (Lewin, 1988; Levi, 1989).

Nobel Prize for Medicine of Physiology


Christiaan Eijkman, a physician, was recognized in 1929 for his discovery of the antineuritic vitamin. Eijkman found that hens fed polished rice were afflicted by neuritic symptoms, and identified that there was a substance in the rice husk that counteracted the illness (Merritt and Tan, 2011). The substance that counteracts beriberi subsequently was designated vitamin B₁ or thiamine (Eijkman, 1929; Rosenfeld, 1997, Verhoef et al., 1999).

In 1937, Albert Szent-Gyorgyi (1893-1986) received the Nobel Medicine or Physiology Prize for his discoveries in connection with the biological combustion processes, with special reference to vitamin C and the catalysis of fumaric acid. Szent-Gyorgyi was one of the great experimental biochemists of the 20th century, who didn’t have qualms in choosing either plant or animal materials for his experiments (Edsall, 1986). By his own admission, he was also a wild theorist, as well as a philosopher and a humorist. The way Szent-Gyorgyi (1963) progressed in isolating, identifying and naming ascorbic acid (vitamin C) had been recorded for posterity.

We provide few excerpts to illustrate Szent-Gyorgyi’s rare story telling talent.

“...I also became interested in vegetable respiration, being convinced that there is no basic difference between man and the grass he mows. Plants, at that time, were divided into two groups: the ‘catechol oxidase’ and ‘peroxidase’ plants. I started with the catechol oxidase plants which contain catechol and a strong catechol oxidase. I simplified the accepted, rather complex ideas about this oxidation system. Then, I shifted to ‘peroxidase plants’ which are called so because they contain peroxidase in high concentration. If peroxide is added to a mixture of peroxidase and benzidine, immediately an intense blue color appears due to the oxidation of benzidine. I found that if the reaction was performed with the plant juice, instead of purified peroxidase, there was a very short delay, of a second or so, in the benzidine reaction. This fascinated me. There had to be present a reducing agent which reduced the oxidized benzidine, the delay corresponding to the

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time necessary to oxidize away this unknown reducing agent, later to be known as ascorbic acid.”

In addition, Szent-Gyorgyi had described how his humorous pun on naming a newly identified sugar failed to pass the muster from the disciplinarian eyes of Arthur Harden (a biochemist cum editor, who was honored with the 1929 Nobel prize in chemistry) as follows:

“In Cambridge I isolated the reducing agent found at Groningen. I crystallized it from oranges, lemons, cabbages and adrenal glands. I knew it was related to sugars, only did not know which. ’Ignosco’ meaning ‘don’t know’ and the ending ‘ose’ meaning sugar; I called this carbohydrate ’Ignose’. Harden, the editor of the Biochemical Journal, did not like jokes and reprimanded me. ’Godnose’ was not more successful and so, following Harden’s proposition, I called the new substance ’hexuronic acid’ since it had 6C’s and was acidic. I got my Ph.D for it.” [Ignose = ’I don’t know’; Godnose = ’God knows’]

In his original paper (Szent Gyorgyi, 1928), the specific sentence appears as,” “Since the exact constitution of the reducing substance is unknown, I propose to refer to it as a hexuronic acid.” The ‘peroxidase’ plants analyzed by Szent-Gyorgyi were, turnip (Brassica rapa), Spanish black radish (Rafanus sat. niger), leek (Allium porrum), Spanish onion (Allium cepa), pineapple (Ananas sativus), tomato (Solanum lycopersicum), orange (Citrus aurantium), lemon (Citrus lemonum), grape fruit (Citrus decumana) and cabbage (Brassica oleracea).

How hexuronic acid became ascorbic acid due to the collaboration with a young scientist was described by Szent-Gyorgyi (1963) as follows:

“One day a nice young American-born Hungarian J. Swirbely came to Szeged to work with me. When I asked him what he knew he said he could find out whether a substance contained vitamin C. I still had a gram or so of my hexuronic acid. I gave it to him to test for vitaminic activity... Swirbely tested hexuronic acid. A full test took two months but after one month the result was evident: hexuronic acid was Vitamin C. We made no secret of this and finished the test which left no doubt about the identity. So, we (Haworth and I) rebaptized hexuronic acid to ’ascorbic acid’. ”

Based on the results of guinea pig feeding experiments using juices of lemon and paprika (Hungarian red pepper Capsicum annuum), Szent-Gyorgyi proved that hexuronic acid (= ascorbic acid) possess antiscorbutic effect (Swirbely and Szent-Gyorgyi, 1932, 1933; Rosenfeld, 1997).

In 1943, Henrik Dam and Edward Doisy jointly received Nobel Medicine or Physiology prize to recognize their contributions for the discovery and isolation of anti-haemorrhagic vitamin K compounds from plants, mainly from alfalfa leaves (Olson, 1979). Dam (1934, 1935) proposed the name ‘vitamin K’ for the antihaemorrhagic factor which was not identical to ascorbic acid, because it is fat soluble (Dam, 1935; Morton, 1976). In the late 1930s, Dam and his colleagues extended their studies on this vitamin to report that it is rich in hemp seed and certain vegetables such as tomatoes and kale, and to a lesser degree in many cereals (Dam, 1937, 1940, 1943; Dam and Schonheyder, 1936; Dam and Lewis, 1937; Dam and Glavind, 1938, Dam et al.,1947). Doisy’s group focused on isolation, distillation and crystallization of two types of vitamin K – vitamin K1 (phyloquinone, empirical formula C_{40}H_{54}O_{2}) from alfalfa and vitamin K2 (menaquinone-n, empirical formula C_{31}H_{46}O_{2}) from putrified fishmeal (Doisy, 1976; Bingley et al., 1939a, 1939b, 1940; MacCorquodale et al., 1939; Doisy et al., 1940).

Tadeus Reichstein received one third of the share of 1950 Nobel Medicine or Physiology prize for his studies on the hormones of adrenal cortex, their structure and biological effects. In his Nobel lecture entitled, ’Chemistry of the adrenal cortex hormones’, Reichstein (1950) had described his African adventure in finding Strophantus seeds to isolate cardiac glycoside sarmentogenin. Though Reichstein received his Nobel prize at the age of 53, his research in the subsequent four decades were plant oriented. It appears that Reichstein was a phytophile of all grades – tending greenhouses, growing ferns, flowers and wild plants. He published well over 100 papers on ferns, during his post-Nobel award career (Rothschild, 1999).

Barbara McClintock was awarded the 1983 Nobel Medicine or Physiology Prize for her discovery of mobile genetic elements (Anon, 1983; Burr and Burr, 1983). She was a cytogeneticist and had earned a PhD in botany. McClintock studied corn’s (Zea mays) hereditary characteristics, for example the different colors of its kernels. She proved that genetic elements can sometimes change position on a chromosome and that this causes nearby genes to become active or inactive (McClintock, 1965; Comfort, 2001). McClintock’s finding of transposon in corn was a trend setting discovery (McClintock, 1965; Comfort, 2001). Later studies had revealed that transposon exists not only in plants but also in other organisms including human (Mills et al., 2007).

In 2015, Youyou Tu was honored with the Nobel Medicine or Physiology Prize for her discoveries concerning a novel therapy against malaria (Owens, 2015; Chen, 2016; Molyneux and Ward, 2015; Xie, 2016). In a correspondence, Zhai et al. (2016)
complimented the 84-year old woman scientist Tu as a “three nos” professor (a professor with no doctorate, no background of studying abroad and no membership in any Chinese national academies). Malaria is caused by 4 species of single-cell parasite *Plasmodium* (*P. malariae*, *P. ovale*, *P. vivax*, and *P. falciparum*) that causes malarial fever. Tu is a pharmaceutical chemist. According to her, in late 1960s (during the height of the Cultural Revolution) she was appointed as the head of the Malaria control (abbreviated as the National 523 Office) and was assigned the task of searching antimalarial drugs used in traditional Chinese medicine. Within three months, Tu was able to collect 2,000 herbal, animal and mineral prescriptions from malaria and reduced the number to 640 prescriptions. Traditional Chinese medicine uses sweet wormwood (*Artemisia annua* L.) to treat malarial fever. Tu and her colleagues found out that though there are 6 species of *Artemisia* genus, only *A. annua* contains meaningful quantities of artemisinin. Tu and her team then isolated and purified artemisinin (Qinghaosu in Chinese) in 1972, which can inhibit the malaria parasite (Tu, 2011, 2015). Early success using Artemisia extracts on malaria-infected monkeys was reported in March 1972. Background to artemisinin research by Tu and her team has been reviewed by White et al. (2015) and Guo (2016).

**Nobel Prize for Peace**
American plant breeder Norman Borlaug (1914-2009) was honored with the Nobel Peace Prize in 1970 for his contribution to the “Green Revolution”. He developed semi-dwarf, high-yield, disease-resistant wheat varieties in Mexico (Borlaug, 1944, 1965; Brown, 1970). Borlaug also introduced dwarf wheat into India and Pakistan, and production increased enormously. This form of “Green Revolution” have the potential to save over a billion people globally from starvation (Borlaug, 1970, 1983, 2000, 2002, 2007). The yield of crop was increased two to three fold by the “Green Revolution” (Borlaug, 2002). Since then, increase in yield is gradual due to improving technique of cultivation and breeding.

**Few Omissions**
Though excluded in this review (due to the criterion adapted that specific mention should be made by the scientist in his/her Nobel lecture), research conducted on plant materials by five other chemistry Nobel laureates (Theodor Svedberg, Alexander Todd, Derek Barton, John Cornforth and Vladimir Prelog) as well as two other medicine/physiology Nobel laureates (Otto Warburg and Severo Ochoa) who contributed to organic synthesis of plant-derived substances and plant metabolism studies, at early, middle or later stages of their careers should not be ignored. It may be of ephemeral interest to mention here that the very first paper of Frederick Sanger as a 24 year old graduate student (Neuberger and Sanger, 1942), the only one scientist to receive two Nobel prizes for chemistry in 1958 and 1980, was on the nitrogen and amino acid contents of different domestic varieties of British potato!

Theodor Svedberg (1884-1971) was a Swedish physical chemist, who was awarded the 1926 Nobel prize in chemistry, for his “work on disperse systems” and devising the ultracentrifuge to separate biological molecules with large molecular weights. Before the conclusion of his Nobel award lecture, delivered on May 19, 1927, Svedberg (1927) had reported his preliminary data on the molecular weights of proteins phycocyanin (blue) and phycoerythrin (red) isolated from red alga *Porphyra tenera*. Subsequently, quite a number of publications from Svedberg lab had described studies on proteins isolated from ‘nori’ *Porphyra tenera* (Svedberg and Katsurni, 1929), Manitoba wheat flour (Krejci and Svedberg, 1935), carbohydrates in plant juices (Svedberg and Gralen, 1938) and cellulose (Gralen and Svedberg, 1943; Svedberg, 1947). Svedberg was also an influential personality on the Nobel award selection process, during the first quarter of the 20th century.

As a mentee of Robert Robinson at the Oxford University, Alexander Todd (1907-1997) studied the constituents of flower pigments, and his D. Phil thesis submitted to the Oxford University in 1933 was entitled, ‘Diglucosidic anthocyanins’ (Brown and Kornberg, 2000). Before he began his Nobel-prize recognized research on the structure and synthesis of nucleosides and nucleotides, Todd and his colleagues published a series of papers on the active principles of *Cannabis indica* (hemp, cannabis resin, aka hashish) in ten parts! (Todd, 1939, 1940, 1946; Jacob and Todd, 1940). Brown and Kornberg (2000) had recorded Todd’s remembrance of what happened after the first publication of his paper on the chemical constituents of *Cannabis* (Work et al., 1939). To quote, “a call to appear at the [British] Home Office led to his [i.e., Todd’s] registration as a holder of 2½ kg of the proscribed resin. This was accompanied by a request for twenty five reprints of any subsequent papers to be sent to the Bureau of Drugs and Indecent Publications!”

Derek Barton (1918-1998) had published co-authored papers, in association with chemists who would subsequently receive Nobel chemistry prize (such as Robert Woodward, Prelog and Elias Corey), on the constitution of some plant alkaloids (Barton et al., 1950) and the bitter principle of citrus, limonin (Arigoni et al., 1960). Early papers published by John Cornforth (1917-2013) were on the constituents of Australian plants (Cornforth, 1938; Cornforth and Earl, 1938; Callow, 1975; Hanson, 2014). Similarly, first independent research of Vladimir Prelog (1906-1998), starting around 1930, was on quinine, the main alkaloid from *Cinchona*...
bark (Dunitz, 1998; Arigoni et al., 2000). Subsequently, Prelog also reported on his investigations on strychnine (Prelog and Szpilfogel, 1945) and strychnine related alkaloid sempervirins from Carolina jasmin Gelsemium sempervirens (Goutarel et al., 1948).

The 1931 Nobel prize for medicine or physiology was awarded to German biochemist of repute, Otto Warburg (1883-1970) “for his discovery of the nature and mode of action of the respiratory enzyme.” Towards the conclusion of his Nobel lecture, Warburg made a passing reference to the common origin of hemoglobin and chlorophyll. In fact, Warburg and his junior colleagues had researched on photosynthesis using green alga Chlorella and spinach Spinacea oleracea as models (Warburg and Luttgens, 1944a, 1944b; Whittingham, 1952; Aronoff, 1957; Warburg, 1958).

The 1959 medicine/physiology Nobel prize was shared by Severo Ochoa (1905-1993) for discovery of mechanisms in biological synthesis of ribonucleic acid and deoxyribonucleic acid’. Photochemical reduction of pyridine nucleotides in spinach grana and isolated chloroplasts have been studied by Ochoa as well (Vishniac and Ochoa, 1951, 1952).

Andrew Fire (b.1959) and Craig Mello (b.1960) received the 2006 Nobel Medicine or Physiology Prize for their discovery of RNA interference (RNAi) gene silencing by double stranded RNA of nematode worm Caenorhabditis elegans (Fire et al., 1998). The contribution of David Baulcombe, a British plant scientist and geneticist as a notable omission for this 2006 award, was reported by Bots et al. (2006). His work (Hamilton and Baulcombe, 1999, Baulcombe, 2004) was considered as a key to understanding the mechanism of RNAi that paved the way for Fire and Mello’s findings. Fire himself had acknowledged his debt to the work of plant scientists on gene silencing (Weissmann, 2007). Thus, concerned views of plant science researchers (Kende, 1998; Gresshoff, 2002) that research on plant science deserve better and more favorable evaluation in the selection of science Nobel prizes can be appreciated.

Nominated but Unlucky Scientists

We also scanned the Nobel Prize nomination database for the chemistry (1901-1966), and medicine or physiology (1901-1953) prizes, and identified eight renowned scientists who did exceptional research in plant sciences and were nominated for the Nobel Prizes in these two categories (Table 2); but were unsuccessful in not receiving the prize. Andrew Benson (1917-2015) and Daniel Arnon (1910-1994) were well known for their contribution to studies in photosynthesis (Arnon et al., 1954a, 1954b; Arnon, 1966; Benson, 2002; Govindjee, 2010). In fact, Benson who had co-authored research papers with Melvin Calvin (Benson and Calvin, 1947, 1950; Calvin and Benson, 1948), had received two joint nominations with Calvin in 1952 and 1960. But, only Calvin was singularly honored with the 1961 Nobel chemistry prize. Separately, Arnon had received 8 nominations cumulatively in the years 1961, 1962, 1965 and 1966.

Umetaro Suzuki (1874-1943) had received two nominations in 1914 (medicine/physiology) and 1936 (chemistry) for his research on rice bran (anti-beri beri factor, or aberic acid, as designated by Suzuki), which later came to be identified as thiamine or vitamin B1. As Suzuki published his original study in a Japanese journal (Suzuki and Imamura, 1911), this attempt failed to gain due recognition among European vitamin researchers. Also, Yasuhiko Asahina (1881-1975), a pioneer researcher on lichens (Perez-Llano, 1944; Kurokawa, 1976), had received two nominations in 1951 and 1952 for the chemistry award.

Mikhail Tsvet or variantly spelled as Michail Tswett (1872-1919) was a Russian botanist, who is credited for devising and introducing the chromatography method for separation of plant pigments in the first decade of the 20th century (Tswett, 1911; Zechmeister, 1946; Asimov, 1982; Sakodynkski, 1972; Ettre and Sakodynski, 1993a, 1993b). He received one nomination in 1918 for the chemistry prize (Ettre, 1996). Unfortunately, in the following year, he died at a relatively young age of 37. Nevertheless, Tswett’s contemporaries Willstatter and Karrer exploited the chromatography method for their pigment analysis and received the Nobel chemistry awards in 1915 and 1937 respectively. Ahead of Tswett, chemist Leon Marchlewski (1969-1946) who studied organic pigments with emphasis on chlorophyll and published the first monograph on chlorophylls in 1907 (Skarzynski, 1946), also did receive cumulatively 4 nominations (2 nominations for 1913 chemistry prize and 2 nominations for 1913 and 1914 physiology and medicine prize) for his work on chlorophyll. Ettre’s (1996) investigative study on the relative contributions of Tswett and that of his two antagonists for the Nobel prize, Machlewski and Willstatter is an interesting document that reveal the reasons why Willstatter received the 1915 Nobel prize for chemistry instead of either Machlewski or Tswett.

Norman Wingate ‘Bill’ Pirie (1907-1997) was a prolific British polymath scientist, who published in diverse fields, and became a proponent of leaf proteins as food for starving population (Pirie, 1979, 1982, Pierpoint, 1999). In 1936, Pirie and Frederick Bawden (1908-1972), with two notable crystallographers, showed for the first time that tobacco mosaic virus (TMV) could be crystallized, then considered as a remarkable work to study the structure of viral DNA and RNA (Bawden et al., 1936; Bawden and Pirie, 1938a, 1938b). For this achievement, Bawden and Pirie received
Table 2: Nominees for the Nobel Prizes for Research on Plant Sciences

<table>
<thead>
<tr>
<th>Year*</th>
<th>Scientist (country)</th>
<th>Field</th>
<th>Research Recognition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1913</td>
<td>Leon Marchlewski (Poland)</td>
<td>Chemistry</td>
<td>work on chlorophyll</td>
</tr>
<tr>
<td></td>
<td>William Kuster (Germany)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1913</td>
<td>Leon Marchlewski (Poland)</td>
<td>Chemistry</td>
<td>work on chlorophyll</td>
</tr>
<tr>
<td></td>
<td>William Kuster (Germany)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Richard Willstatter (Germany)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1913</td>
<td>Leon Marchlewski (Poland)</td>
<td>Medicine or Physiology</td>
<td>work on chlorophyll and hemoglobin</td>
</tr>
<tr>
<td></td>
<td>William Kuster (Germany)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1914</td>
<td>Leon Marchlewski (Poland)</td>
<td>Medicine or Physiology</td>
<td>work on chlorophyll</td>
</tr>
<tr>
<td>1914</td>
<td>Umetaro Suzuki (Japan)</td>
<td>Medicine or Physiology</td>
<td>studies on anti-beriberi factor</td>
</tr>
<tr>
<td>1918</td>
<td>Mikhail Tswett (Russia)</td>
<td>chemistry</td>
<td>work on chlorophyll and other plant pigments</td>
</tr>
<tr>
<td>1936</td>
<td>Umetaro Suzuki (Japan)</td>
<td>Chemistry</td>
<td>studies on anti-beriberi factor</td>
</tr>
<tr>
<td>1939</td>
<td>Frederick Bawden (UK)</td>
<td>Chemistry</td>
<td>identification tobacco mosaic virus</td>
</tr>
<tr>
<td></td>
<td>Norman W. Pirie (UK)</td>
<td>Chemistry</td>
<td></td>
</tr>
<tr>
<td>1951</td>
<td>Yasuhiko Asahina (Japan)</td>
<td>Chemistry</td>
<td>pioneering studies in lichenology</td>
</tr>
<tr>
<td>1952</td>
<td>Yasuhiko Asahina (Japan)</td>
<td>Chemistry</td>
<td>pioneering studies in lichenology</td>
</tr>
<tr>
<td>1952</td>
<td>Melvin Calvin (USA)</td>
<td>Medicine or Physiology</td>
<td>studies in photosynthesis</td>
</tr>
<tr>
<td></td>
<td>Andrew A. Benson (USA)</td>
<td>Medicine or Physiology</td>
<td></td>
</tr>
<tr>
<td>1960</td>
<td>Melvin Calvin (USA)</td>
<td>Chemistry</td>
<td>studies in photosynthesis</td>
</tr>
<tr>
<td></td>
<td>Andrew A. Benson (USA)</td>
<td>Chemistry</td>
<td></td>
</tr>
<tr>
<td>1961</td>
<td>Daniel I Arnon (USA)</td>
<td>Chemistry</td>
<td>studies in photosynthesis</td>
</tr>
<tr>
<td>1962</td>
<td>Daniel I Arnon (USA)</td>
<td>Chemistry</td>
<td>studies in photosynthesis</td>
</tr>
<tr>
<td>1965</td>
<td>Daniel I Arnon (USA)</td>
<td>Chemistry</td>
<td>studies in photosynthesis</td>
</tr>
<tr>
<td>1966</td>
<td>Daniel I Arnon (USA)</td>
<td>Chemistry</td>
<td>studies in photosynthesis</td>
</tr>
</tbody>
</table>

*Number within parenthesis indicates the number of nominations received.

one nomination in 1939 for the chemistry prize.

**Present Status**

If we analyze the trend of recognition for plant science research by the Nobel committee by collapsing the three major categories (chemistry, medicine/physiology and peace), with one decade as a unit, the emerging pattern is shown in Table 3. From 1901 to 2017, pioneering work on five major research themes, namely, (1) chlorophyll and photosynthesis, (2) elucidation of the structure of vitamins (carotene, thiamin, ascorbic acid and vitamin K), (3) use of radioisotopes for metabolism studies, (4) plant natural product chemistry and (5) plant genetics had received Nobel award recognition 17 times. Given the reality of tough evaluation of the screening process, the eventual selection of a Nobel award depends on multiple factors. Table 4 indicates the prize awarding institutions for selection of different Nobel prize categories.

The Nobel selection committee for chemistry prize consists of five regular members. To widen the range of expertise, few decades ago, adjunct members (five in 1998) with equal voting rights as the regular members were added. Currently, a member may serve a total of 9 years, in the committee. Invitations for nomination to the chemistry prize were sent to around 2,650 qualified nominators in 1998. For each year, the number of valid nominations received by the committee range between 250 and 350 (Malmstrom and Anderson, 2001). For the chemistry prize, the selection committee’s decision is first passed to the respective section members of the Swedish Academy of Sciences, for a vote. The results of this voting is then forwarded to the full membership (~350) for final approval at the plenary session (Feldman, 2000).

Similarly, the Nobel selection committee for medicine or physiology prize consists of 5 regular members and an executive secretary. An additional 10 ad hoc committee members (who serve for a nine month period, but need not be members of the Nobel assembly) chosen for expertise and evaluation of nominees aid in the selection. Like that of the chemistry prize, invitations around 2,500 – 3,000 are sent to qualified nominators, according to a rotating system (Lindsten and Ringertz, 2001). Thus, the ‘fashion and whim’ of the majority of the selection committee members, reputation of the nominators of the scientists, merit and reproducibility of the results symbolic of the scientist nominees, and last but not the least, ‘politics’ do play vital role in the eventual selection for the Nobel award.

Though advances in sciences had outgrown Nobel’s 1895 vision of his famous will (Larsson, 2008), when choosing one or two or three suitable laureates for each of the science prizes, still the Nobel award selection committees focus on two specific conditions identified by Hevesy (1951): these are, "General merit alone in promoting science does not qualify for obtaining a Nobel prize. Several contributions by the same person but in different fields, none of which is important enough by itself to qualify for an award, are not considered."

**Future Predictions**

It may be pertinent to look at what past Nobel laureates in plant science research had proposed as challenging issues awaiting resolution, in their Nobel award lectures. We provide a couple of examples here.

Calvin (1961) noted the following problem: "We are now in

---

**Table 3: Nobel Prizes awarded for Research in Plant Sciences**

<table>
<thead>
<tr>
<th>Decade</th>
<th>Number of Nobel awards for plant science research (specific year with Nobel award recognition)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1901-10</td>
<td>0</td>
</tr>
<tr>
<td>1911-20</td>
<td>1 (1915)</td>
</tr>
<tr>
<td>1921-30</td>
<td>2 (1929, 1930)</td>
</tr>
<tr>
<td>1931-40</td>
<td>3 (1937*, 1937*, 1938)</td>
</tr>
<tr>
<td>1941-50</td>
<td>5 (1943†, 1945,1947, 1950)</td>
</tr>
<tr>
<td>1951-60</td>
<td>0</td>
</tr>
<tr>
<td>1971-80</td>
<td>1 (1978)</td>
</tr>
<tr>
<td>1991-2000</td>
<td>0</td>
</tr>
<tr>
<td>2001-10</td>
<td>0</td>
</tr>
<tr>
<td>2011-17</td>
<td>1 (2015)</td>
</tr>
</tbody>
</table>

†Incomplete decade.
*Unusually, chemistry and medicine/physiology awards recognized carotene and ascorbic acid research in plant material respectively..
†Chemistry award recognized radioisotope research in plant material; medicine/physiology award recognized vitamin K research in plant materials.
the midst of trying to determine precisely what happens after the chlorophyll has absorbed the quantum and has become an excited chlorophyll molecule, a problem that involves the physicist and physical chemist, as well as the organic and biochemists. The determination of the next stage in the energy-conversion process is one of our immediate concerns. Either it is an electron transfer process, and thus comes close in its further stages to the electron transfer processes which are being explored in mitochondria or it is some independent non-redox method of energy conversion. This remains for the future to decide.

In her Nobel award lecture, McClintock (1983) had emphasized the significance of genome research as follows: “In the future attention undoubtedly will be centered on the genome... We know about the components of genomes that could be made available for such restructuring. We know nothing, however, about how the cell senses danger and instigates responses to it that often are truly remarkable.”[Fig. 2]

Studies to improve plant production in the field which is unsuitable for agricultural production has been carried out in the last two decades (Kasuga et al., 1999; Nelson et al., 2007).

**Table 4: Prize Awarding Institutions for selection of different Nobel award categories**

<table>
<thead>
<tr>
<th>Prize Awarding Institution</th>
<th>No. of Members</th>
<th>Award category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Royal Swedish Academy of Sciences</td>
<td>approximately 350</td>
<td>Chemistry and Physics</td>
</tr>
<tr>
<td>Nobel Assembly at Karolinska Institutet</td>
<td>active full professors 50</td>
<td>Medicine or Physiology</td>
</tr>
<tr>
<td>Swedish Academy</td>
<td>18</td>
<td>Literature</td>
</tr>
<tr>
<td>Norwegian Nobel Committee</td>
<td>5*</td>
<td>Peace</td>
</tr>
</tbody>
</table>

*Appointed by the Norwegian Parliament (Storting)

*source: Lemmel (2001)*

![Fig.2 Barbara McClintock delivering her Nobel lecture on Dec 8, 1983 [photo courtesy, American Philosophical Society, Barbara McClintock Papers - Photographer unknown]
In-depth knowledge on the ecosystems within and surrounding plants, called phytobiomes is needed for vital understanding of varied factors. Thus, interdisciplinary teams including expertise in botany may be vital for trend-setting new discoveries (Leach et al., 2017). Pioneering studies along the line of plants that can grow in a desert or sea, plants which can be an enriched source of fuel and hydrocarbon-like materials (Nielsen et al., 1977; Calvin, 1980, 1983) may have potential to be considered for a Nobel Prize for plant science research.

Acknowledgement

We dedicate this contribution to the memory of Dr. Eugene Garfield (1925 – 2017), a pioneer in scientometrics and studies on Nobel prizes, for inspiration offered. Dr. Garfield died on February 26, 2017.

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Environ


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