Plant Signaling & Behavior

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/kpsb20

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To cite this article: Peter V. Minorsky (2021) American racism and the lost legacy of Sir Jagadis Chandra Bose, the father of plant neurobiology, Plant Signaling & Behavior, 16:1, 1818030, DOI: 10.1080/15592324.2020.1818030

To link to this article: https://doi.org/10.1080/15592324.2020.1818030

PLANT SIGNALING & BEHAVIOR
2021, VOL. 16, NO. 1, e1818030 (17 pages)
https://doi.org/10.1080/15592324.2020.1818030

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REVIEW

American racism and the lost legacy of Sir Jagadis Chandra Bose, the father of plant neurobiology

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ABSTRACT

Sir Jagadis Chandra Bose, India's first modern biologist departed boldly from mainstream botany by claiming that plants possess "nerves" and "pulsating cells" that function respectively much like the nerve and heart cells of animals. These ideas were based on highly sensitive measurements he made of various plant functions by means of assorted ingenious instruments of his own design. Despite being the most internationally celebrated plant biologist of the early 20th century, by the end of his life, Bose had become a scientific pariah whose work was expunged from Western histories of plant biology for nearly a century. In the 21st century, Bose's contributions to biology have begun to be appreciated anew, particularly within the plant neurobiology community. The present contribution examines the motivating factors behind the anti-Bose camp in the United States in the 1920s. It is concluded that the opposition to Bose's ideas during this period had less to do with scientific dialectics than with jealousy over Bose's international acclaim and the prevailing racism of the era.

ARTICLE HISTORY
Received 29 June 2020
Revised 27 August 2020
Accepted 28 August 2020

KEYWORDS
Jagadis Bose; Racism; Plant Neurobiology

Introduction

> "*We are at one both in the East and in the West for the spread of knowledge and the removal of ignorance. We shall pass away, nations will disappear; Truth alone will survive, for it is beyond the reach of time and is eternal.*"[1]
>
> – Sir Jagadis Chandra Bose

Sir Jagadis Chandra Bose (1858–1937), founder of the Bose Institute in Kolkata, is largely forgotten outside South Asia despite the fact that he was, a century ago, an international scientific celebrity whose lectures and demonstrations drew large audiences. An observer of a Bose lecture in Washington DC in 1914 recounted how " . . . *long before the scheduled time the big lecture hall was literally packed. Prominent men and women were seen perched upon the windowsills or even seated on the floor. Dr. Graham Bell, the inventor of the telephone, came long before the meeting started. But the crowd at the door was so large that he could not get within a half block of the hall.*"[2] Celebrations of Bose, however, were not just limited to the general public. Numerous honors and prizes were bestowed upon him: he was knighted in 1917, elected to the Royal Society in 1920, and in 1924, nominated to the League of Nations Committee on Intellectual Co-operation, an elite group of intellectuals, including Albert Einstein and Marie Curie, who were internationally regarded as possessing among the greatest minds of the era. Einstein, the most iconic scientific genius of the era, was so impressed by Bose that he reportedly opined that, " . . . *any one of* [*Bose's*] *inventions and discoveries would win him a statue at the capital of the League of Nations.*"[3] So, how did Bose come to be a scientific pariah? In the case of the United States, the answer is not difficult to discern. Bose's opponents in the United States accused him of a litany of offenses, including fraud, technical incompetence and mysticism. To assess these charges, it is first necessary to examine Bose's contributions to science.

Bose's contributions to science

Before focusing on Bose's contributions to plant physiology, it should be noted that the unsurpassed fame that Bose achieved as a plant biologist is even more remarkable when one considers that he was a highly successful experimental physicist before, in his mid-forties, switching his research focus to plants. Within the province of pure and applied physics, Bose was a pioneer in the fields of radio transmission and the application of semiconductors, but he is perhaps best remembered as being the first physicist to create microwaves in the laboratory and to characterize their properties.[4,5] Bose's researches in physics, unlike his contributions to plant biology, were compatible with contemporary thought and were integrated seamlessly and with relatively little fanfare into the existing corpus of scientific knowledge.

In 1901, after a brief transition period, Bose shifted his research focus entirely to plant physiology, and for the last three decades of his career, the study of plant function consumed his scientific attention. (During this brief transitional phase, Bose noted numerous similarities in the electrical responses of animals, plants, and oxidized metal wires that led him to hypothesize that all matter is alive.[6] From a scientific historical perspective, Bose stumbled badly during this period but when he arose, thankfully for plant biology, he had switched paths from physics to plant physiology Much of

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Bose's botanical research concerned the leaf movements of two legume species, the sensitive plant (*Mimosa pudica*) and the telegraph plant (*Codariocalyx motorius*; Formerly *Desmodium gyrans*) although more importantly, he extended the findings he had made concerning these two species to "ordinary" plants, i.e., those not showing obvious motile behaviors. *Mimosa pudica* rapidly folds its leaflets when touched, and the folding response propagates down the leaf, each pair of leaflets closing in turn. In Bose's mind, the propagating movements of *Mimosa* were reminiscent of the action potentials (APs) that propagate along the nerves of animals. C*odariocalyx*, on the other hand, exhibits a spontaneous oscillatory leaf movement in which the two, diminutive lateral leaflets of the trifoliate leaf alternately rise and fall with a periodicity of a few minutes: these movements reminded Bose of the beating of a heart.

In studying these two species, both of which thrive in the warm climate of Bengal, Bose had an enormous advantage over his Western counterparts. First, both species can only be grown year-round in temperate climes in heated greenhouses. Greenhouses of a century ago were typically heated in cold weather by wheelbarrows of hot coal, the burning of which releases ethylene, a powerful gaseous plant hormone that reduces excitability.[7] Second, the specimens he studied were grown in native soil, even those that he carried with him on his deputations abroad. Many plants benefit from mutualistic associations between their root systems and specific strains of native soil fungi. One of the more common benefits of these mycorrhizal associations is that the soil fungi supply the plant with phosphate in exchange for carbohydrates. Thus, plants growing in foreign soil, and not in contact with their native strains of mutualist soil microbes, might be wanting in nutrients necessary for optimal excitability. Researchers have recently discovered, for example, that phosphate deficiency strongly dampens the increases in cytoplasmic calcium that are evoked by mechanical, salt, osmotic, and oxidative stress in the model plant *Arabidopsis thaliana*.[8] Third, plant excitability itself is a very temperature-dependent process.[9] Bose didn't always cite the ambient temperature of his laboratory in Kolkata but when he did, it was typically 30°C or so; on a few occasions it was as high as 38°C. By way of contrast, H. H. Dixon, a Northern Irish plant biologist who reported that he had been unable to repeat certain aspects of Bose's findings was working at temperatures as low as 13 to 14°C.[10]

Bose, who had trained under Lord Rayleigh at Cambridge University, had an undeniable genius for the creation and perfection of measuring apparatus of exquisite sensitivity: he invented over 50 instruments for the study of plant physiology.[11] By means of electrodes as well as a series of delicate, almost frictionless apparatus that allowed him to explore the microscopic expansions and contractions of whole organs with unprecedented resolution, Bose revealed a complexity of signaling and behavior in ordinary plants that had hitherto been unimagined. As such, Bose has rightfully been called the "Father of Plant Neurobiology."[12] Indeed, from a historical perspective, the modern plant neurobiology movement[13] can be regarded as "Bose 2.0."

It is impossible to give a full accounting of the dozens of inventions that Bose created to record plant autographs but a feature that almost all of them had in common was enormous magnification. Bose's *pièce de résistance* in this regard was the magnetic crescograph, the essence of which was a long magnetic lever, the short arm of which was attached to the plant by a fine fiber. In response to plant movement, the free end of the lever moved in close proximity to a small suspended magnetic needle bearing a small mirror. A beam of light was aimed at the mirror and as the magnetically deflected needle moved, the reflected beam of light moved across a screen.[14] In this way Bose was successful in obtaining magnifications up to a hundred million times, although at this magnification, the beam of reflected light streaked across the screen too rapidly to be useful for demonstration or recording purposes: Thus, the useful upper limit of magnification was closer to 1 to 10 million-times.

The Plant "Nerve" – Perhaps Bose's greatest discovery as a plant biologist was that excitability is a property of all plants not just botanical oddities such as *Mimosa* and Venus' flytrap that show rapid movements.[15,16] He established that local graded potentials and propagating, all-or-none APs could be elicited in plants by a variety of environmental stimuli, including rapid temperature change,[17,18] electrical shocks[19,20] and mechanical stimuli.[15,21] Bose also determined that the velocities of propagation of plant APs are several orders of magnitude slower than the APs of animals,[22] and that direct stimulation as well as the passage of excitation are accompanied by a transient shrinkage of plant stems.[22–26] Bose determined that the rate of AP propagation was faster in one direction than the other,[27] and that plant APs propagate long distances through plants via phloem cells that he called "plant nerves."[28,29] Many more examples of confirmations of Bose's experimental results could be cited but the point is evident: Bose's experimental findings relating to plant function have withstood the test of time extremely well. Bose was neither technically incompetent nor a fraud.

In regard to APs, Bose was wrong in one respect: he thought that the APs of plants and animals were so similar that plants might serve as a useful model for testing pharmaceutical drugs.[30] This idea, although reasonable a century ago based on the evidence at hand, turned out to be wrong. Given that plant APs employ Ca^{2+}-activated anion channels rather than voltage-dependent Na^{+} channels as in animals, the most parsimonious interpretation is that the APs of plants and animals evolved convergently.

But was Bose wrong to call the cells in which plant APs propagate "nerve cells?" The answer to that question depends upon whether one defines "nerve cells" based on their form or their function. Biologists who emphasize the forms of life, of course, focus on the unique structure of the animal nerve cell which is without comparison in the plant world. There are other biologists, however, who by their training or inclination prefer to define nerve cells by their function, *i.e.*, as cells in which all-or-none electrical signals propagate, in which case, plants can be considered to have a diffuse nervous system.

The Plant "Heart" – Bose established that the oscillatory movements of the lateral leaflets of *Codariocalyx* are accompanied by electric oscillations in their pulvini.[31,32] Because these electrical oscillations resembled in Bose's mind, the beating of a heart, he sought to determine whether treatments that

affect the pulsing of the animal heart might similarly influence the leaf movements of *Codariocalyx*. To simplify his pharmacological investigations, Bose established conditions whereby he could study the pulsations of isolated pulvini. He found that the immersion of isolated pulvini in water abolished the oscillatory movements but their occurrence could be restored by the addition of dilute hydrogen peroxide.[33] Bose assumed that the effects of hydrogen peroxide were related to its ability to restore oxygen to the bathing solution: later, an alternative explanation will be suggested.

Bose found that the leaflet oscillations of *Codariocalyx* were inhibited by general anesthetics, low oxygen, metabolic inhibitors and cold. None of these agents, however, are particularly specific. Much more intriguing were Bose's findings that some of the more common cardiac stimulants and depressants of his time had the predicted effects on *Codariocalyx* leaflet movements. For example, two drugs, pilocarpine and atropine, which through their opposing actions on muscarinic acetylcholine receptors in animal cells, have opposite effects on the beating of the heart, also had opposite effects on the pulsations of *Codariocalyx* (see ref. 33, p. 270). Although many subsequent pharmacological and immunological studies seemed to confirm the idea that acetylcholine receptors were present in plants, especially in motor cells,[34] genomic data suggests that plants have no close homologs to animal acetylcholine receptor genes. This combination of positive pharmacological evidence coupled with negative genomic evidence is not a unique conundrum: Identical riddles arose during the search for GABA receptors and extracellular ATP receptors in plant cells. Subsequently, it was found that GABA receptors[35] and extracellular ATP[36] receptors do exist in plant cells and despite topographical and pharmacological similarities to their counterparts in animal cells, they are phylogenetically quite distinct from them: it is possible that the current plant acetylcholine receptor quandary may find a similar solution.

Bose wondered whether the exceptionality of *Codariocalyx* leaflet movements lay not in the fact that they exhibit electrical oscillations but to the fact that their electrical oscillations are tightly coupled to leaflet movements: Is it possible that all plants demonstrate electrical oscillations and, if this is the case, in what tissues are these electric oscillations located, and what is their function? These considerations led Bose to contemplate whether there might be something akin to a "heart" in plants – not a multi-chambered heart like that found in humans – but a much more primitive structure like the peristaltic "aortic arches" found in earthworms. In order to determine the location of this hypothesized pulsating tissue, Bose advanced a fine-tipped extracellular electric probe by small increments into the stems and petioles of various plant species. He could detect no pulsatory activity at the epidermis but in each case as the probe reached a depth corresponding to the inner cortex, strong electrical oscillations could be recorded.[37] Since Bose's time, the existence of electrical oscillations in the inner cortex of plant roots has also been found.[38] Due to the perivascular location of this pulsating tissue, Bose hypothesized that the beating of this "heart" was the primary mechanism driving the ascent of sap through plants.

In order to study the proposed action of the "plant heart," Bose created a continuous recording apparatus to document the re-erection upon rehydration of wilted excised shoots. Bose reported that the application of camphor, a heart stimulant whose cardio-pharmacological mode of action is poorly understood, to withered cut shoots greatly stimulated their re-erection. This was not news. Burgerstein found that the "wilt reversing" effect of camphor was widespread in plants and cited several earlier references that reported the same.[39] Today, the effects of camphor remain anomalous. According to modern conceptions of how water ascends the plant, the water in the conductive tissue of plants (the xylem) is under tension, and when a xylem tube is severed the water under tension rapidly withdraws from the cut surface, forming an embolism. No more water can be drawn past the embolism. The effects of camphor are so at odds with orthodox views concerning the ascent of water through plants that the British plant physiologist W. O. James snidely compared Bose to a magician or an illusionist, writing, "*In the less genial climate of England drooping shoots do not erect themselves when stimulated by aqueous contact upon their cut ends, except it be with special precautions . . . Neither can little boys ascend unattached ropes before the eyes of hypnotized beholders.*"[40]

Although the genomic evidence argues against Bose's hypothesis that the pulsating inner cortex of plants is homologous to the animal heart, this fact is irrelevant insofar as assessing the validity of Bose's claims: The fact of the matter is that other researchers have presented experimental evidence in support of Bose's pharmacological findings.[41,42] Oscillations in the uptake and exudation of water by and from roots have also been reported,[43] and these oscillations are enhanced by acetylcholine and camphor.[44] *In toto*, the evidence suggests that Bose was correct that there is some sort of metabolically-driven water transport system in plants that is sensitive to drugs that in vertebrate systems interact with acetylcholine receptors. Whether this oscillatory secretion of water is the primary mechanism of water ascent in plants, as Bose proposed, is another matter entirely. Indeed, at an intuitive level, it is difficult to imagine how these feeble cellular contractions that Bose could detect only by extreme magnification, could drive the enormous volume of water that a typical plant transports daily. In fact, H. M. Benedict published an abstract shortly before his tragic death in which he took Bose to task on this very point.[45] This does not mean, however, that the faint pulsations recorded by Bose do not exist or that they are unimportant.

Nearly a century after Bose's discovery of "pulsating plant cells" in the inner cortex of plants, scientists have made a discovery that may explain the mechanism underlying the oscillations recorded by Bose. Waves of calcium release have been recorded propagating through the inner cortex of the roots of the model plant *Arabidopsis thaliana*.[46] These calcium waves in the roots have systemic effects on gene expression in the shoot, suggesting that they propagate by way of the inner cortex along the entire length of the plant from root tip to shoot tip. It seems likely that the electrical waves detected by Bose in the inner cortex are simply electrical correlates of these calcium waves. Indeed, there is a close correspondence between the passage of calcium waves and variations in the surface potential of plant leaves.[47]

Initially, the calcium waves revealed by microscopy in *Arabidopsis* were found only in salt-stressed plants.

Subsequently, it was discovered that wounding and insect herbivory also elicit calcium waves in *Arabidopsis*.[47] These same three stresses also induce hydrogen peroxide production in plants.[48,49] It is interesting, therefore, to recall Bose's aforementioned observation that the immersion of isolated *Codariocalyx* pulvini in water abolished their oscillatory movements but their occurrence could be restored by the addition of dilute hydrogen peroxide. Conceivably, the immersion of plant organs either for physiological study or microscopical viewing may reduce hydrogen peroxide concentrations *in planta* to levels insufficient for maintaining normal Ca^{2+} wave function: factors, such as salt stress, wounding or herbivory, may raise hydrogen peroxide to levels sufficient to restore normal Ca^{2+} wave function.

In summary, although one may reasonably question Bose's overarching paradigm concerning the unity of all life as well as his hypothesis concerning the primary role of pulsatory activity in the ascent of sap, Bose's experimental discoveries concerning plant function have withstood the test of time very well. Plant physiology would have progressed down a very different path and at a greatly accelerated pace if Bose's research had not been so vehemently rejected by powerful scientists in the United States.

Bose's adversaries in the United States

Daniel T. MacDougal – The main driving force behind the American opposition to Bose was Daniel Trembly MacDougal (1865–1958), Director of the Carnegie Institution of Washington (CIW)-supported Desert Laboratory in Tucson, Arizona. MacDougal had an enormous range of interests, but is perhaps best remembered today for his contributions to plant ecology, especially his studies concerning the survivorship of plants transplanted to new environments.[50] To facilitate these studies, a second CIW-sponsored facility, the Coastal Laboratory in Carmel-by-the-Sea in California, was opened in 1909, also under MacDougal's directorship.

MacDougal felt strongly about the public dissemination of science, so much so that he became the unofficial spokesperson of American plant physiology. As a self-proclaimed "*Citizen Fix-It*."[51] MacDougal regarded poor science journalism as anathema. Due to these proclivities and his professional stature, MacDougal was appointed a Trustee of the Science Service, an organization founded in 1921 with the goal of accurately informing the American public of the latest scientific discoveries. In a 1922 letter to the membership of the American Association for the Advancement of Science (AAAS), MacDougal, acting in his capacity as the General Secretary of that organization, sought the help of members in recruiting local newspapers to subscribe to the Science Service news syndicate, noting that "*At present the service is subscribed for by 30 newspapers in as many different cities, with a total of 1,500,000 readers.*"[52] MacDougal was also a Consulting Editor for *Scientific American* and was influential in determining the botanical content of that popular monthly magazine. Eventually, MacDougal would bring to bear all his connections with the press to wage war against Bose and his ideas.

MacDougal's career advancement was in no small part driven by favorable press coverage. Prior to his appointment at the Desert Laboratory, MacDougal, as a junior administrator at the New York Botanical Garden (NYBG), managed to be featured three times in the *New York Times* (*NYT)* Sunday Magazine in the span of 4 years. MacDougal's research concerning the etiolation response in nearly a hundred plants of all sorts, ranging from algae to coconut palms,[53] garnered an article entitled "*Growing Plants in Darkness*" with the strapline "*SOME STRANGE RESULTS FROM PROF. MACDOUGAL'S EXPERIMENTS AT THE NEW YORK BOTANICAL GARDENS.*"[54] At its heart, however, MacDougal's study was purely descriptive and other than its massive scope, not too different in concept from a schoolchild's experiment examining the effects of light versus dark on the morphology of germinating bean seedlings. In a second *NYT* article, sensationally entitled "*Dodging Hostile Yaquis*," the reporter recounts MacDougal's "bravado" during a NYBG-sponsored cactus-collecting expedition in northwestern Mexico. The fact of the matter, however, is that the only trace of the "hostile Yaquis" he and his "Papago" (a term now disfavored for the Tohono O'odham indigenous people of the Sonoran Desert) guide encountered were "*Indian footprints, presumably left by the Yaquis.*"[55] Finally, in 1905, the results of an entirely new line of research by MacDougal made the front page of the *NYT* Sunday magazine. MacDougal had injected the ovaries of flowers with various salts and found that the seeds from the flowers thus treated sometimes produced lines of progeny phenotypically different from the mother plant.[56,57] The *NYT* headline screamed, "*DR. MACDOUGAL'S BOTANICAL FEAT THREATENS EVOLUTION THEORIES.*"[58] The details of this chapter in MacDougal's research career, discussed elsewhere,[59] are not germane to the Bose affair and need not be recounted here: Suffice to say, "evolution theories" emerged unscathed.

When the CIW appointed MacDougal as the Desert Laboratory's first Director in 1905, it must have seemed a perfect fit: MacDougal was an energetic 40-year-old who had administrative experience, a good eye for talent, and a wide variety of research interests. Moreover, unlike many American scientists of the era who departed reluctantly for positions at the newly founded schools of the American West, MacDougal had no use for east coast academic elitism: he embraced the American West. MacDougal was an avid outdoorsman whose greatest passion was taking select friends, often fellow eugenicists, on expeditions to remote areas of the American Southwest.[60] MacDougal also possessed one more trait that made him attractive: toward those he considered his peers, MacDougal had a genial personality that attracted lifelong friends and devotees. One friend described MacDougal as " … *a jolly good fellow all the time and everywhere.*"[61]

It was while reading an appreciative history of the Desert Laboratory[62] that a photograph (see p. 35) contained therein piqued my interest concerning whether Bose may have a been a victim of racism. The photograph, taken in 1906, is a group portrait commemorating the CIW's inspection visit of the new Desert Laboratory. What grabbed my attention was the presence of Charles B. Davenport (1866–1944), a geneticist often referred to as the "Father of American Eugenics". The eugenics movement was embraced by many educated elites in the 1920s, who disproportionately " … *believed in the superiority of the white race, and saw eugenics as a means of securing its survival.*"[63]

Eugenics-based racism, the tenets of which rested squarely on the deeply flawed, culturally biased "intelligence tests" of the day,[64] was considered by eugenicists to be distinct from and superior to the coarse nativism and racism espoused by the Klu Klux Klan (a significant political force in the 1920s): the views of the latter were considered to be founded on prejudice and ignorance.

Not long after Cold Spring Harbor Laboratory came under the auspices of the CIW, Davenport, as its Director, established the Eugenics Record Office. As its Superintendent, Davenport appointed Harry H. Laughlin, who successfully lobbied various legislative bodies in the United States for the implementation of Nordic-only immigration reform laws and the compulsory sterilization of the "dysgenic". In 1914, a Vice-Consul of the Austro-Hungarian Empire, Geza von Hoffman, wrote to Laughlin, "*I thank you sincerely for the transmission of your exhaustive and interesting reports. The far reaching proposal of sterilizing one tenth of the population impressed me very much.*"[65] During the prewar Nazi era, when the disabled were becoming the first victims of the Holocaust, Davenport joined the editorial boards of two German eugenics journals and contributed to two *Festschriften* honoring Nazi eugenicists.[66]

It is possible that Davenport was present in Tucson simply in his capacity as the Director of another CIW-sponsored facility, but, in fact, Davenport and MacDougal were good friends who maintained an active correspondence for more than three decades. During his frequent trips to New York, MacDougal often made it a point to meet with Davenport socially, and on occasion, was his houseguest at Cold Spring Harbor. The two men also shared an interest in the effects of transplantation on the fitness of organisms. Much as MacDougal was interested in the effects of transplantation to foreign environments on the survivability of plants, Davenport was interested in the effects of the same on humans. For example, to explain the high death rate of African-Americans, especially in urban areas, Davenport suggested that, "*The negro is not yet adjusted to the white man's civilization. Especially does this folk of jungle origin wither away in our large cities.*"[67]

Davenport was not the only eugenicist in the Desert Laboratory photograph: in fact, of the remaining six Ph.D.s in the photograph, four, including MacDougal, had ties to the eugenics movement. Robert S. Woodward, the President of the CIW and, hence MacDougal's overseer, presided over the General Committee of the Second International Eugenics Congress held in New York City in 1921. Francis E. Lloyd, a plant physiologist who made major contributions toward understanding stomata and carnivorous plants, was a member of the 1929 Advisory Council of the Eugenics Society. George H. Shull, who was later to gain fame as the developer of hybrid maize, was an Advisory Council member of the Eugenics Society of America and a member of the Eugenics Research Association. MacDougal, too, had sympathies with the eugenics movement. In 1914, MacDougal accepted "*with pleasure*" his nomination to the General Committee of the Second International Congress of Eugenics.[68] Although I have uncovered no link between the eugenics movement and William A. Cannon or Burton E. Livingston, the two remaining Ph.D.s in the photograph, it would appear from their anti-Semitic remarks in letters to MacDougal that they were not paragons of multicultural enlightenment.[69–70]

Although MacDougal accepted his nomination to the General Committee of the Second International Congress of Eugenics, it is not clear that he ever actually served on the Committee. This might be related to the fact that although the Congress had been scheduled to be held in New York City in 1915, it did not actually convene until 1921 because of the outbreak of World War I. Perhaps his nonparticipation resulted from a falling out he had had with Woodward who was strongly critical of MacDougal's fiduciary administration of the Desert Laboratory, going so far as accusing MacDougal in 1915, of acting like a " … *kind of Tammany Hall politician … to work the Institution for all its worth.*" (Tammany Hall was a notoriously corrupt political machine in New York City.)[71]

Another possibility is that events in his personal life might have tempered MacDougal's eugenic zeal, particularly relating to the implementation of eugenic policies. At some time during this period, MacDougal fell in love with the writer Mary Austin, who had a severely disabled and institutionalized daughter.[72] Moreover, MacDougal's only child, Alice, too, had congenital problems of a gynecological nature that led her doctors to predict great difficulty in her giving birth: she did, in fact, die in early 1920, a week after giving birth for the first time, to a son, who MacDougal and his wife eventually adopted.[73] Alice's husband, Harold Stearns, also had a dysgenic affliction, an egregious addiction to alcohol. Finally, MacDougal's wife, Louise, unlike her vigorous husband, was reportedly of frail health. It has been suggested that her in-firmities were exacerbated by her husband's infidelity: "*By the early 1920s she was often absent from Carmel because of her husband's infidelities. His lengthy affair with the writer Mary Austin was the subject of gossip on the Peninsula and reportedly caused Mrs. MacDougal's serious 'nervous disorder.'*"[74]

In 1907, one year after becoming Director of the Desert Laboratory, MacDougal led a "scientific expedition" to Pinacate, a remote region of the Sonoran Desert to study the natural history of the area and to seemingly decimate by gunfire a subpopulation of mountain sheep clinging to existence amidst its lava fields. Accompanying him on this expedition was William T. Hornaday (1854–1937), Director of the New York Zoological Park (the Bronx Zoo). Hornaday had gained infamy the year previous for orchestrating arguably the most egregious of all public exhibitions of "scientific" racism in the history of the United States: the display, as part of an exhibition of human evolution, of an African pygmy named Ota Benga and an orangutan in a bone-littered cage in the "Primate House" of the Bronx Zoo.[75] According to Hornaday, a few months after this travesty, "*On a whizzing cold night in January, 1907, Daniel Trembly MacDougal said to me: 'Look here! I wish you to go with me on a fine desert trip, in the near future; and I also wish you to know that there are mighty few men whom I ever invite to go with me into the desert. When I say that I would really like to have you go with me, I mean it*!" (see ref. 61, p. 4). Hornaday later recounted their adventures in

a travelogue sprinkled with Social Darwinist sentiments such as, "*The Papagos all wore the unattractive raiment of cheap civilization; and to me, Anglo-Saxon clothes on a savage invariably look out of place. If an Indian is not picturesque, why is he?*"(see ref. 61, p. 67). For his part, MacDougal held the "Papagos" in somewhat higher regard, noting that they " … *are far superior to the United States red man when it comes to hard labor.*"[76]

The fact that MacDougal was close friends with Davenport and Hornaday, two of the more infamous promoters of racist "science" in the history of the United States does not necessarily make him a racist but any reticence I had in besmirching a dead man's legacy by publicly branding him as such was dissipated when I read the following in a letter MacDougal wrote to Hornaday: "*We can go in and go as far as we like* [into Mexico] *with our present military disposition, but what troubles me is getting out again. I am not so enthusiastic over conditions in New Mexico and southern Arizona as to wish to take on a third of a continent more of the same kind. We have got a major problem in the negro and a minor problem in the Mexican and other foreign races and to take over another big section of the same kind would be pretty bad when mixed in with our kind of politics.*"[77]

Even more germane to evaluating MacDougal's response to Bose was his use of pejorative terms for South Asians, namely "Babu" and "Hindoo" in his professional correspondence. For example, in a letter to Watson Davis, MacDougal wrote, "[*Bose's*] *lectures are in England in places where British politics demands that he give them … I wish I could convey to you the bitterness of the British scientists who are compelled by political reasons to sit by and let this Babu put over his sensational stuff in England. I am willing to go on record here in print or anywhere as saying that his pulsations, heart-beats and nerves in plants are sheer nonsense with no scientific foundation whatever.*"[78]

MacDougal's use of pejoratives for South Asians was not limited to the specific case of Bose. In a letter to Edward E. Free, a science writer, friend and former junior colleague, MacDougal wrote, "*A matter has just come up here which is possibly a reverberation of the Bose affair. This is the fact that I have recently received a message from the Hindoo University at Benares, India, asking if I would be one of the examiners of a thesis … I have cabled acceptance, but I am wondering what the relations between the physiological elements in the two places may be. Also I shall be confronted with reading a Babu scientific paper …* "[79] MacDougal's use of "Hindoo" and "Babu" is especially noteworthy because MacDougal as a rule did not use racial epithets in his correspondences.

There was one nuance to MacDougal's racism, which to be fair, should be mentioned. Uncharacteristically and for reasons lost to history, MacDougal was supportive of the Chinese who had settled in the American West. Indeed, he gave a sympathetic account to the *NYT* in 1931 concerning the humanitarian plight of ethnic Chinese Mexicans who, having been expelled by state decree from Mexico's northern states, had amassed at the U.S.-Mexico border unsuccessfully seeking entry into the United States.[80]

Due to his concern for the ethnic Chinese in North America, MacDougal engaged in a brief correspondence with Sidney L. Gulick, founder of the National Committee for Constructive Immigration, an organization aimed at easing U.S. immigration restrictions against Asians. MacDougal's interest in the Committee waned very quickly, however, when it became apparent to him that the Committee was also supportive of Japanese immigration to the United States. MacDougal opined, " … *that the Japanese can be or are being amalgamated in California or anywhere in America, or that they eagerly grasp American ideals and standards, is quite contrary to all of my observations. I have met and studied with and have had Japanese students in Europe, in New York, in Indiana, in Minnesota, Arizona and California; and my opinion is based upon experiences gained in this way. I must claim as near freedom from personal prejudice as anyone can have on such questions. Action in California, as you doubtless know, is based almost altogether upon prejudice: a fact which must be recognized in dealing with the matter.*"[81] MacDougal's condemnation of racial prejudice in others was probably consonant in his own mind: no doubt he considered his own racial views to be free of prejudice because they were based not on ignorance but on the latest "scientific" evidence gleaned from the annals of eugenical research.

MacDougal launched his first attack against Bose at a lecture at Barnard College in New York City at the end of 1922. In the 1920s, MacDougal's ever-changing research interests turned to the modeling of "living matter." MacDougal's contributions to this subject, although widely trumpeted in the public press, turned out to be irretrievably wrong. As reported in a *NYT* account of this lecture, MacDougal told the audience, "*Twist and tangle together a few hundred short frayed fibres of cotton, silk, wool and linen, wetted in mucilage, and you will have a model of the invisible structure of protoplasm magnified many thousands of times …* "[82] He then explained how these twisted ropes form a complex sponge, and that the intimate processes that constitute life take place in the liquids filling the spaces within this sponge. Missing from MacDougal's "spongy colloidal goo" model of protoplasm was the concept of membranes, a feature of cells of such fundamental importance that is difficult for modern biologists to conceive of a time when their existence was debated.

The *NYT* account continued: "*Dr. MacDougal indicated that he regarded as fanciful the conclusions of Professor Bose and other investigators who measure the quiverings of this sponge under the impression that the action of ultimate forces of life are being observed … [S]tudies of the quiverings of the jelly structure in the hands of this Indian mystic have been made the basis of fanciful and sentimental interpretations of the action of living matter which have attained a great vogue …* "[82]

MacDougal's opening salvo against Bose at the end of 1922 had little effect, but MacDougal's wrath flared anew in 1926 when the *NYT* published a full-page book review by Van Buren Thorne concerning Bose's research.[83] In response, MacDougal acerbically remarked in *Scientific American*, "*The naïve review of Mr. Van Buren Thorne of the work of the Indian scientist Bose calls for some attention, because the wide publicity resulting from its appearance in the Times Book Review of June 20 may mislead many people of even less discrimination than the author of the review, who assumes the pose of discoverer of unappreciated genius.*"[84]

By mid-1926, MacDougal's disdain for Bose had reached a breaking point. In July, in a letter to Albert G. Ingalls, an editor at *Scientific American*, MacDougal declared, "*I have about made up my mind I am going to protect the American public from the products of* [Bose's] *pathological or East Asian imagination.*"[85] In July, MacDougal submitted a letter to the editor of the *NYT* but to his frustration, the newspaper declined to publish it. In response to this setback, MacDougal enlisted the help of two popular science writers, Edwin Emery Slosson (1865–1929) and Edward Elway Free (1883–1939), both of whom incidentally, in keeping with a theme of this paper, were sympathetic to the eugenics movement. Perhaps it was to these two men that MacDougal was referring when in 1928 he reported to the Irish botanist H. H. Dixon that " … *a few of us have set ourselves the task of putting the extinguisher on this Bose nonsense every time it gets into print. Science Service has included in its editorial 'don'ts' the mention of hearts, pulsations, nerves, etc. in plants, and many newspapers have adopted the rule.*"[86]

Slosson, the editor of the Science Service's *Science News-Letter*, responded to MacDougal's appeal by publishing an interview with MacDougal in which MacDougal branded Bose's *Physiology of the Ascent of Sap* as "*utterly lacking in scientific significance*" and "*a menace and danger to sound science*." MacDougal further opined that, "*The heartbeats of plants which Sir Jagadis Chunder Bose claims he has demonstrated are mere figments of a romantic Oriental imagination, unsupported by any genuine scientific fact.*"[87] Burton E. Livingston, the Permanent Secretary of the AAAS and one of MacDougal's closest friends, recapitulated this interview in the "Science News" section of *Science*.[88]

For his part, E. E. Free, who had recently found a new position as the science editor for the *New York Herald Tribune*, penned four intemperate and illogical anti-Bose editorials.[89–92] In the last, for example, in response to the visiting British theosophist Edward L. Gardner having advocated during a lecture in New York City for the existence of fairies and having also cited Bose's ideas approvingly, Free attempted to forge a link between the acceptance of Bose's research and a belief in the existence of fairies. It is amusing to note that an updated version of this codswallop was recently espoused by some critics of the modern plant neurobiology movement who charged that plant neurobiology " … *has its roots in plant ecology and its philosophical offshoot, the Gaia hypothesis, rather than plant physiology* … "[93]

In December at the 1926 convention of the AAAS in Philadelphia, MacDougal "*characterized as 'infantile fancies' the declarations of Sir J. Bose … that plants have souls and nervous systems* … "[94] In this instance, MacDougal seems guilty of either seeding a lie or promulgating misconceptions he had read in the popular press concerning Bose's beliefs regarding "plant souls". In the single instance in which Bose used the term "soul" in reference to plants, he was dismissive of the idea.

Bose's one-time reference to "plant souls" needs to be placed in context in order to be understood correctly. In the opening decades of the 20th century, one of the more discussed works of pseudoscience was research suggesting that human souls have mass. This idea stemmed from the research of a Massachusetts physician, Duncan MacDougall, who put dying patients and their beds on a scale and claimed that an average loss of 21 grams occurred precisely at the time the patient expired.[95] Bose was referring to this study when he wrote, "*I have recently succeeded in devising a new method which reminds one of the alleged weighing of the human soul … So many extravagant claims are now made in the name of science that one must be skeptical about it … The recent results obtained with plants are very startling; they show that a plant immersed in a heating bath suddenly loses its buoyancy and sinks at the fatal temperature. This can, however, be explained without postulating a soul in the plant.*"[96]

MacDougal also attempted to defame Hans Molisch (1856–1937), an eminent Austrian plant physiologist who had been so taken by Bose's presentation in Vienna that he made the long passage to Kolkata to learn from Bose directly. As a textbook author of the time recounted, " … *Molisch, went out to India as a sort of representative from the West to see just how much Bose was enlarging his results with the very sensitive auxographs he has constructed, but, much to the surprise of the Occident, Molisch became a convert and has supported the main contentions of Bose.*"[97] Molisch, in fact, published several testimonials in *Nature* and *Science* attesting to the veracity of several of Bose's key findings.[98–100]

In light of Molisch's confirmatory reports, Frank Thone, a new hire at the Science Service, contacted MacDougal and asked him whether he cared to make any comments concerning Molisch's article in *Science*.[101] MacDougal was dismissive, attributing Molisch's confirmations of Bose's work to senility: "[Molisch] *is past the age of which retirement is compulsory in America, and as you may see, is simply repeating things that Bose says* … "[102] Two years later, in 1931, Molisch became Vice President of the Austrian Academy of Sciences, a position he held until his death in late 1937. A memorialist noted accurately that, "[Molisch] *continued to publish in an interesting and original way until his last days.*"[103] Indeed, in his final year, Molisch published a seminal monograph concerning "allelopathy", a term he introduced to the lexicon of biology.[104]

Richard B. Goldschmidt – Because MacDougal was an eminent scientist and because he co-resided in two of the more picturesque towns of the American West, namely Tucson, Arizona and Carmel-by-the-Sea, California, MacDougal enjoyed a parade of international visitors over the years. Stopovers in Tucson, in particular, were popular with visiting biologists traversing the country by rail. One of the more eminent scholars to have visited MacDougal in Tucson during a round-the-world tour was the German (later American) geneticist Richard B. Goldschmidt (1878–1858) who then, after crossing the Pacific Ocean, made his way to Kolkata where he visited Bose. Goldschmidt had little to say about his visit with MacDougal, merely calling him "*charming*," but he had a great many things, all negative, to say about India in general, and about the Bose Institute in particular. Goldschmidt recounted, "*While in Calcutta I remembered that Sir J.C. Bose lived there. I had met him before and was anxious to see the working place of this much advertised scientist. We informed him of our arrival and received an invitation to tea and a visit to his institution. Bose was originally an engineer but later turned to botany. He used his engineering talent to build refined instruments, which were attached to*

plants. The instruments produced graphs, which Bose explained as recording the heartbeat of the plant, and he wrote some books on his experiments in which he claimed to have discovered the soul of plants … As he was very wealthy, he traveled often to Europe, lectured in a half-scientific, half-mystical style, and of course made a great success of it, though the profession did not think highly of it … In his home town Bose founded and endowed a laboratory where the most marvelous things were to be done, a kind of unification of the spirit of all living creatures. The place turned out as I expected. A number of halls and galleries surrounded a large courtyard; the halls were the laboratories, and they clearly showed that no work was going on. But in some of the rooms and galleries an instrument was installed, and an assistant stood by to make a demonstration. We were to see the heartbeat and soul of plants. In each instrument hung a withered bit of some plant in touch with a lever, and from the instrument one could read oscillations. The oscillations were there all right, but nobody could say where they came from. One could think that Bose was honest, but too ignorant to know or to find out what his instruments were taking down. I have [no?] *idea what it was – but it certainly was not the heartbeat of the plants. The whole thing was just a joke, and I wonder how he could get away with it and be feted all over Europe as a great man … Tea in his house was served by an English lady, in Indian garb, who lived in the house as a kind of adoring disciple. This made me believe that after all Bose was a fake."*[105]

Goldschmidt embraced a Jewish school of thought that took pride in the belief that the Jews had been practicing eugenics for thousands of years. Indeed, Goldschmidt begins his autobiography, " … *many German-Jewish families, like my own, belong to the caste of the Levites, the literary and teaching caste since Moses' time some three thousand years ago. The Levites kept to themselves through the centuries except for intermarriage with the priestly caste, the Cohens, and thus the members of the Levite caste are the product of an age-long selection of intellectual performance*" (see ref 105, p. 3). Beyond this eugenic pride in his own pedigree, Goldschmidt was also an advocate of the German eugenic sterilization program during the inter-bellum Weimar era: "*Geneticists like Goldschmidt … regarded biology as having a major role in the social and economic reconstruction of the nation after the massive war casualties, national collapse and ensuing starvation.*"[106] Even after the Holocaust, Goldschmidt remained unapologetic, indeed, prideful about his previous eugenicist efforts, complaining, "*Actually, the Nazis took over our entire plan (never mentioning its origin) but substituting the most extreme and most unethical methods of application for our cautious and humane proposals* (see ref. 105 p. 271).

There is much to consider in regard to Goldschmidt's account of Bose. First, Bose did not believe in "plant souls" as previously discussed. Second, is Goldschmidt's concluding *non sequitur* that Bose was a "fake" because tea in his house was served by an English woman. Third, is the strange matter of Goldschmidt's (and, to be discussed, MacDougal's) obsession with Bose's wealth, as if the personal finances of a scientist have any bearing whatsoever on the quality of his or her science. The Western media of the time, however, often portrayed wealthy Indians, visiting maharajahs, for example, as effete and degraded. Through this lens, the preoccupation of Bose's detractors with Bose's supposed wealth may perhaps be viewed as a racist codeword or "dog whistle."

For the record, Bose was not spectacularly wealthy. Bose's father, a progressive-minded provincial magistrate of unremarkable origins had made some poor investments in support of the Indian self-sufficiency movement and was financially embarrassed and in failing health when Bose returned to India following his studies in England. Bose's financial hardships during this time were further exacerbated by a controversy surrounding his wages from Presidency College. As Mukherje explains, "*In those days, an Indian professor's salary was two-thirds of what his English counterpart used to get. Furthermore, on the plea that Bose's post was an officiating one, he was offered only half of even this two-thirds.*"[107] Bose's response was to fulfill all his academic responsibilities to show that Indians could be as successful as Europeans in teaching science, but he resolved never to accept his pay until his protest succeeded three years later in undoing this wrong. Bose was so impecunious during these years that he and Abala, his newlywed wife, rented a cottage on the opposite bank of the Hooghly River from Presidency College. To save money, Abala would row across the river to assist in her husband's commute.[108] Later, as Bose's international scientific reputation began to take seed, two well-connected Bengali friends, the religious leader Swami Vivekananda and the Nobel Prize winning poet Rabindranath Tagore, managed to ease his financial burdens by securing for him a number of "genius grants" from wealthy individuals. The idea that Bose was fantastically wealthy because he used much of his personal wealth to fund in part the founding of the Bose Institute may be the result of a cross-cultural misunderstanding. While retirement in the West is typically a time of personal frugality, among devout Hindus it is typically a time of munificence. During *Sannyasa*, the final life stage within the traditional Hindu ashram system, the devout renounce worldly and materialistic pursuits and dedicate their lives to spiritual pursuits.[109]

Finally, Goldschmidt's assertion that Bose's lectures were "*half-scientific, half-mystical*" is a gross caricature; if they were perceived as such, then that is not the fault of Bose but the listeners' prejudices. The science journalist Waldemar Kaempffert wrote, "*Although he is a native of India, there is not a trace of Oriental mysticism in Dr. Bose, nor of that curious mixture of occultism and metaphysics which we associate with the East.*"[110] Aldous Huxley also visited the Bose Institute and described Bose thusly: "*At the Bose Institute in Calcutta, the great experimenter himself was our guide. Through all an afternoon we followed him from marvel to marvel. Ardently and with an enthusiasm, with a copiousness of ideas that were almost too much for his powers of expression and left him impatiently stammering with the effort to elucidate methods, appraise results, unfold implications, he expounded them one by one.*"[111]

George J. Peirce – Another American plant physiologist who shared with MacDougal a deep antipathy for Bose's paradigm was George J. Peirce (1867–1954), a professor of plant physiology at Stanford University. In a 1927 review of Bose's *Plant Autographs* that he penned for *Science*, Peirce wrote, "*The trouble with Bose, as I see it with my Occidental eyes and my American mind, is that while his curiosity is directed to biological phenomena, his mind is inadequately equipped with the*

information and habits necessary for accurate study, and his reflections are addressed to philosophical problems. He is practical-minded to the extent of using self-recording apparatus in his laboratory . . . but his ambitions exceed his capacities . . . "[112]

A mind, of course, may be "inadequately equipped" due to nature or nurture. Bose, in addition to receiving a fine education from Calcutta University (B. A., 1880), was also a graduate of Cambridge University (B. Sc., 1884), and received his Ph.D. in 1896 from the University of London for a physics paper published in the *Proceedings of the Royal Society* and communicated by Lord Rayleigh. Thus, he received one of the best scientific educations available in the West. Bose's "inadequacies" as perceived by Peirce, therefore, were clearly due not to nurture but to nature. Peirce attempted to undercut Bose's technical triumphs by implying that Bose was only capable of using scientific apparatus when, in fact, Bose had created them. Pierce's racist views toward Indians were commonplace. As noted in a 1917 issue of *Scientific American*: "*While the Hindu race has achieved brilliant success in science, literature and arts, it has given very little to the world in the way of inventions; in fact, the prevalent impression among the Occidental peoples has been that the Indian brain was imitative and assimilative and sadly lacked inventive faculties.*"[113]

Lest there be any doubt about Peirce's views on race and eugenics, a college biology textbook coauthored by Peirce and several colleagues at Stanford University, devotes two full pages to the eugenics of race, and ends with the message, " . . . *the sooner serious general attention is paid to racial betterment through eugenics the better it will be for mankind, both in the near and the long-term future.*"[114] To be clear, these words were penned by Peirce's coauthors, but it seems evident that the message was one with which Peirce, a dues-paying member of the American Eugenics Society, was comfortable.[115]

Peirce and MacDougal had a friendly correspondence that spanned decades and included several unfulfilled invitations by MacDougal to join him on scientific expeditions. Although there is no evidence that MacDougal and Peirce colluded against Bose, they did discuss him in their correspondences. Peirce, for example, wrote to MacDougal, "*I am very grateful to you and to* [Burton E.] *Livingston for your appreciation of my attempt to appraise Bose's work. Among us we may possibly manage to let the gas out of that balloon.*"[116] MacDougal and Peirce also shared a chuckle over the respective placement of their photographic portraits and Bose's in Raber's *Principles of Plant Physiology* (see plate between p. 352 and p. 353).[117] Peirce wrote to MacDougal, "*When I saw the publisher's announcement, ornamented with the likenesses of Bose et alii, I wondered in what company mine might appear. The book came today. I congratulate us both on escaping Raymond Pearl's fate, for his head and that of Bose's share the same page!*"[118]

Gustof A. Persson – In the main, the chief strategy of the American biologists and science writers aligned against Bose was to publish negative book reviews and snarky letters to editors. It wasn't until 1929 in an article entitled "Have Plants a Heart Beat?" in *Scientific American* that Gustof A. Persson actually challenged the validity of Bose's experimental findings.[119] Persson reported that he had achieved tracings that resembled those of Bose but claimed that when he carefully insulated his apparatus against vibration and electrical disturbance and refrained from walking near his plant or causing any air currents in its neighborhood, the apparent pulsations ceased. Persson also claimed that he had " . . . *been able time and time again to produce a perfectly good heart beat of fine rhythmical quality in a mere cotton lamp wick steeped in cabbage juice*" (see ref. 119, p. 393). Persson attributed Bose's findings not to fakery but to "wish fulfillment."

Persson's charge that Bose had been hoodwinked by vibrations is ludicrous: Experimental physicists of Bose's caliber are keenly aware of vibrations as a source of possible artifact. Indeed, as the streets of 20th-century Kolkata became ever more subject to the rumblings of motorized traffic, Bose lamented, "*Great precautions have to be taken to eliminate all mechanical disturbances by the invention of special shock-absorbers. The artificial earthquake produced by the passage of motor-vans is however introducing increasing difficulty in the use of supersensitive instruments.*"[11]

The technical aspects of Persson's contribution were also terminally flawed: the "replicas" he constructed of two of Bose's apparatus, a sphygmograph and an electric probe, were insufficient to magnify the pulsations enough to be seen. Bose states that only his invention, the magnetic sphygmograph, which had the capacity to magnify 10,000,000 times, allowed one to obtain mechanical records of the pulsations he proposed were involved in the propulsion of sap.[120] In contrast, Persson's sphygmograph magnified only 260,000 times, that is, 1/38th that of Bose's (see ref 119, p. 396). If one takes Bose's clearest tracing of sphygmographically recorded plant pulsations, taken from an unspecified plant, and shrinks their amplitudes 38-fold, the oscillations are too small to be seen (see ref. 120, Figure 89, p. 170).

Persson constructed his sphygmograph based on a diagram in Bose's *Plant Autographs* (see ref. 120, Figure 88, p. 170). Unfortunately, *Plant Autographs* was a thin, detail-light work written for mass consumption, and Bose's description therein of his "optical sphygmograph" which could magnify one million times is unartfully jumbled with a brief mention of his "magnetic sphygmograph" which could magnify ten million times (see ref. 120, pp. 168–171). In the first, the movement of the reflecting mirror component of the optical lever is driven mechanically; in the second, by the frictionless movement of one magnet past another (see ref. 33, 309–310, 364). Judging from Persson's diagram of his sphygmometer in *Scientific American* (see ref. 119, Figure 2, p. 396), it would appear that Persson was confused by Bose's uncharacteristically poor exposition in this instance, and mistakenly built a replica of Bose's "optical sphygmograph." If so, his efforts were doomed from the start.

Persson also attempted to replicate Bose's electric probe based on Bose's description of this instrument in *Plant Autographs* (see ref. 120, Figure 74, p. 144). However, in this brief, popular work, Bose did not state specifically whether he used an Einthoven or a D'Arsonval galvanometer. Bose had previously reported being successful recording electrical oscillations in plants using either type but not with equal facility. The D'Arsonval had the advantage of yielding high amplitude signals but the high inertia of its mechanism made it difficult to record uniform trains of

pulsations; the Einthoven, on the other hand, yielded perfectly sinusoidal waves suffering much less distortion but having weaker amplitudes. In fact, the oscillations that Bose recorded using the Einthoven were so weak that the vigor of the plant and the environmental conditions had to be optimal in order to record satisfactorily (see ref. 37, pp. 213–214). Since Persson specified neither the type nor the sensitivity of the galvanometer he used, it is impossible to assess his claim that his was an apparatus of far greater delicacy. However, given that Persson was a physician with experience in electrocardiography, it is a fair guess that he used an Einthoven galvanometer, the type then used in electrocardiography and which had given Bose such a struggle insofar as recording clear pulsations.

So, who was Gustof A. Persson and how did his patently flawed work ever find its way into print? Persson was a Swedish immigrant to America who, after a rather peripatetic education in the Great Lakes region, eventually earned his M. D. from Illinois Medical College, an institution described as a "*flagrantly commercial*" enterprise in the 1910 Flexner Report that led to its shuttering.[121] In due course, Persson settled down as the medical director and eventual owner of a Gentile-only health spa in Mount Clemens, Michigan.[122–124] There, he championed the medicinal benefits of bathing in the muddy, radioactive spring waters for which the town was famous.[125] The radium-rich water was claimed to be especially effective in treating arthritis, a malady of especial concern in the 1920s because of the raging syphilis epidemic that followed World War I.

Persson, an entrepreneur by nature, dreamed of founding a pharmaceutical company in Mt. Clemens. Therefore, he was intrigued by Bose's suggestion that the pharmacological study of plant pulsations might be useful in screening potential drug candidates for pharmaceutical development. Persson himself, however, was poorly qualified for such an undertaking. Indeed, it would appear, based on his mislabeling of a petiole as a stem, that Persson had little background in botany (see ref. 119, Figure 8, p. 396). Moreover, given that there is not a hint of a trace of "*beats of fine rhythmical quality*" evident in the electrical chatter he recorded from a wick soaked in cabbage juice (see ref. 119, Figure 9, p. 396), one is forced to question his expertise in electrophysiology.

Persson's article was an unusual piece to appear in *Scientific American*, a publication that then, as now, was devoted to the public dissemination of scientific knowledge that had already been vetted in primary, peer-reviewed journals. There was also some serious editorial malfeasance in the handling of this article by the Associate Editor Albert G. Ingalls. Indeed, the sole reviewer of Persson's submission was none other than MacDougal who was foreknown by Ingalls to be a vitriolic foe of Bose. In fact, Ingalls and MacDougal had been privately discussing Bose for years.

The Ingalls/MacDougal correspondence began with Ingalls, a young editor and astronomer by training, seeking MacDougal's counsel about possible topics or contributors for *Scientific American* (during his brief tenure as editor-in-chief of *Scientific American*, E. E. Free had appointed MacDougal a Consulting Editor). In due course, Ingalls sent MacDougal a clipping from *English Mechanics* summarizing a lecture Bose had recently delivered in England and asked whether Bose's research might be a suitable topic.[126] MacDougal fired back, "*Bose has been publishing this kind of thing for years. He is a Hindoo, is wealthy and the English feel compelled to stand for him. The scientists simply writhe. When he comes to England he is not invited to lecture at the scientific laboratories but will be invited to give lectures in the office or waiting room of the Prime Minister.*"[127] A detail apparently missed by MacDougal was that the clipping from *English Mechanics* was a summary of a lecture Bose had delivered at University College London, one of Europe's leading research institutes. (In 1923–1924, during his sixth deputation abroad, Bose lectured additionally at the Universities of London, Paris and Prague, the Royal Society of Medicine, and the India Office, London, a presentation attended by Prime Minister Ramsay MacDonald (see ref. 107, pp. 88–89)). That irony also escaped Ingalls, who responded, "*Thank you for characterizing the work of our Hindoo friend. You may rest assured that after that, nothing of his or about him will get into "Sciam" if I have my way.*"[128]

Ingalls was excited to get Persson's submission. He wrote to MacDougal, "*I am running the Persson article … The form in which you saw it was very dull and stupid … I fired it back with a list of specific instructions for rewriting …* "[129] In a brief and tardy review of the proofs, MacDougal pronounced Persson's submission "*pretty good.*"[130]

In April 1929, the news of Persson's failure to replicate Bose's key findings was heralded in the *Science News-Letter*.[131] A Science Service news release bearing the same title was also widely disseminated in US newspapers as well as in the "News" section of *Science*. As a result of MacDougal's machinations, *Science*, the foremost science journal in the United States for publishing original science was reporting upon primary research published in *Scientific American*, the United States' foremost popular science magazine.

Was Bose a mystic?

MacDougal's most constant refrain from the beginning to the end of his anti-Bose campaign was that Bose was a "mystic." In some contexts, "mysticism" is a derisive catchphrase for supernaturalism and the occult: in loftier contexts, it refers to the experience of religious ecstasy, that is, a spiritual union with the Almighty. So, which of these two definitions did MacDougal mean?

The 1920s were a fertile era for supernaturalism and occultism. Many Westerners were psychologically traumatized in the wake of the twin horrors of World War I and the pandemic influenza outbreak, the "Spanish flu." *In toto*, these events killed more humans than any preceding wars or pandemics. Many of the survivors of these twin calamities were left with deep psychological scars that made them easy targets for occultists. Séances and Ouija boards became popular activities for contacting "spirits." Even some well-known scientists who were crushed by personal grief, including Sir Oliver Lodge, fell prey to these antics. In his bestseller *Raymond or Life and Death*, Lodge claimed to have made contact with the spirit of his son Raymond who was killed in World War I in 1915.

Regarding the two meanings of "mystic" discussed above, it was MacDougal's clear aim to pin the label of "occultist" on Bose. In a letter to Ingalls, MacDougal opined, "*The approval of Bose all comes from people who have little information on Bose's subject or who run to the mystical. Think of the fine stuff this may be to such men as Sir Oliver Lodge, and his tribe is a numerous one. Never was mysticism so prevalent as just now, at least certainly not at any time in the last fifty years. The world seems to have had such a dose of facts and to have had such a tremendous lot of staggering ones to assimilate in recent years that they run to something smoothly flowing and without corners.*"[132]

Contrary to MacDougal's assertion, however, Bose abhorred occultism. Indeed, in one instance, Bose applied the scientific method to examine a "miracle" causing quite a stir in Bengal, the so-called "Praying Palm of Faridpore." This peculiar specimen of date palm (*Phoenix sylvestris*) leaned at a large angle from the vertical but this angle varied diurnally to such an extent that the plant's tip moved up and down through a distance of a meter over the course of a day. Bose wrote, "*This extraordinary phenomenon was regarded as miraculous, and pilgrims were attracted in large numbers. It was alleged that offerings made to the tree had the means of effecting marvellous cures.*" He then adds, like a true skeptic, "*It is not necessary to pronounce any opinion on this subject; these cures may have been effective in the same ways as other faith cures now prevalent in the West*" (see ref. 120, p. 48). Bose then proceeded to demonstrate that there was nothing supernatural about this palm: its daily stem movements were manifestations of thermonasty. Bose found that stem nyctinasty was not limited to this singular specimen but was fairly common, albeit it in less dramatic form, in the branches of many flowering plants,[133] a phenomenon rediscovered a century later using terrestrial laser scanning.[134] Bose concluded, "*Natural science does not believe in the occult, for to it nothing is extraphysical, but only mysterious owing to some hitherto unascertained cause*" (see ref. 120, p. 50).

So, was Bose a mystic in the more exalted theological sense of the word? He was certainly a religious man. He was not a Hindu in the traditional sense but a follower of Brahmoism, a sect or religion embraced by much of Bengal's intelligentsia. Reasonable people can disagree whether Brahmoism is a Hindu sect or a distinct religion. Founded in the early 19th century, Brahmoism was closely aligned with Unitarianism. Brahmos were monotheists who did not discriminate between caste, creed or religion. They eschewed many of the more flamboyant aspects of Hindu worship, and met publicly for the sober, orderly, religious and devout adoration of "*the (nameless) unsearchable Eternal, Immutable Being who is the Author and Preserver of the Universe.*"[135] The liturgy of a Brahmo religious service included songs, prayers and readings from a variety of religious works including the Bible, the Q'oran, and the Vedas; other than the diversity of religious texts invoked and the melanin content of its practitioners, a Brahmo service was not too different from the sabbath services attended by the majority of Western scientists of this era.

The Brahmo Samaj, the Progressive social arm of Brahmoism, was deeply engaged in social reform, including the education of women and the abolition of the caste and dowry systems, child marriage and widow burning.[136] The Brahmos were also extremely pro-Science. Keshub Chandra Sen, the third Brahmo leader, was so besotted with Western science he exalted, "*Science will be your religion … above the Vedas, above the Bible. Astronomy, geology, botany and chemistry, anatomy and physiology are the living scriptures of the God of Nature.*"[137] In Bose's mind, there was no distinction between science and religion. As he wrote in *Century Magazine*, "*According to the best traditions of ancient India, there can be no conflict between knowledge and religion, for the highest knowledge is religion.*"[138]

Since Bose's contribution to *Century Magazine* was one of a series of essays written by spiritually-minded scientists, Bose can be forgiven in this instance for mixing science and religion. The fair and proper way, however, to gauge a scientist's contributions to science is to read and assess the corpus of his or her professional publications. In Bose's ten books and in his dozens of peer-reviewed scientific articles, there is only one occasion in which Bose added a metaphysical flourish. In his first book, Bose began with a 9-word Vedic verse, "*The real is one: wise men call it variously.*"[6] Such epigraphic flourishes are not unheard of in scientific works and usually go unremarked upon. Save for this one metaphysical flourish early in his career, which was urged upon him by the physical chemist Sir William Crookes,[139] Bose's written scientific legacy is devoid of religious reference.

But what about his oral scientific legacy? Much has been made of Bose's concluding remark in his 1901 lecture before the Royal Society of London: *"It is when I came on this mute witness of life and saw an all-pervading beauty that binds together all things – it was then for the first time I understood the message proclaimed on the banks of the Ganges thirty centuries ago – "they who behold the One, in all the changing manifoldness of the universe, unto them belongs eternal truth, unto none else, unto none else"* (see ref. 139, p. 65).

There is, of course, a secular reason why Bose might have chosen to end his lecture in this fashion. India's self-respect had suffered a terrible blow in the colonial era. There was during the British *Raj* a struggle among India's intellectuals to recover this self-respect and to renew in Indians a sense of national pride. Bose's message was as much political as religious. In effect, he was reminding his overlords that India and its belief systems were around long before the British *Raj* planted its flag in Indian soil, and that they would remain so long after the *Raj* departed.

Bose's world view can be summarized as a search for unity. Much as Bose's religion and science were based on a search for unity, so, too, were his political views. Like most Bengalis, Bose was an ardent nationalist. Based on a speech Bose had given to Indian students in the United States, a political scientist recalled, "*That smooth-running, high-powered, high-ranged intelligence of his becomes highly keyed up when he talks of Indian unity and Indian nationality.*"[2]

Despite their celebrity and status, the Boses were not immune to the indignities and humiliations of living in an occupied country. A biography of the Boses' dear friend, Sister Nivedita, recounts a poignant vignette of the Boses' life under colonial rule: "*Dr. and Mrs. Bose were going to Calcutta*

by the Bombay Mail . . . Two Englishmen were seated in a first-class compartment. When Dr. and Mrs. Bose tried to get into the carriage, the Englishmen objected violently; they were not going to travel with Indians. One of them went to fetch the station master to remove the Boses: the station master was unwilling to take action."[140]

In struggles for national independence, those who are moved to resist, can resort to armed resistance, noncooperation, or, as in Bose's case, by outperforming their oppressors to such an extent that the oppressors have no choice but to acknowledge the oppressed peoples' equality. Bose's strategy was to beat India's Western oppressors at the very thing that had given them the upper hand politically, that is, science and technology.

Racism or scientific dialectics?

The accusations that Bose's opponents made against him in regard to fraud, technical incompetence and mysticism do not hold up under scrutiny. Moreover, there is no question that Bose's foes in the United States were, to a man, racist. But was it their racism that turned them so vehemently against Bose? To understand Bose's Western enemies, perhaps it is necessary to imagine oneself a Nordic supremacist who unquestioningly believes himself to be not just a member of a superior race but to have one of the more superior minds within that exalted group. Imagine how vexing it must have been to such a person to witness a member of a genetically "inferior" group surpass him and rise to international stardom.

In the mind of a Nordic supremacist wrestling with Bose's international acclaim two possible explanations for this state of affairs was that the person of "inferior" genetic stock achieved this revered status either by tricking the ignorant and gullible or by profiting unduly from the agencies of positive discrimination. Both these charges are alluded to in MacDougal and Overton's review of Bose's *Physiology of the Ascent of Sap* in *Science*: "*Since the acceptance of Bose's work . . . has been widely proclaimed in the popular press of Great Britain, we are led to say that such recognition of Bose's work on the ascent of sap and the nervous mechanism of plants has been confined to persons of nonscientific training, political propagandists and literary reviewers, whose capacity for judgments, motives and purposes may not be adequately discussed here.*"[141] Thus, in MacDougal's mind, the honors and acclamations bestowed upon Bose were due not to the importance of his scientific achievements but to the political machinations of British officials intent on throwing a public relations bone to an increasingly restive colony.

Earlier, I have recounted many disparaging comments that MacDougal made against Bose both in public and private. Beyond this general malevolence, however, what precisely were MacDougal's *scientific* objections to Bose's paradigm? Why, in his own words, did this "*Bose stuff act like a red rag*" to him?[142]

The closest MacDougal came to providing a blow-by-blow critique of Bose's research was in a letter to E. E. Slosson that was part of a correspondence initiated as a consequence of Bose's publication in *Century* of an article entitled "*Is the Plant a Sentient Being*[?]." Bose's temperate opinion concerning this question was that "*One cannot give a direct answer to this inquiry, without being a plant.*"[138]

Bose's *Century* article created a flurry of activity amongst MacDougal's confederates. Ingalls mailed a copy of *Century* to MacDougal and wrote excitedly, "*I got hold of the current* Century *and read Bose's effusion. A fine lot of jelly. By golly, that boy can write, though. He must be a hit-maker with the ladies' Wednesday Morning Clubs!*"[143] Later, in returning the magazine, MacDougal joked that he was enclosing Ingalls' copy of "*Scientific Indian.*"[144]

Bose's piece in *Century* also created a problem for Slosson, although this difficulty would soon be rendered moot by Slosson suffering a debilitating heart attack and dying later in the year. Wrote Slosson, "*Dear Dr. MacDougal: Have you seen Sir Jagandis* [sic] *Chandra Bose's article on "Are Plants Sentient Beings?"* [sic] *in the last Century Magazine? If so, what do you think of it frankly? I have a reason for asking, for the editor of the Century Magazine asked me to contribute an article for the Century on chemistry, to form one of a series by distinguished scientists on the trend of modern thought. I was disposed to comply, since the Century offered pretty good pay ($300): but on looking over the last two numbers of the Century, I became dubious and finally declined.*"

Slosson's discomfiture was a result of the first two articles in the series having been written, respectively, by Sirs Oliver Lodge and J. C. Bose. Lodge, a famous physicist despondent over the death of his son in the trenches of World War I, had made a fool of himself in scientific circles by falling prey to the hocus pocus of psychics and mediums but what was the reason for all the scorn that MacDougal had heaped upon Bose? Slosson, a chemist by training, wanted to be sure. Slosson ended his letter with a request for a favor: "*So that I can have some ammunition in case this dispute comes to a show-down, I wish that you would buy an extra copy of the Century . . . and go through it with a fine-tooth comb, marking whatever is wrong with it.*"[145]

MacDougal obliged about a fortnight later unaware that Slosson had been stricken ill. MacDougal cited four offensive portions of Bose's *Century* article that he labeled A through D on the annotated copy. This annotated copy appears not to have been preserved but the letter that accompanied it was, and it provides enough detail to understand MacDougal's objections.[146]

At A, MacDougal complained that Bose " . . . *restates the commonplaces as if he had discovered, or first formulated them.*" In the particular case of Bose's *Century* piece, however, this charge is baseless since the *Century*, although highbrow, was a popular magazine not a scholarly journal. In general, however, MacDougal stood on firm ground on this point. As others have rightly pointed out, there is a regrettable paucity of relevant citations in many of Bose's works,[147] a peccadillo of scientific conduct for which he has been repaid manifold.

At B, MacDougal took offense to Bose's statement, "*We will now try to discover whether the ordinary plants are as inert and insensitive as they are supposed to be.*" MacDougal then asked rhetorically, "*What biologist or naturalist has taken plants to* [be] *insensitive or inert?*" Unfortunately, it is not clear whether Bose was referring to the opinions of biologists or those of the public-at-large. Certainly, if the

English language is any indicator, the view that plants are "*insensitive or inert*" is commonplace among the general public. Indeed, the third definition of "vegetable" in the Merriam-Webster online English dictionary is "*resembling or suggesting a plant (as in inertness or passivity).*"[148] But there were also biologists who viewed ordinary plants as insensitive. Indeed, Bose's debut as a plant physiologist was quashed in Great Britain by Sir John Burdon-Sanderson who blocked the publication of Bose's paper in the *Proceedings of the Royal Society* in part because Burdon-Sanderson vehemently rejected the idea that ordinary plants were sensitive.[149]

At C, MacDougal remarked, "*You will find the devastated remnants of another straw man. The idea that impulses were conducted by waves of hydrostatic pressure has long gone by the board and was signally disproven by myself so long ago … when I showed that impulses could be sent through sections of stem killed by heat.*[150] *The same thing has been confirmed by many writers.*" MacDougal's findings concerning *Mimosa*, however, are not really comparable to Bose's since the destructive stimuli (e.g. burning, cutting, *etc.*) used by MacDougal are known to cause the release of chemicals that can pass through heat-killed sections and cause leaf closure; Bose, on the other hand, favored nondestructive stimuli (e.g., small electric shocks) that work by eliciting APs that propagate only through living cells.

At D, MacDougal sniffed that, "*If Bose … has ever found nerve centers in plants he has not taken scientists into his confidence. Likewise if he has identified nervous structures in plants he has not communicated their description in a manner which would convey information to specialists in the structure of protoplasm or the anatomy of plants.*" It's certainly true that Bose never described "nerve centers" or "brains" in plants but he also never claimed that such structures existed.

MacDougal, near the end of his letter to Slosson, expressed displeasure with the predicament in which Slosson had involved himself, writing rather menacingly, "*As a trustee of the SCIENCE SERVICE I have had but little occasion to question the soundness of your decisions as its Director. You would be letting us down if you wrote anything which in any sense could be put on the same plane as Bose's mystical maunderings.*"

But how did MacDougal regard Bose's views on plant sentience? Since MacDougal in a letter to H. H. Dixon had mocked Bose for having had a "*sentimental session with some plant*,"[151] I fully expected MacDougal to decry Bose's attribution of higher faculties to the plant kingdom: I could not have been more wrong. MacDougal's main complaint was not that Bose's paradigm hinted at the existence of consciousness in plants but that others, including MacDougal himself, had embraced the concept of plant consciousness long ago. As evidence of this, MacDougal enclosed a copy of *Living Plants and Their Properties*, a book of botanical essays that he had coauthored decades earlier with Joseph C. Arthur, his Ph. D. mentor at Purdue University.[152] In his letter to Slosson, MacDougal wrote: "*I have just fished out from a collection of old stuff a small volume published by Professor J.C. Arthur and myself in 1898, the titles to the chapters of which seem pertinent to this discussion … you will see that we discuss*

The Special Senses of Plants

The Development of Irritability

Mimosa; a typical sensitive plant

Universality of consciousness and Pain

`among other topics … thirty years later Bose sells these ancient formulations with an Eastern varnish to the literary world and to the Century."

Although the chapter entitled "*Universality of Consciousness and Pain*" was penned by Arthur, MacDougal apparently did believe in plant consciousness. Insights into MacDougal's thoughts about plant consciousness come from an unexpected quarter; a book written by his alleged mistress, the author Mary Austin. Austin playfully recounts a discussion she overheard between MacDougal and Harvard psychologist [and eugenicist] William McDougall:

"*Said the Botanist to the Psychologist, 'Where do you think that self-consciousness might begin in the life of plants?' Said McDougall, the Psychologist, after consideration, 'Possibly where there is accommodation between two tropisms.'*

'Then' said MacDougal, the Botanist, 'there is self-consciousness in a daffodil.'"[153]

Thus, to recapitulate MacDougal's arguments against Bose: 1.) Bose's recordings of "APs" in plants were artifacts of vibration; 2.) the electrical oscillations described by Bose were figments of Bose's romantic Oriental imagination, and 3.) although plants have neither brains nor nerves nor any commonly recognizable bioelectrical activity, they are nonetheless self-conscious.

The anti-Bose camp in the United States, as has been discussed, had an extremely high density of racist eugenicists. It is important to emphasize that I did not selectively choose these individuals from a pool of possible candidates: they were the opposition. Of course, since the 1920s were an especially racist period in U.S. history, it could be argued that the high concentration of eugenicists amongst Bose's adversaries was perhaps nothing unusual. I do not think this was the case. Of the hundred or so American botanists included in the third edition of *American Men of Science* published in 1921,[154] I recognize only eight who were active eugenicists in that they wrote articles on the topic or were members of eugenics societies (John M. Coulter, Edward M. East, William D. Hoyt, Francis E. Lloyd, David Starr Jordan, Daniel T. MacDougal, George J. Peirce and George H. Shull); of these eight, only three were plant physiologists (MacDougal, Peirce and Lloyd). Of course, it is impossible to assess the percentage of U.S. botanists who were sympathetic to the eugenics movement without being actively engaged in its promulgation. However, it is telling that of the three plant physiologists who can be definitely linked to the eugenics movement, two, MacDougal and, to a lesser extent, Peirce, spearheaded the American opposition to Bose.

Of course, Bose's opponents maintained, in their own minds, genuinely held scientific objections to Bose's paradigm (from a historiographic viewpoint, it matters not whether these genuinely held beliefs were correct or not). Scientists who express maverick views always face strong opposition from the scientific orthodoxy: so, was the opposition that Bose faced out of the ordinary? One way to address this question is

to examine whether Western scientists who held ideas as controversial as Bose's were vilified by their peers to the same extent as was Bose. In considering Bose's most unpopular botanical hypothesis, concerning the role of living, pulsating cells in the ascent of sap, it should be noted that Godlewski[155] decades earlier, and Canny[156] decades later, both proposed hypotheses similar to Bose's in that they proposed a role for living cells in pumping or transmitting the xylem sap: their critics, however, neither decried them as "frauds" or "mystics" nor raised any concerns relating to their ethnic origins or religious beliefs.

The intense animus directed at Bose by his U.S. adversaries in the 1920s stemmed directly, in my view, from jealousy. Fame is a scarce commodity amongst plant physiologists, and in the 1920s Bose commanded nearly all of it. To a racist, Bose's fame must have been especially galling. For those removed from the spotlight by Bose's ascendancy, it was clear that Bose had to be toppled, and topple him they did: racism was the primary tool by which they did so.

Conclusion

Alas, for the progress of science, the voices of Bose's supporters faded and an entire generation of American plant physiologists were instilled with MacDougal's view that, "*The wholly mystic nervous mechanisms and pulsations of Bose have so far eluded all observation, and nothing in the implied conceptions may be properly included within the domain of science, or of reality, or may be deemed worthy of metaphysical consideration.*"[157] Incredibly, as late as 2010, a leading American plant physiology textbook made no mention of plant APs.[158]

Bose was not perfect; his overly speculative theories and overreliance on inductive reasoning, in some cases, made him a target for condemnation. Such criticisms, of course are part and parcel of the "rough and tumble" of academic debate. However, when such debates become personal, or take aim at the opponent's ethnic origins or religious beliefs, or purposefully distort the opponent's arguments, then they become reprehensible, and should be decried as such. Clearly, Western scientists of the current generation are not responsible for the racist sins of the past but in cases where the xenophobia and cultural ignorance of our intellectual forebears has effectively erased, marred or diminished the legacy of a great scholar, it is morally imperative that we, as scholars, not be implicit in perpetuating a gross, historical injustice. Bose was one of the most brilliant minds to ever contemplate plant function. It is high time that we in the West recognize and celebrate Bose's contributions to plant biology and humanity.

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