Fabrício A. Rodrigues
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Silicon and Plant Diseases

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Foreword

Silicon (Si) is the most abundant mineral element in the earth's crust, so all plants rooting in soil contain Si in quantities that exceed many essential mineral elements. However, due to its universal existence and lack of obvious visible deficiency symptoms, very little attention was paid to the role of this element in plant growth until 1917, when the first scientific report on Si suppressing a plant disease was published by Onodera in Japanese. Onodera found that rice leaves with a low Si content was susceptible to blast while leaves with high Si were more resistant to this disease. Nowadays, Si is known to suppress many plant diseases in both monocots and dicots such as bacterial blight, brown spot, grain discoloration, leaf scald, leaf and panicle blast, stem rot, and sheath blight in rice as well as powdery mildew in wheat and cucumber. Mechanisms underlying the Si-mediated resistance to different diseases have also been intensively studied.

In this book written by Drs. Rodrigues from Brazil and Datnoff from USA, the authors comprehensively cover all aspects on the relationship between Si and plant disease that span from history to disease control, mechanisms involved and finally to future prospects. Both authors are excellent scientists, who have been working in the field of Si and disease control together for many years. This book widely collects data from their own research and other groups around the world.

Yield loss due to disease is a major problem in crop production worldwide, therefore control of disease occurrence is an important issue. Different from most fungicides, Si is able to decrease the intensity of multiple diseases at the same time. In some cases, Si fertilizers have been demonstrated to be as effective as fungicides in reducing pathogen infection. Therefore, application of Si fertilizers has become a routine agronomic practice for sustainable crop production. In fact, Si has been recognized as an "agronomically essential element" for rice production in Japan, and Si fertilizers have been applied in many countries such as Brazil, China, Japan, and the USA. Since the effect of Si is more obvious in reducing disease intensity under intensive cultivation with heavy applications of nitrogen fertilizers, the demands for Si fertilizers will increase in the future. This book will provide very useful information on how Si controls plant diseases not only for students at the university, but also for researchers in other agricultural fields of study.

Professor, Institute of Plant Science and Resources, Jian Feng Ma
Okayama University, Japan

Preface

Silicon, considered to be the second-most abundant mineral element in soil, plays an important role in the mineral nutrition of plants. A wide variety of monocot and dicot species have benefited from silicon nutrition, whether direct or indirect, when they are exposed to different types of abiotic and/or biotic stresses. Besides the many agronomic and horticultural benefits gained by maintaining adequate levels of this element in the soil and also in the plant tissue, the most notable effect of silicon is the reduction in the intensities of a number of plant diseases caused by biotrophic, hemibiotrophic and necrotrophic plant pathogens in many crops of great economic importance.

The aim of this book is to summarize our current understanding of the effects of silicon on plant diseases. The chapters address the dynamics of silicon in soils and plants; the history of silicon in the control of plant diseases; the use of silicon to control soil-borne, seed-borne and foliar diseases in monocots and dicots; the mechanisms involved in the host resistance against infection by plant pathogens mediated by silicon as well as the current knowledge at the omics level and, finally, highlights and prospects for using silicon in the future. We hope this book will be a valuable asset for managing plant diseases as well as a useful resource for undergraduate and graduate courses in plant pathology and other related disciplines. We believe the in-depth information found in this book will be useful to plant scientists worldwide and of interest to agronomists, horticulturists, plant pathologists, plant physiologists and soil scientists in its references to numerous commodity crops, ornamentals and turf. As researchers and growers become more aware of silicon and its potential, it is likely that this often overlooked, quasi-essential element will be recognized as a viable means of enhancing plant health and performance.

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Chapter 1
History of Silicon and Plant Disease

Lawrence E. Datnoff and Fabrício A. Rodrigues

Abstract The use of silicon in agriculture probably began in China more than 2000 years ago because farmers at that time incorporated rice straw along with manure as a fertilizer to enhance plant performance and yield. In 1917, the potential of silicon to reduce blast on rice was first reported by a plant chemist, and his discovery launched a cascade of silicon research in Japan. The role of silicon in plant growth and potential disease reduction was first noted for dicots in 1939. As a result of research from the 1980s until today, silicon's potential to decrease the intensity of many diseases is now known for a large number of plant species. Since the early discovery that this quasi-essential element believed to be unimportant in plant development plays a major role in reducing plant diseases, research has revealed that amending plants with silicon is a simple, sustainable way to help maintain and enhance plant health in agriculture.

Introduction

The use of silicon in agriculture most likely began more than 2000 years ago in China (Matichenkov et al. 2001). At that time, the emperor decreed that farmers must incorporate rice straw along with manure as a fertilizer to enhance plant performance and yield (Yoshida 1978). Because rice plant tissue is now known to contain anywhere from 1 to 10 dag/kg silicon, this would be the first indirect evidence of early agriculturists using silicon as a soil amendment/fertilizer.

In the early 1800s, plant naturalists began to measure the elemental composition of a number of plant species and discovered that plants contained silicon in quantities that greatly exceeded those of other mineral elements (De Saussure 1804;

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Snyder et al. 2006; Tottingham 1908). Even with these findings, the general scientific community at that time considered silicon to be unessential for plant development (Tottingham 1908). Davy (1819), however, was one of the first scientists to investigate the form of silicon in the epidermis of a number of monocots, including horsetail, oats and wheat. This author believed that the use of silicon in agriculture might be important because the plant's epidermis was siliceous and probably served to support, as well as protect, the plant from biotic stresses. Liebig (1840) surmised that silicon was involved in cereal stalk rigidity and that the lodging of wheat was simply caused by a deficiency in this element. Leibig further suggested that sodium silicate could be used as a silicon fertilizer and conducted research with this silicon source on sugar beet development under greenhouse conditions. In 1842, Berzelius discovered silicon as an element and studied its role with organic matter under field conditions (Matichenkov et al. 2001). Kreuzhage and Wolff (1884) and Grob (1896) first studied microscopically the distribution and specific location of silicon bodies in different leaf tissue of oats. Based on these authors' observations that the cell lumen contained a high level of silicon, Grob (1896) suggested that this element might be involved in resistance against plant diseases.

Discovery of Silicon Affecting Plant Diseases in Monocots

Isenosuke Onodera in 1917 was probably the first scientist to demonstrate that silicon may play a role in reducing plant disease (Onodera 1917; Ishiguro 2001). As such, the history of this element in association with a known plant disease infecting a monocot began with his studies. This scientist was a plant chemist by training and was interested in determining whether rice infected by *Pyricularia oryzae*, the causal agent of rice blast, would reduce the mineral content of the plant. He collected rice plants that were visibly non-infected and infected with *P. oryzae* in the same field from 13 Western provinces of Japan. He then compared the nutritional compositions of these plants to each other and observed that the plants infected with *P. oryzae* contained a lower silicon content than those not infected. Therefore, Onodera demonstrated a potential relationship between the silicon content and rice susceptibility to blast. Furthermore, he deduced that the silicon content of the rice plant was probably dependent on the soil type in which the plant was grown, suggesting that some soils are inherently lower in elemental silicon compared to others.

Onodera's discovery launched a cascade of silicon research on rice blast in Japan (Ishiguro 2001; Suzuki 1963; Kozaka 1963). Miyake and Adachi (1922) demonstrated that rice cultivars that contained more silicon were more resistant to blast than those with lower concentrations of this element. Kawashima (1927) showed that increasing silicon rates in the soil in which rice plants were grown increased the concentration of silicon in the plant tissue and subsequently decreased blast development. Other investigators in the 1930s also showed that the application of silicon increased rice resistance to blast (Ishiguro 2001). Over the next 20 years, researchers