




# Phosphagen kinase function in flagellated spores of the oomycete *Phytophthora infestans* integrates transcriptional regulation, metabolic dynamics and protein retargeting

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## Summary

Flagellated spores play important roles in the infection of plants and animals by many eukaryotic microbes. The oomycete *Phytophthora infestans*, which causes potato blight, expresses two phosphagen kinases (PKs). These enzymes store energy in taurocyamine, and are hypothesized to resolve spatial and temporal imbalances between rates of ATP creation and use in zoospores. A dimeric PK is found at low levels in vegetative mycelia, but high levels in ungerminated sporangia and zoospores. In contrast, a monomeric PK protein is at similar levels in all tissues, although is transcribed primarily in mycelia. Subcellular localization studies indicate that the monomeric PK is mitochondrial. In contrast, the dimeric PK is cytoplasmic in mycelia and sporangia but is retargeted to flagellar axonemes during zoosporogenesis. This supports a model in which PKs shuttle energy from mitochondria to and through flagella. Metabolite analysis indicates that deployment of the flagellar PK is coordinated with a large increase in taurocyamine, synthesized by sporulation-induced enzymes that were lost during the evolution of zoospore-lacking oomycetes. Thus, PK function is enabled by coordination of the transcriptional, metabolic and protein targeting machinery during the life cycle. Since plants lack PKs, the enzymes may be useful targets for inhibitors of oomycete plant pathogens.

## Introduction

The life cycles of many eukaryotic microbes include a zoospore stage, which is used for dissemination and host infection. Microbes producing these flagellated cells include apicomplexans, brown and green algae, excavates, foraminiferans, myxomycetes, oomycetes and others (Adl et al., 2005). Additional microbes such as alveolates form motile cilia, which are shorter forms of flagella. The movement of cilia and flagella is driven by dynein motors that hydrolyze adenosine triphosphate (ATP), which causes microtubule doublets to slide against each other (King and Sale, 2018). The resulting high rate of ATP use may lead to temporal or spatial mismatches between energy demand and availability.

Understanding how cells meet their energy needs is a major issue in biology. Most ATP in eukaryotes is generated in mitochondria and then diffuses across the cell to its sites of use. However, some cells may periodically use ATP faster than it can be made or transported. Cells cannot stockpile ATP since it must remain within a narrow concentration range to avoid misregulating cellular pathways. To circumvent this challenge, some cells have evolved to replenish ATP using enzymes, such as phosphagen kinases (PKs), which catalyze the reversible transfer of the  $\gamma$ -phosphoryl group of ATP to guanidino acceptors called phosphagens (Ellington, 2001; Wallimann et al., 2011). Most data on this come from studies of vertebrate cells such as muscle, brain and spermatozoa, although PKs have been also identified in bacteria, lower animals and eukaryotic microbes (Watts and Bannister, 1970; Ginger et al., 2008; Ooi et al., 2015). Some cells also use adenylate kinase to replenish ATP, which creates ATP and AMP from two molecules of ADP (Dzeja and Terzic, 2009). PKs and adenylate kinases may also help high-energy phosphoryls diffuse across cells or organelles by raising local concentration gradients in a 'bucket brigade' system (Dzeja and Terzic, 2009). PKs may also accelerate energy diffusion since phosphagens are smaller than ATP, and may relieve thermodynamic blocks to oxidative phosphorylation by siphoning off mitochondrial ATP (Ellington, 2001).

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# Phosphagen Kinases

**Gennady P. Manchenko**



## **Phosphagen Kinases:**

*Phosphagenkinases* S. N. Lyzlova, V. E. Stefanov, 1990-12-07 *Phosphagen Kinases* discusses phosphagen kinases and their substrates and demonstrates that the role of the phosphagen phosphagen kinase system is not limited to energy depositing functions. The book is unique in its complex biological chemical and physiological coverage of the family of related enzymes and phosphagen kinases. This book also emphasizes creatine and arginine kinases in the evolution of phosphagen kinases and provides information regarding biosynthesis structure physico chemical properties catalytic mechanisms and the regulation of the enzymes. Other topics discussed include heterogeneity intracellular localization and developmental physiological and pathological changes of creatine kinase. Researchers and students specializing in biochemistry enzymology zoology developmental biology physiology and medicine will find the book to be an invaluable source of information. *Creatine Kinase* Christian Vial, 2006 Creatine kinases and arginine kinases are an historical model in enzymology. They belong to the large family of phosphagen kinases which transfer a phosphoryl group from ATP to a nitrogen atom within a guanidinium group to form that was called by the early muscle physiologists a phosphagen. These compounds and the enzymes that catalyse their formation and use are present in cells with important and rapidly fluctuating energy requirements.

**Comparative Animal Biochemistry** Klaus Urich, 2013-04-17 tribute greatly to understanding the origins of The plan for this book goes back almost 20 years. Already at that time it was possible to recognize organisms an extraordinary variation in metabolites and To provide the biochemist with a ready over processes superimposed upon the basic biochem view of the structural diversity of animals the book includes a simplified version of animal sys ical system of animals. Each species each indi tematics for further information on the classifica vidual in fact each type of cell of the multicellu lar organism possesses its own biochemical char tion structure and life of particular animal spe acter and this molecular variety its biological sig cies the reader should consult the relevant text nificance and its evolutionary development books. It is assumed that the zoologist reader has throw up many interesting questions. The com a basic knowledge of biochemistry important general biochemical facts are in any case given for parative approach that has been so productive at many of the subjects covered the higher levels of complexity of morphology and physiology can also be used to great effect at I had already completed several chapters of the molecular level this book by the beginning of the 1970s **Environmental Stressors and Gene**

**Responses** J.M. Storey, K.B. Storey, 2000-07-31 *Cell and Molecular Responses to Stress* is a new multi volume book series from Elsevier Science that focuses on how organisms respond at a molecular level to environmental stresses imposed upon them. All organisms deal with variations in multiple environmental factors including temperature oxygen salinity and water availability. Many show amazing tolerances to extreme stress with remarkable biochemical adaptations that allow life to persist under very difficult circumstances. This series explores the molecular mechanisms by which cells and organisms respond to stress focusing on the variations in metabolic response that allow some cells and organisms to deal with extreme

stress others to endure stress within strict limits and others to have a very low tolerance for changes in environmental parameters Articles from within the series highlight the elastic limits of molecular responses in Nature with examples drawn from animal plant and bacteria systems Volume 1 begins by considering some of the roles of environmental stress in determining the geographic distribution of animals and in promoting species divergence and then explores gene expression and metabolic responses to environmental stress with examples of adaptation to high and low temperature osmotic anoxia ischemia desiccation high pressure and heavy metal stresses

Creatine and Creatine Kinase in Health and Disease Gajja S. Salomons, Markus Wyss, 2007-10-16 Although creatine was discovered already in the 1830s it is only in recent years that its crucial role for human health and general well being has been increasingly realized and appreciated A number of beneficial health effects have been ascribed to oral creatine supplementation such as neuroprotective ergogenic anti diabetic anti inflammatory antiviral or antitumor effects Creatine may even improve memory and intelligence In the present book emphasis is placed on the intricate interplay between creatine and creatine kinase function on one hand and proper brain function neurodegenerative disease and or neuroprotection on the other hand The book also elaborates on the recently identified inborn errors of creatine biosynthesis and transport the so called cerebral creatine deficiency syndromes The clinical hallmarks of these disorders are mental retardation epilepsy autistic like behaviour and speech and language delay In addition the muscle growth and strength promoting effects the pharmacokinetics and the safety of oral creatine supplementation are discussed Finally the present book outlines the emerging systems biology approaches for understanding the pleiotropic effects of creatine and creatine kinase and hypothesizes on the most promising and influential future avenues of research towards creatine based nutritional strategies for the prevention of neurological disease and for improving the quality of life in general

Advances in Phosphotransferases (Nitrogenous Group Acceptor) Research and Application: 2012 Edition, 2012-12-26 Advances in Phosphotransferases Nitrogenous Group Acceptor Research and Application 2012 Edition is a ScholarlyBrief that delivers timely authoritative comprehensive and specialized information about Phosphotransferases Nitrogenous Group in a concise format The editors have built Advances in Phosphotransferases Nitrogenous Group Acceptor Research and Application 2012 Edition on the vast information databases of ScholarlyNews You can expect the information about Phosphotransferases Nitrogenous Group in this eBook to be deeper than what you can access anywhere else as well as consistently reliable authoritative informed and relevant The content of Advances in Phosphotransferases Nitrogenous Group Acceptor Research and Application 2012 Edition has been produced by the world s leading scientists engineers analysts research institutions and companies All of the content is from peer reviewed sources and all of it is written assembled and edited by the editors at ScholarlyEditions and available exclusively from us You now have a source you can cite with authority confidence and credibility More information is available at <http://www.ScholarlyEditions.com>

Creatine and Creatine Phosphate Michael W. Conway, Joseph F. Clark, 1996-09-20 Creatine and Creatine Phosphate Scientific and Clinical

Perspectives is an up to date summary of both the scientific and medical aspects of creatine and creatine phosphate metabolism and therapy It covers in detail the basic biochemistry bioenergetics and biophysics of these agents with particular emphasis on their role on the cardiovascular and muscle systems Modern in vivo myocardial and skeletal muscle measurements are outlined and the importance of the molecules in cardiovascular medicine sport science and cardiac surgery are highlighted This book is designed for those interested in the basic scientific background to creatine and creatine phosphate and also for physicians treating or studying heart and vascular disease The book will also be vital for sports scientists who wish to acquire a comprehensive knowledge of the molecule which is currently being promoted for performance and exercise programmes

**Phosphotransferases: Advances in Research and Application: 2011 Edition**, 2012-01-09 Phosphotransferases Advances in Research and Application 2011 Edition is a ScholarlyEditions eBook that delivers timely authoritative and comprehensive information about Phosphotransferases The editors have built Phosphotransferases Advances in Research and Application 2011 Edition on the vast information databases of ScholarlyNews You can expect the information about Phosphotransferases in this eBook to be deeper than what you can access anywhere else as well as consistently reliable authoritative informed and relevant The content of Phosphotransferases Advances in Research and Application 2011 Edition has been produced by the world s leading scientists engineers analysts research institutions and companies All of the content is from peer reviewed sources and all of it is written assembled and edited by the editors at ScholarlyEditions and available exclusively from us You now have a source you can cite with authority confidence and credibility More information is available at <http://www.ScholarlyEditions.com>

**Chemical Zoology V4** Marcel Florkin, 2012-12-02 Chemical Zoology Volume IV Annelida Echiura and Sipuncula presents chemical information on zoological significance of Annelida Echiura and Sipuncula This book is organized into 13 chapters that tackle the biological and biochemical aspects of these phyla The opening chapter describes the comparative anatomy phylogeny and classification of Annelida Echiura and Sipuncula The book goes on discussing the biological aspects of these phyla including nutrition and digestion respiration and energy metabolism oxygen transport and carbohydrate and nitrogen metabolism This volume also covers these organisms composition of guanidine compounds and phosphagens lipids inorganic components and pigments Other chapters deal with the growth and development luminescence endocrines and pharmacologic properties of Annelida Echiura and Sipuncula This book is an invaluable resource for zoologists and biochemists

**Cellular Bioenergetics: Role of Coupled Creatine Kinases** Valdur A. Saks, Renée Ventura-Clapier, 2012-12-06 Most of the information on the functional role structure and molecular biology of creatine kinase is scattered in several hundreds of publications The editors of this volume invited all authors who are most active at present in experimental research on creatine kinases to summarize their work and make the information easily available to a wider scientific audience especially to young investigators who are entering this field Since the functional role of coupled creatine kinases is directly related to the phenomenon of

compartmentation and structural organization of metabolic networks we also invited experts in the related areas to contribute to the volume Almost all invited authors responded enthusiastically and the results of this collective work are presented here For biochemists biophysicists physiologists and medical research workers

**Molecular Cloning** Gregory G. Brown, 2011-10-12 The development of molecular cloning technology in the early 1970s created a revolution in the biological and biomedical sciences that extends to this day The contributions in this book provide the reader with a perspective on how pervasive the applications of molecular cloning have become The contributions are organized in sections based on application and range from cancer biology and immunology to plant and evolutionary biology The chapters also cover a wide range of technical approaches such as positional cloning and cutting edge tools for recombinant protein expression This book should appeal to many researchers who should find its information useful for advancing their fields

Issues in Life Sciences—Bacteriology, Parasitology, and Virology: 2012 Edition, 2013-01-10 Issues in Life Sciences Bacteriology Parasitology and Virology 2012 Edition is a ScholarlyEditions eBook that delivers timely authoritative and comprehensive information about Virology The editors have built Issues in Life Sciences Bacteriology Parasitology and Virology 2012 Edition on the vast information databases of ScholarlyNews You can expect the information about Virology in this eBook to be deeper than what you can access anywhere else as well as consistently reliable authoritative informed and relevant The content of Issues in Life Sciences Bacteriology Parasitology and Virology 2012 Edition has been produced by the world's leading scientists engineers analysts research institutions and companies All of the content is from peer reviewed sources and all of it is written assembled and edited by the editors at ScholarlyEditions and available exclusively from us You now have a source you can cite with authority confidence and credibility More information is available at <http://www.ScholarlyEditions.com>

**Handbook of Detection of Enzymes on Electrophoretic Gels** Gennady P. Manchenko, 2002-12-26 Still widely used as gene markers isozymes detected by zymogram techniques have proven valuable in a range of other biological applications over the last few years Along with these new applications many new techniques have also emerged Yet more than eight years since the Handbook of Detection of Enzymes on Electrophoretic Gels was first published

**Oxygen Sensing in Tissues** Helmut Acker, 2013-03-14 This book covers a wide biological range of problems regarding oxygen sensing in tissues Oxygen sensing is defined as a process in which O<sub>2</sub> reacts with different cellular components to avoid hypoxic cell damages Oxygen sensing contributes to auxiliary mechanisms which help bacteria invertebrates vertebrates and mammals to survive and withstand hypoxic sensations For the first time experts from different disciplines have cooperated in examining various biological systems exhibiting this phenomenon

**Muscles as Molecular and Metabolic Machines** Peter W. Hochachka, 2019-06-04 First published in 1994 this book explores the paradigm of muscles as molecular and metabolic machines in which all structures and functions are exquisitely integrated and matched to each other The analysis begins with a standard reductionist approach reviewing the integrated machine

parts The key working components of the complete muscle machine are proteins soluble organelle or membrane localized and a conservative count indicates that today more than 100 such machine parts are known essentially all occurring as cell specific isoforms Random assortment of these machine parts or protein isoforms could generate an astronomical number of muscle machines and an equally enormous number of muscle fiber types The question is why aren't such large numbers ever seen To attack this problem the reductionist approach is complemented with an integrationist adaptational one Evidence is presented that the more highly specialized the muscle type the further one moves from the above extreme in the most highly specialized muscles typically only one fiber type is found It is argued that instead of random assortment of isoforms or machine parts only specific and often unique combinations can work in appropriate fashion A few established examples of this fundamental principle are reviewed but emphasis is placed on the fact that we know dreadfully little about why this is so and what kinds of further studies are needed The issue of why the very large numbers of fiber types theoretically possible are never even approximately realized has never before been addressed Indeed it is rarely recognized Muscles as Molecular and Metabolic Machines is the first work of its kind on the subject      *Cell and Muscle Motility* Jerry Shay, 2013-06-29 The term cytoskeleton in muscle and nonmuscle cells refers to fibrous proteins that are directly or indirectly associated with cell shape contractility and or motility These cytoskeletal elements include microtubules and associated proteins microfilaments and their binding proteins and lastly intermediate filaments Even though the structure and function of myosin and tropomyosin have been extensively investigated in muscle cells considerably less is known about their functions in nonmuscle cells they are often referred to generically as actin binding proteins as are actinin filamin vinculin and others Indeed most nonmuscle researchers are unaware that the term intermediate filament was derived from the observation that the diameter of intermediate filaments is intermediate between those of actin 5 nm and myosin 15 nm and not intermediate between those of actin 5 nm and microtubules 25 nm It has therefore been the purpose of this series to attempt to bridge the communication gap that appears to exist between muscle and nonmuscle researchers For those students and active scientists who are faced with the task of absorbing new data and concepts at an ever accelerating rate review essays are an excellent way to keep up The essays in this volume as well as in the previous ones focus on topics of current interest They are intended to be critical rather than exhaustive      *The Enzymes*, 1973-07-04 *The Enzymes      Molecular Aspects of Animal Development* Rudolf Weber, 2014-05-10 The Biochemistry of Animal Development Volume III Molecular Aspects of Animal Development provides an account of the developments in the molecular approach to vertebrate development with particular emphasis on the functions of nucleic acids The book discusses topics on oocyte maturation transcriptional patterns in early development the post transcriptional control of gene expression and the significance of gene amplification Morphogenetic substances growth promoting proteins and the functional differentiation of mitochondria in embryonic systems are covered as well Biochemists biologists and zoologists will find the book invaluable      **Genomics of Plant-Associated Fungi and**

**Oomycetes: Dicot Pathogens** Ralph A. Dean, Ann Lichens-Park, Chittaranjan Kole, 2014-08-22 This book describes how genomics has revolutionized our understanding of agriculturally important plant associated fungi and oomycetes It illustrates some fundamental discoveries about these eukaryotic microbes with regard to the overall structure of their genomes their lifestyles and the molecular mechanisms that form the basis of their interactions with plants Genomics has provided new insights into fungal lifestyles and led to practical advances in plant breeding and crop protection such as predictions about the spread and evolution of new pathogens This volume focuses on fungi and oomycetes that are typical dicot plant pathogens and includes *Sclerotinia sclerotiorum* *Botrytis cinerea* *Alternaria* sp *Verticillium alfalfae* and *Verticillium dahliae* *Fusarium oxysporum* *Phytophthora capsici* *Phytophthora sojae* *Phytophthora ramorum* *Phytophthora infestans* *Hyaloperonospora arabidopsidis*     The Chemical Biology of Nitrogen Christopher Walsh, 2021-05-21 The Chemical Biology of Nitrogen book provides a chemocentric approach to both the inorganic and organic chemical biology of nitrogen Following an introduction to nitrogen trivalency the book progresses through the logic of inorganic nitrogen metabolism and organic nitrogen metabolites to nitrogen proteomics



The Top Books of the Year Phosphagen Kinases The year 2023 has witnessed a remarkable surge in literary brilliance, with numerous captivating novels enthralling the hearts of readers worldwide. Lets delve into the realm of popular books, exploring the captivating narratives that have captivated audiences this year. The Must-Read : Colleen Hoover's "It Ends with Us" This poignant tale of love, loss, and resilience has captivated readers with its raw and emotional exploration of domestic abuse. Hoover masterfully weaves a story of hope and healing, reminding us that even in the darkest of times, the human spirit can succeed. Phosphagen Kinases : Taylor Jenkins Reids "The Seven Husbands of Evelyn Hugo" This spellbinding historical fiction novel unravels the life of Evelyn Hugo, a Hollywood icon who defies expectations and societal norms to pursue her dreams. Reids absorbing storytelling and compelling characters transport readers to a bygone era, immersing them in a world of glamour, ambition, and self-discovery. Discover the Magic : Delia Owens "Where the Crawdads Sing" This captivating coming-of-age story follows Kya Clark, a young woman who grows up alone in the marshes of North Carolina. Owens spins a tale of resilience, survival, and the transformative power of nature, entrancing readers with its evocative prose and mesmerizing setting. These popular novels represent just a fraction of the literary treasures that have emerged in 2023. Whether you seek tales of romance, adventure, or personal growth, the world of literature offers an abundance of captivating stories waiting to be discovered. The novel begins with Richard Papen, a bright but troubled young man, arriving at Hampden College. Richard is immediately drawn to the group of students who call themselves the Classics Club. The club is led by Henry Winter, a brilliant and charismatic young man. Henry is obsessed with Greek mythology and philosophy, and he quickly draws Richard into his world. The other members of the Classics Club are equally as fascinating. Bunny Corcoran is a wealthy and spoiled young man who is always looking for a good time. Charles Tavis is a quiet and reserved young man who is deeply in love with Henry. Camilla Macaulay is a beautiful and intelligent young woman who is drawn to the power and danger of the Classics Club. The students are all deeply in love with Morrow, and they are willing to do anything to please him. Morrow is a complex and mysterious figure, and he seems to be manipulating the students for his own purposes. As the students become more involved with Morrow, they begin to commit increasingly dangerous acts. The Secret History is a brilliant and gripping novel that will keep you guessing until the very end. The novel is a cautionary tale about the dangers of obsession and the power of evil.

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