COMMENTARY / COMMENTAIRE

Plant biology and food science in Canada: a vision for the future

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Abstract: The Natural Sciences and Engineering Research Council of Canada (NSERC) recently announced a plan to undertake a "reallocations exercise" designed to provide support for new initiatives and emerging fields of research in a period of fiscal restraint. NSERC's Grant Selection Committees (GSC) were instructed to establish committees charged with preparing reports that respond to the question "Why is it important for Canada that your research community should receive some of the funds available for reallocation?" The Plant Biology and Food Science Grant Selection Committee (GSC03) responded by striking a committee representing the breadth of research it supports. Extensive input was obtained from the scientific community through a web site and electronic discussion group. A discussion document was then prepared and distributed to 34 "consultants" representing NSERC-funded researchers and leaders in the agricultural, food, and forest industries. After refining the report, a second draft was circulated to more than 90 scientists for further review. This process provided us with a collective "vision" of our discipline that focuses on the importance of fundamental research, guided by excellence, innovation through multidisciplinary approaches, international leadership potential, and relevance to Canada and Canadians. To achieve this vision, NSERC must introduce a strategy to attract, train, and retain our best young minds, establish a broad, realistic funding base, and create opportunities for more interaction among disciplines. Six specific recommendations were put forward to achieve these goals with a total request for $15.3 million in reallocated and new money. If funded, this initiative will provide GSC03 researchers with the support required to generate the ideas, communicate the insights, develop the skills, and educate the personnel that will be essential for Canada's participation in the biotechnology revolution that is transforming global agriculture, food, and forest industries. Moreover, fundamental knowledge of the interaction between plants and their environment will also help Canada play a leading role in the effective, responsible stewardship of planetary resources in the 21st century.

Key words: Natural Sciences and Engineering Research Council of Canada, reallocations exercise, plant biology, food science, biotechnology, fundamental research.

Résumé : Le Conseil de recherches en sciences naturelles et en génie (CRSNG) du Canada vient d'annoncer un plan pour entreprendre un "exercice de réallocation" en vue de supporter de nouvelles initiatives dans des domaines de recherche en émergence, dans le cadre d'une période de restriction fiscale. On a demandé aux comités de sélection de mettre en place des comités chargés de préparer des rapports qui répondent à la question "Pourquoi est-il important pour le Canada que votre comité reçoive une partie des fonds disponibles pour la réallocation?" Le comité de biologie végétale et sciences de l'alimentation (GSC03) a réagi en mettant sur pied un comité représentant l'ensemble du champ de recherche qu'il supporte. Le comité a reçu une vaste information de la communauté scientifique par l'intermédiaire d'un site web et de discussions de groupe par courrier électronique. Par la suite un document pour fin de discussion a été préparé et remis à 34 "consultants" représentant des chercheurs supportés par le CRSNG et des chefs de file dans les industries agricoles, alimentaires et forestières. Après avoir revue le rapport, une seconde version a été mise à la disposition de plus de 90 scientifiques pour une nouvelle révision. Ce processus a conduit à une "vision" collective de la discipline qui met l'accent sur l'importance de la

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recherche fondamentale basée sur l'excellence, l'innovation par des avenues pluridisciplinaires, le potentiel de leadership international et l'intérêt pour le Canada et les canadiens. Pour compléter cette vision, le CRSNG doit introduire une stratégie pour attirer, former et retenir les meilleurs de nos jeunes talents, établir une large base de financement réaliste, et créer des opportunités susceptibles d'encourager une meilleure interaction entre les disciplines. Le comité a mis de l'avant six propositions pour réaliser ces objectifs avec un total de $15,3 millions, en argent réalloué et nouveau. Si elle est supportée, cette initiative fournira aux chercheurs supportés par le GSC03 le support nécessaire pour générer des idées, communiquer leurs perceptions, développer les talents et entraîner le personnel qui sera essentiel pour assurer la participation du Canada à la révolution biotechnologique, laquelle transforme présentement de façon globale les industries agricoles, alimentaires et forestières. De plus, la connaissance fondamentale de l'interaction des plantes avec leur milieu aidera également le Canada à jouer un rôle de chef de file dans la prise en charge efficace des ressources, au cours du 21e siècle.

Mots clés : Le Conseil de recherches en sciences naturelles et en génie du Canada, exercice de réallocation, biologie végétale, sciences de l'alimentation, biotechnologie, recherche fondamentale.

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1. The scientific foundation needed to meet Canadian and global challenges in plant biology and food science

The global economy is witnessing a revolution in the processes by which knowledge is created, innovation conceived, and the resulting economic advantages captured. These changes are particularly profound for endeavours related to Plant Biology and Food Sciences (PB&FS). Fundamental[2] research will play a central role in our efforts to guide this revolution for the benefit of all Canadians. Canada's capacity to feed an ever-increasing global population, protect the nation's natural resources, ensure sustainability of production capacity and environmental quality, respond to the growing demand for new plant-derived products, and capture a share of emerging industries, depends on our strategic response to this new era.

Historically, Canada's large land base, long coastlines, vast forests, and small population conferred both a strategic opportunity and a global responsibility in the agriculture, aquaculture, food, and forestry sectors. While the global responsibility remains, the strategic opportunity is at risk. Without a deliberate and significant investment in our domestic knowledge base, Canada will lack the scientific foundation needed to address the needs of an emerging biotechnology industry that will be central to the success of our renewable resource industries in the coming decades. The insights, innovations, and highly qualified personnel from fundamental PB&FS research will be required by Canadian industries to succeed in a global marketplace in which competitors are rapidly restructuring to emphasize access to the most advanced research and development capabilities. A broad scientific understanding of the fundamental principles of plant function and food production will provide the basis for our participation in the new agricultural biotechnology (ag-biotech) industry. Developing this scientific knowledge base requires a sustained effort from the full breadth of Canada's PB&FS research community.

The Natural Sciences and Engineering Research Council's (NSERC) PB&FS Grant Selection Committee (GSC03) must be at the heart of Canada's investment strategy, since NSERC is the largest, and virtually the only funding source, for fundamental research in Canadian PB&FS. The structure of the renewable resources sector of the Canadian economy means that the traditional agricultural and forestry industries invest little in research. Furthermore, federal and provincial research agencies in PB&FS have targeted their dwindling resources to applied projects with short-term goals. Research sponsored by GSC03 must continue to provide our fundamental knowledge base by elucidating the mechanisms and principles that underlie the growth, development, reproduction, and metabolism of plants in a wide range of environments, as well as the properties, processing, and storage of food products.

A vision statement for GSC03

GSC03 will be Canada's premiere vehicle for a strategic national investment in fundamental plant biology and food science research. The themes guiding GSC03 will be research excellence, innovation through multidisciplinary approaches, international leadership potential, and relevance to Canada and Canadians. In this way, GSC03 researchers will generate the ideas, communicate the insights, develop the skills and educate the personnel that will be essential for Canada's participation in the biotechnology revolution that is transforming global agriculture, food, and forest industries. Fundamental knowledge of the interaction between plants and their environment will also help Canada play a leading role in the effective, responsible stewardship of planetary resources in the 21st century.

To achieve this vision, we recommend that NSERC:

(*i*) Boost the number of successful new applicants from 55 to 75% and increase the average start-up grant from $28.9 thousand to $40 thousand per year ($2.76 million funding increase over the next 4 years).

(*ii*) Make a strategic investment in the top 25% of our funded researchers to allow them to achieve and maintain international stature in their fields ($2.74 million funding increase, reflecting a 47% budget increase to our top 5% of funded researchers and a 58% increase to the next 20%).

(*iii*) Broaden the diversity and capability of Canada's PB&FS research base by funding a larger share of deserving researchers with realistic ($30 000) grant sizes ($2.39 million; raises success rate from 75 to 80%).

(*iv*) Address the increased costs and demand for laboratory equipment by funding a larger share of equipment grant proposals ($881 thousand; increase percentage of requests funded from 28 to 40%).

(*v*) Stimulate the formation of Multidisciplinary Network Groups among researchers by underwriting administrative and travel costs for groups exploring promising, shared areas of research ($500 thousand).

[2] In this document, "fundamental" research is that research whose purpose is to elucidate underlying principles or mechanisms, whether it may (applied) or may not (basic) have an obvious or immediate application in industry or society.

(*vi*) Encourage intensive multidisciplinary research efforts directed at significant fundamental problems through a competitive process within a new Synergy Grants Program ($6.00 million).

2. Research in plant biology and food science takes the global stage

From photosynthetic bacteria to the tallest trees, plants are biological factories that synthesize complex organic molecules essential to life. Many of these compounds are far beyond our existing synthetic skills, and are not produced by any animal cell. Plants are the earth's lungs, regulating O_2 and CO_2 concentrations, influencing precipitation levels and filtering impurities from air, soil, and water. Plant products, including carbohydrates, oils, proteins, and secondary metabolites, are also used as food for our sustenance, wood for buildings, fibre for paper products, fuel for transportation, raw materials for industries, and pharmaceuticals for our health.

Global change is moving the disciplines of PB&FS to centre stage. Upheaval in world politics, economics, and environment has created demand for innovative solutions to regional, national, and global problems in the agricultural, forestry, fisheries, industrial, and medical sectors. At the same time, advances in science and technology, including the ability to isolate genes and genetically transform plants, have given us powerful new tools to address these problems. To use these tools effectively, we must understand the fundamental principles of PB&FS. All too often, central questions remain unanswered.

As Canada's primary mechanism for funding PB&FS research, GSC03's mandate is to support excellent fundamental research in the related disciplines of PB&FS. The mandate of the GSC is broad, encompassing understanding and innovation in the agriculture, aquaculture, forestry, and food processing sectors of the Canadian economy. In Plant Biology, GSC03 supports research into how plants work: the acquisition of basic resources and conversion of these resources into the tremendous array of end products on which humankind, and most other life forms, rely. In Food Science, research contributes to our understanding of the chemical, microbiological, nutritional, and engineering processes associated with food production, from both plant and animal sources. These areas of research will be front-runners in the scientific community in the years ahead.

3. Canada's wealth of renewable resources are challenged by emerging trends

The renewable resources sector accounts for more than $43 billion of the country's GDP, produces 18% of our exported goods, and including indirect spinoff, provides more than 20% of the jobs in this country. On a global scale, Canada supplies 5.1% of the world's demand for wood products and 2.1% of the world's grain, while having only 0.5% of the world's population. The following global trends suggest that these sectors will require new insights and capabilities in plant biology and food science to meet national and global challenges:

Increasing demand for food. The world's population of 5.8 billion is increasing by 90 million persons per year, and is expected to reach 7–8 billion by 2020 (1). In addition, increasing wealth in Asia will expand demand for cooking oil, animal protein, and dairy products, resulting in a multiplier effect on the demand for agricultural crops (2). With the collapse of many of the world's ocean fisheries, crops are also being used in fish farms. Meeting these new demands will require a doubling of agricultural productivity over the next 25 years and the development of integrated aquaculture. We need to create another green revolution similar in magnitude to the last one. This time, it will be more difficult. Unlike many countries, Canada is fortunate to have the capacity to meet some of this additional demand. Can we do so economically and sustainably?

Decrease in prime agricultural land. Most countries are experiencing loss of prime agricultural land due to urbanization, pollution, and soil erosion. Fortunately, Canada has unused marginal land. With appropriate management and the development of stress-resistant crop cultivars, this land could be suitable for crop production. Can we develop the expertise to capitalize on an underutilized resource?

Higher demand for forest products. Increasing world population and expectations of a rising standard of living are driving a growing demand for high quality forest products. While Canada has tended to rely on its natural forests, other countries have developed plantations of fast-growing forests using genetically superior trees. The historic distinction between forest ownership and harvesting rights has limited Canadian industrial interest in funding this area of research. Can we intensify research efforts to meet increased demand without decimating our natural forests?

Requirements for sustainability. Our citizens and those of affluent importing nations are now demanding that our agricultural and forest products be grown using environmentally sustainable practices. Countries that fail to meet this expectation will find deteriorating resource bases, a diminished market size, and declining health and quality of life for their citizens. Can we meet this challenge with our current knowledge base?

Effects of a changing climate. Evidence of rising temperatures caused by increased emission of anthropogenic greenhouse gases continues to mount. Canada recently agreed to reduce CO_2 emissions by 6% below 1990 levels. Biomass, alcohol, and other plant-based alternatives to fossil fuels can help us meet this target. Plant communities also play a key but poorly understood role in the regulation of atmospheric CO_2, yet we know surprisingly little about how plants will respond to changes in climate and atmospheric CO_2. Depletion of stratospheric ozone may also affect plant growth through the damaging effects of UV radiation. How will Canadian agriculture, fisheries, and forestry be affected by dramatic changes in the ecosystems upon which these industries rely?

Demand for safe, nutritious, high quality foods. Demographic changes such as increasing cultural diversity, aging, and the "baby-boomer" bulge will alter food market demand. Affluent groups are spearheading the demand for safe, healthy, minimally processed foods. In addition, functional foods (traditional foods enriched in naturally occurring compounds beneficial to health), probiotics (bacteria consumed for their beneficial attributes), and nutraceuticals (isolated natural compounds) are in increasing demand as alternative medicines.

Will Canada possess the basic science needed to understand and respond to these demands?

4. Knowledge from GSC03 research is vital to Canadian success in global markets

Worldwide, Canada is in a unique position in relation to agriculture, aquaculture, silviculture, and food processing. The available arable land and coastline in Canada is higher than most other food and fibre producing nations. Our investment in primary production as a fraction of GDP has been substantial. Our basic industries are well developed. However, we are not ready to take advantage of new opportunities to add value to our raw food and fibre products.

As the economic trend toward globalization and knowledge-based industries (3) continues, Canada's ability to compete in renewable resource markets will be increasingly dependent on the capacity of our agriculture, aquaculture, forest, and food industries to deliver high quality products for specific markets at competitive prices. Other major exporters, including the U.S.A. and European Union, are investing heavily in the research and development needed to improve quality, add value, and reduce costs. Without a commitment of comparable scale, Canada will be relegated to a mere supplier of low-cost commodities, allowing others to capture the more lucrative markets for value-added products.

To lay the foundation for Canadian food and fibre industries in the emerging global market, we must make a strategic investment in (*a*) building an understanding of the major underlying biological and biophysical principles affecting the plants, animals, and food products that are key to each renewable resource industry, and (*b*) developing novel technology for food production, processing, and storage. The integrated mandate of GSC03 can provide the knowledge base for both of these investments by addressing fundamental questions such as:

How do plants control the allocation of resources (including carbohydrate, water, minerals) among plant organs (e.g., fruits, leaves, roots)? How do the cells within each organ regulate the chemical composition of the compounds produced?

What controls the timing of flower production in plants, the rate of fruit or seed development, and the ultimate size of the fruits or seeds?

How do plants regulate the timely expression of genes in specific tissues, cells, or subcellular components?

How are various hormonal and external signals perceived, transduced, and integrated within the plant, ultimately resulting in a specific physiological or biochemical response?

How do plants defend themselves against the attacks of insects and pathogens? How do they develop tolerance to environmental stresses such as drought, nutrient limitation, pollution, low temperature, UV radiation, or global warming?

What physiological, biochemical, and molecular factors control growth and carbon sequestration in forest species? How do these factors direct the formation of wood, lignin, oil, starch, protein, and therapeutically active secondary metabolites?

What effect will rising atmospheric CO_2 concentrations have on the metabolism, growth, development, and productivity of our native, agricultural, marine, and forest species?

What factors limit and control the rate and efficiency of photosynthesis, respiration, nitrogen fixation, and phosphate acquisition? Why are these processes more efficient in some plants than in others?

What are the properties of proteins, carbohydrates, oils, enzymes, etc. that make them valuable as food ingredients and (or) products? How can these properties be manipulated?

What lessons can be learned from the study of biological systems to maintain food freshness and quality (sensory and nutritional), ensure food safety, improve the nutritional value of food products, develop new products and (or) processes, and ensure effective long-term preservation?

5. Generating and accessing knowledge in PB&FS will fuel a new revolution

Just as new discoveries and understanding in chemistry and physics drove the economies of the 19th and 20th centuries, the biological sciences will fuel the economy of the 21st century. Evidence that we are in the early stages of a major revolution in the agriculture, aquaculture, forest, and food industries is found in the restructuring of companies such as Monsanto, Novartis, AgrEvo, Dupont, and DowElanco. These firms have concluded that future success is contingent upon integrating knowledge of plant and animal science into food production and processing. This shift is a "strategic repositioning" away from the traditional emphasis on chemical enterprises with some involvement in the life sciences to becoming life science companies whose major focus and source of profit will be in biological or biotechnological activities.

We have already witnessed the introduction of important new export products such as insect-resistant potato and cotton plants, and herbicide-resistant canola, soybeans, and corn (4). These products were generated by relatively simple genetic transformations using one or two genes. The challenge for future products will be more sophisticated multigene plant transformations. The success of these efforts will be even more dependent upon our understanding of the underlying biological mechanisms and interaction between plant "systems." A multidisciplinary approach will be essential to these endeavours.

Future products that could ultimately emerge from a better understanding of gene function and biological mechanisms include:

major crop species that are resistant to insect, fungal, or bacterial diseases, decreasing crop losses without the use of pesticides;

nutrient efficient crops with reduced reliance on expensive and environmentally harmful fertilizer;

greenhouse vegetable or flower crops that grow rapidly at low light, decreasing the energy cost for supplemental lighting;

trees and crops that are frost tolerant or that grow more rapidly at low temperature, increasing the length of the northern growing seasons;

nutraceuticals, functional foods or aids to food processing that are produced in various biological systems (plant, animal, and microbial) at a fraction of the current cost of production;

plants that make "designer oils," improved protein quality or other specialty compounds;

fast-growing trees that can be harvested more quickly, that are high in cellulose, or low in lignin, resulting in increased value of the forest stand;

pharmaceutical products that are made in plants at a fraction of the current cost of production;

plants that make polyhydroxybutyrate, so that plastics or nylon can be made from a renewable resource, rather than from crude oil.

6. Canada at the crossroads in its commitment to PB&FS research

The number of these exciting new innovations that appear first (or at all) in Canadian crops, forest species, and food products will depend on the number and success of Canadian biotechnology companies. This, in turn, will be largely dependent upon the strength and quality of the fundamental science done by researchers in PB&FS. The time between fundamental discoveries at the laboratory bench and practical application in agriculture, aquaculture, forestry, and the food industry has never been shorter. Canadian research must be intensified and well integrated (from fundamental research to product development) to earn success in these new fields.

Canada has begun to respond to the challenges posed by the new global market for agricultural products. In Saskatoon, for example, the University Research Park (Innovation Place) houses about 40 companies, from large multinationals to small start-up companies, most of which are focused on plant ag-biotech. This development is a direct response to the presence of a rich research community in plant biology at the University of Saskatchewan, Agriculture and Agri-Food Canada, and the NRC Plant Biotechnology Institute. Other provinces are creating similar research parks focused on exploiting opportunities from research in PB&FS and scientists funded by GSC03 are playing central roles in these endeavours. In addition, more than 10 GSC03-funded researchers have established companies in the past 3 years in an effort to commercialize the products of their research. Many others have worked closely with the commercial sector to move their knowledge and insights into the marketplace (5). Recently, DowElanco made a $17 million investment (6) in a new technology developed from research funded by GSC03. This investment is almost double the entire 1997–1998 budget for GSC03. If NSERC support for PB&FS research is enhanced in the right ways, we can expect to see more such developments in these sectors.

New research findings and the biotechnology industries that bring their applications to market will be particularly important to Canada. Today, ag-biotech accounts for 26% of the biotechnology work force in Canada, compared with only 5% in the U.S.A. The current ag-biotech market in Canada is estimated at $600 million per year, and is expected to grow to $2.1 billion by the year 2000. Moreover, this growth rate of 45% per year is expected to continue over the next decade (7).

These estimates are predicated on our ability to generate the required knowledge base and the highly trained personnel to develop and apply this knowledge. At the moment, this assumption can be challenged. Canada's current investment in fundamental research and the numbers of personnel being trained both fall short of our needs. Our investment must be both strategic in direction and of sufficient magnitude to ensure a place for Canada in these new fields.

7. GSC03's role in positioning Canada to meet the challenge: a multidisciplinary emphasis

Given the important role of fundamental PB&FS research to Canada's, and the world's, future, it is imperative that GSC03 use its limited resources wisely to maximize the generation of new knowledge, and the training of highly qualified personnel. This will require both analytical and integrative approaches to inquiry. The analytical approach has dominated the disciplines of PB&FS, focusing on the isolation and investigation of individual causal factors. The success of this approach is illustrated by our ability to control the expression of specific genes and see how these affect plants and their value as food products. However, the desire to bring together a set of high-value characteristics reflecting complex sets of genetic and metabolic manipulations will mean that future research must apply strategies that combine the analytical approach with an integrative, multidisciplinary approach. This combination emphasizes an understanding of how "systems" function, using large bodies of data collected at various levels of organization.

Major discoveries and insights often occur at the interface between disciplines. Future GSCs must continue to encourage and support multidisciplinary research efforts that cross boundaries between disciplines, such as anatomy, physiology, biochemistry, pathology, molecular biology, silviculture, and food science. This approach can have added costs, but will be crucial if GSC03-funded researchers are to be at the forefront of new discoveries and innovation in their fields. We recognize that insights and techniques from laboratories that focus on other biological systems (for example, GSC33) are transferable to PB&FS. However, since many disciplines are supported within GSC03, it is ideally suited to serve as the focus for multidisciplinary work in the fields of PB&FS.

Canadian PB&FS is positioned to take advantage of multidisciplinary approaches to address significant problems in the field. Because the NSERC funding system has focused on long-term research programs, rather than specific projects, Canadian PB&FS has developed a broad base of high quality research with representation from a range of disciplines. Unlike some countries, our research community has not become dominated by molecular biologists, although about half of our grantees use molecular techniques in their research programs. While this approach means we have not become world leaders in high-input fields such as plant genomics, we do have an opportunity to differentiate ourselves in another way. If we can work together more effectively, we could be world leaders in using the fruits and tools of molecular biology to improve our understanding of how plants function and the properties and production of human food. This latter goal, while still rooted in fundamental science, is most likely to lead to the insights, innovations, and highly qualified personnel that will be required by Canadian industry and society in the new millennium.

We recognize four research areas where we are poised for major scientific advances and where multidisciplinary, inte-

grative approaches will be particularly effective. The four research areas are as follows:

(*i*) Decoding plant development. The use of mutant and transgenic plants has led to major advances in our understanding of how plant cells, tissues, and organs develop and the role of plant cell and tissue structures in growth and development. Progress in this area will benefit from close collaboration between plant anatomists, morphologists, physiologists, geneticists, and molecular biologists with results feeding directly into the agricultural, forestry, and food industries.

(*ii*) Dissecting plant metabolism. By combining the use of new molecular tools with new and traditional physiological and biochemical approaches, rapid advances are being made in our understanding of the regulation of primary and secondary metabolism in plants, including photosynthesis, N and P assimilation, respiration, and the synthesis of many specialized compounds that plants produce. Canada has internationally renowned researchers working at all levels of organization in this area. We are poised to make a major contribution to the field, especially if these groups were to coordinate and integrate their research efforts.

(*iii*) Exploring plant–environment interactions. Coupling traditional and new tools in plant physiology, biochemistry, anatomy, and pathology, with the isolation and characterization of genes associated with tolerance to plant stresses, will be key to major advances in plant–environment interactions. Key areas include how crop and forestry species respond to rising atmospheric CO_2, the mechanisms of stress tolerance (including salt, temperature, freezing, drought, anaerobic conditions, nutrient limitation, and pollution), or the strategies plants use to resist pests. Compared with many other countries, Canadian agriculture, aquaculture, and forestry are particularly susceptible to many of these stresses. We must invest in the fundamental science now if we hope to find effective solutions to applied questions in the future.

(*iv*) Innovations in food quality and safety. The future success of the food industry will depend on its ability to add value to Canada's agricultural products and to understand the interaction of food and microorganisms that are the primary determinant of food safety. If we are to reduce food spoilage, enhance preservation, and protect food supplies from pathogens and toxins, we will require fundamental research efforts to understand microbial growth, toxin production, and the effect of microorganisms on the human body. To enhance the nutritional and sensory value of foods, we need to understand the fundamental physiology of plant and animal tissues. Major advances in these areas of food science will require the coordinated efforts of biochemists, microbiologists, molecular biologists, engineers, and food scientists.

Many of the results of this work will have direct application in ag-biotech. To identify strategies for engineering future products, this industry will need a fundamental understanding of how complex processes are regulated in plants, and how the expression of gene(s) within specific organelles, cells, or plant tissues affect the characteristics of the whole plant.

Addressing public concern over ag-biotech: The general public accepts the widespread use of molecular biology and biotechnology in pharmaceutical products. While producers are exhibiting the same acceptance and demand in agriculture, aquaculture, forestry, and food production, the public has more reservations about use of biotechnology in these sectors (8). The PB&FS research community is in a unique position to address public questions and concerns. An objective, scientific approach will be helpful in assessing risk, calming public concerns, or, if necessary, creating appropriate regulations.

8. Three essential commitments are required to achieve our vision

To achieve our vision, NSERC must provide sufficient funding to allow GSC03 to:

Introduce a strategy to attract, train, and retain our best young minds. At a time when demand is strong and growing, it is increasingly difficult to attract our best students into a career in PB&FS. Seeing talented faculty struggling with grossly inadequate funding, many opt for a career in medicine, law, or business, when, in fact, their first love is science. Reversing this trend is essential to meeting demand for individuals with the ability, expertise, and motivation to work in these fields.

NSERC predicts that university researchers in PB&FS will produce 93–123 Canadian doctorates per year between 1996 and 2001. Yet, the level of funding for GSC03 has been decreasing since 1992 (9; Tables 4 and B9), and the number of doctorate graduates has been stable at about 82 per year (± 7.2 SD; 1986–1995). Without substantial new investment, we will fall short of the NSERC estimate. This is particularly worrisome in light of the recent release of the Price Waterhouse study (7) by the Canadian Agricultural Research Council. This study estimates future *demand* for scientists in the agricultural and food science industry and in the university departments within agricultural and veterinary schools at 1650 new graduates (540 at the doctorate level) over the next 10 years. The study also noted low unemployment rates for current graduates, concluding that the demand for doctorates in these disciplines currently exceeds supply. Their numbers are underestimates, since they do not consider the needs of universities with researchers in traditional science or forestry faculties. Similar shortages of high calibre scientists are also expected for faculties, government, and industry laboratories dealing with forestry (10).

Given the rapid growth rate of ag-biotech industries, and their reliance on highly qualified personnel, we underscore the need for Canada to increase its training of graduate students and post-doctoral fellows (PDFs) in PB&FS (7; pp. 5-23 and 7-4 to 7-6). This can only be achieved with an appropriate level of funding for high quality research. Canada is significantly below the threshold. The current average grant of $32 347 per year effectively precludes most of our scientists from providing PDF opportunities in Canada. This comes at a time when NSERC-sponsored PDFs in all biological sciences have declined from 265 in 1992 to only 200 in 1996. At a time when Canada should be a choice destination for the best PDFs from around the world, we have little to offer. As a result, we are effectively "exporting" our most talented individuals. Although only about 300 doctorates are awarded annually to Canadians in the biological sciences, 169 Canadians are doing PDF work in the U.S.A. (1993 data) and 69 in other countries (7; p. 5-21). The majority of these are in the field of molecular biology, a high-demand area for the U.S. biotechnology sector.

All the projections described above assume a modest role for government research. This assumption is based on the premise that the world's food supply will continue to exceed demand as it has for more than 20 years. There are indications that this will not be the case. International crises may alter the Canadian government's priority for investment in this area, and increase the demand for highly qualified personnel.

We propose a two-part strategy to address this situation. First, we must place special emphasis on increased support to new researchers. Second, we must provide our best researchers with grants sufficient to ensure excellence in their research programs. These researchers will use these funds to support the best graduate students and PDFs.

Establish a broad, realistic funding base. Of all the Grant Selection Committees, GSC03 has suffered the most from NSERC funding decisions over the past few years. From 1992–1993 to 1997–1998, support for GSC03 declined by 12.8%. In the same period, total funding for the Biological Sciences declined by "only" 1.8% and funding for total Research Grants rose by 3.9% (11; Table A3). This pattern was also reflected in total NSERC grant funding (11; Tables A15 and A18) to researchers in GSC03 (including Strategic, Equipment, University and Industry Grants, etc.), which declined by 16% in the 1992–1993 to 1995–1996 period. This was the largest decrease experienced by any discipline over that time.

GSC03 dealt with the decline in Research Grant funding by reducing the number of successful applicants by 21% and increasing the size of the average grant by 10% over the last 6 years (11; Tables 8, A1, and A3). These decisions were deliberate strategies to focus on excellence and to ensure that the very best researchers had the resources to counteract at least some of the other pressures on their grants. These pressures include inflation, university off-loading of costs to research grants, higher student costs, and increased costs of research. However, the impact of these choices has been significant. Success rates in GSC03 dipped as low as 54%, a sharp contrast to the 75–90% success rates in the Engineering and Physical Science GSCs over the same period (11; Table 8). Regretfully, many good researchers doing valuable fundamental work have not been funded by GSC03 in the past few years. The pool of PB&FS researchers must be enlarged if Canada is to have the research diversity and capability to apply new tools and approaches to fundamental questions in these sectors.

In most parts of Canada, GSC03 is the *only* source of funding that consistently supports fundamental research in the disciplines of PB&FS that lead to improved understanding of how plants function or the properties and production of human food. Other federal, provincial, and private sector funding sources focus on the *direct* application of science and technology to meet the needs of industry and society. Given an average grant size of only $32 347 per year and the fact that researchers can only hold a single grant from GSC03, Canadian funding for fundamental research in this field is grossly inadequate. Even our top scientists ($80–$100 thousand per year) are struggling to compete with researchers from countries with grants (and infrastructure) many times higher. We propose to address this situation by increasing both applicant success rates and grant size, with particular emphasis on enhancing support to world-class researchers.

Create opportunities for more interaction among disciplines. Funding pressures and increased workloads for university faculty have constrained both the opportunity and inclination for researchers to develop synergistic working relationships with other researchers in different disciplines.

Given the potential for highly innovative results from the synergy found in an interdisciplinary approach, we propose that a portion of new GSC03 funding be targeted to facilitating interaction among researchers from the disciplines of plant pathology, biochemistry, anatomy, food science, genetics, silviculture, physiology, and molecular biology. A strategic investment will differentiate Canada from international competitors, build on existing strengths, and increase the prospects of research outcomes that are intrinsically valuable and can be acted on by researchers with more applied interests.

9. Funding recommendations that reflect the three essential commitments

The following funding recommendations for GSC03 represent a request for a significant influx of new support ($15.3 million per year) by the 4th year of the reallocation cycle (2002–2003). In funding fundamental PB&FS research in 1997, GSC03 distributed about $2.11 million in Equipment Grants and $9.963 million (11; Table A3) in Research Grants to 308 grantees (11; Table A1). We enter the 1998 reallocation process with our Research Grants budget reduced by 10% to $8.97 million. If all six recommendations were fully funded, the total support for Research and Equipment Grants in PB&FS would be $26.4 million by 2002–2003.

Recommendation 1. Cost: $2 760 000
"Jump start" our new applicants. GSC03's record of strong support for successful new applicants is reflected in start-up grants that have been about 90% of the average grant to successful applicants, and 1.4 times the average first grant from all GSCs (12; Table 1). Unfortunately, this level of funding is still low, permitting just 55% of new applicants to be funded (12; Table 1).

We propose to push this success rate to 75% and increase the average "starter" grant size from $28 909 to $40 000, a level more consistent with the needs of young researchers. Our success rate would then approximate the NSERC average for all disciplines (70.7%) and the non-life science GSCs (over 80%) (12; Table 1). Assuming 23 new applicants per annum (12; Table A19, average of last 10 years), the cost of this recommendation will be $690 000 per year, resulting in a total commitment of $2.76 million in year 4.

Recommendation 2. Cost: $2 744 728
Fund our best researchers at a level that allows them to compete and lead internationally. The search for knowledge, acknowledgment of pre-eminence, and resulting scientific and economic endeavour are now global in nature. As a result, Canada's "visibility" in the world Plant Biology and Food Science community and our ultimate success in spawning related industries are most likely to be determined by our very best researchers. Properly funded, these individuals have the best prospects for generating breakthroughs that change the prevailing paradigm in a field of study, thereby setting the stage for the emergence of new applications and industries. We

recommend that GSC03 be given the funds to allow the top 25% of our researchers to compete at an international level within their research area. The GSC03 strategy would:

Support the top 5% of funded researchers in their efforts to achieve *a primary leadership role in the world in their research area*, as evidenced by invited keynote lectures at international conferences, major papers and review articles in top journals, and a research program consistently producing discoveries or insights with far-reaching impact within and beyond the fields of PB&FS. We estimate that 2.5% of GSC03 grantees currently meet these criteria.

The average funding level for a Research Grant for these researchers would be $120 000 per year. Based on 308–335 successful applicants in GSC03, 16 applicants would be in this group for a total cost of $1.92 million. Assuming that these individuals would be drawn from our best funded researchers (1997–1998 funding level of about $1.31 million or an average of $81 704 per researcher), the incremental cost of this recommendation would be $743 467.

Encourage a further 20% of its funded researchers to achieve *a well recognized leadership role in the world in their research area*, as evidenced by invited symposium lectures at national and international conferences, invited review articles, and a research program that makes a significant contribution to our understanding of how plants function or the properties and production of human food. We estimate that 10% of our GSC03 funded grantees have achieved this level of international recognition.

The average funding level for a Research Grant for these researchers would be $75 000 per year. Of the successful applicants in GSC03, 62 applicants would be in this group for a total cost of $4.65 million. Assuming that these individuals would be drawn from our second tier researchers (1997–1998 funding level of about $2.94 million or an average of $47 468 per researcher), the incremental cost of this recommendation would be $2 001 261.

Recommendation 3. Cost: $ 2 396 807

Strengthen the broad base of fundamental PB&FS research in Canada. In a dynamic field of research that will draw increasingly on the insights generated by a range of disciplines, Canada requires a broad base of researchers to advance our understanding in each of the major areas of PB&FS, bring specific expertise to interdisciplinary investigations, respond to new opportunities, and serve as the wellspring for finding and nurturing the next wave of world-class researchers.

We propose to expand the existing base by reinstating 10 deserving researchers who lost funding simply as a result of insufficient funds. This will increase our success rate for all renewals from 74 to 80%, which would then be in line with NSERC averages. The average grant size for the expanded base (the remaining 75% of funded researchers) would also be increased to $30 000 per year. Based on 1997–1998 data, this would require incremental funding of $2 396 807.

This recommendation acts on NSERC's conclusion that development of highly qualified personnel is required for Canada's global competitiveness and provides better prospects for achieving the "critical mass" of graduate students and technicians required for an active research laboratory.

Recommendation 4. Cost: $880 500

Equip the laboratories. GSC03 is able to fund less than a third of the dollar value of all equipment grant requests received (estimated at $7.4 million per year), despite the fact that virtually all are justified and well over 50% of the applicants are highly deserving. The 1996–1997 GSC reported that "the current equipment budget is simply incapable of meeting the burgeoning and well justified demand for new technology and replacement of decaying instrumentation."

The changing nature and costs of PB&FS research make Equipment Grants a vital corollary to the main research grant. Roughly half of GSC03 grantees use molecular technologies that rely on the latest instrumentation, whereas others are dependent upon medium (HPLCs, etc.) to high priced (mass spectrometers, NMR, electron microscopes) equipment to meet their research goals. Finally, the field is also experiencing strong demand for expensive equipment and facilities such as plant growth chambers and research-class greenhouses for the cultivation of transgenic and nontransgenic plants.

To address the current equipment grant shortfall, we propose to increase success rates (by dollar value) for equipment grant proposals from 28 to 40% for the next 4 years. Meeting this objective will require an additional $880 500 per year.

Recommendation 5. Cost: $500 000

Establish multidisciplinary network grants (MNGs) for groups focusing on fundamental questions in PB&FS. To provide demonstrable encouragement for increased interaction among researchers across disciplines, we propose to target a funding envelope for the formation of multidisciplinary network groups that address questions key to the future of Canadian PB&FS. Working together, the researchers participating in these networks would share information and ideas about a common research interest from different disciplinary perspectives. For example, a network group focused on nutraceuticals may include a physiologist, molecular biologist, food chemist, and nutritionist, among others.

Proposed organization and selection criteria

Administered within GSC03, groups of three or more NSERC-funded researchers would be encouraged to apply for a MNG Grant to support their collaborative research efforts. This grant could be held at the same time as a Research Grant.

Applicants should represent a range of disciplines, within or outside GSC03, with activities focused on answering important fundamental questions in PB&FS.

Funds would be used to support travel to meetings of the group, graduate student and postdoctoral travel and accommodation, support of a visiting scientist, basic administration (e.g., production of newsletter, interdisciplinary bibliography, etc.).

As a rule of thumb, grants would be about $10 000–$15 000 per network "node."

We anticipate that 10 vibrant MNGs would be funded by GSC03 at an average MNG grant size of $50 000. The additional funding required for this initiative would be $500 000 per year.

Recommendation 6. Cost: $6 000 000

Establish synergy grants for fundamental PB&FS research. To

provide a mechanism for encouraging multidisciplinary research and accelerating the pace of fundamental PB&FS research of significance to Canada's environment or economy, we propose that NSERC establish a Synergy Grants Program using new money from the federal government. This program would be similar to the recent collaborative projects grants program, but would involve larger groups and grants, and would only be initiated if the base level of funding in the Research Grants program was at least 30% higher (in 1997 dollars) than the current (1997–1998) level. We propose that some of these funds could be used for bridging appointments to university faculty positions.

The MNG Grants proposed under Recommendation 5 would be a springboard for applicants to be funded by the more substantial Synergy Grants program. In the smaller, GSC03-managed MNG Grant, groups would be established or formalized so that issues regarding organizational structure, working relationships, project leadership, administrative responsibilities, and research focus would be worked out to position the team for the best chance to obtain a Synergy Grant.

We envisage the creation of 8–15 grants that would be funded at from $250 000 to $1.5 million each, and would be renewable. The total allocation recommended for this initiative is $6 000 000 per year.

10. Distribution of funding by recommendations dependent on allocation

The amount of additional support (funding above $8.97 million for 1998) provided to GSC03 must determine how the GSC will allocate funds among the six recommendations. The following graduated system of allocation is based on two principles: proportional distribution of funds among a selected set of recommendations, and at the margins of each category, modest allocations to "seed" recommendations for which significant funding is unavailable. Regardless of the outcome of the allocations process, we recommend that excellence in research serve as the overriding theme in granting decisions.

New funding	Proposed distribution by recommendation
$2 million or less	Recommendations 1–3 in proportion to amounts requested
$2 million to $4 million	Most funds allocated to Recommendations 1–3 with modest allocation to Recommendations 4 and 5
$4 million to $7.2 million	Recommendations 1–5 in proportion to amounts requested with an allocation to implement Recommendation 6. The size of this allocation would be modest at the $4 million level and more substantial if new funding approached $7.2 million
Above $7.2 million	Recommendations 1–5 are essentially fully funded with the balance being applied to implement Recommendation 6

11. Canada's ag-biotech and renewable resource industries will face severe consequences if funding remains static

NSERC is making decisions about funding GSC03 at a time when other countries such as Japan, Germany, and the United States are stepping up their investment in PB&FS research. Canada cannot remain "in the game" with reduced or static funding. Even at the 1997–1998 level of support, we cannot achieve the vision set out for GSC03. Further reductions would exacerbate the already marked erosion in research capability that has taken place in the past 5 years. At current funding levels, we cannot nurture the broad base of talent from which the next generation of leading individuals will emerge. Canada's opportunity to capitalize on PB&FS research opportunities through multidisciplinary action will be lost. The Allocation Committee must understand that reduced or static funding means that:

Our best researchers will leave for more attractive working environments in other countries. Canada's research capability and quality of post-secondary institutions will be immediately diminished.

Young researchers starting out in their careers will follow the leaders in their fields, looking abroad first to capitalize on graduate student and PDF opportunities, then to set up their own laboratory.

The broad base of research expertise in Canada will atrophy, leaving this country ill-prepared to respond to domestic challenges such as the effect of climatic change on agriculture or forestry.

Our agricultural sector will encounter increasing difficulty when seeking solutions suited to a Canadian context. The focus of plant biology research and ag-biotech applications will shift to crops that reflect the needs of other countries.

Canadian farmers will be at a competitive disadvantage because access to cultivars with desirable characteristics will be limited and more costly. Evolution of the agricultural sector will be stalled as farmers find it harder to compete in markets for value-added crops.

The Canadian forestry sector will lose out to international competitors with improved silviculture systems and regeneration techniques that demonstrate sustainable resource management.

Canadian food companies will lose out to international competitors who find better ways to process and store foods with enhanced properties.

Biotechnology and food companies will choose to locate in other countries that can offer interaction with an active PB&FS research community.

In the absence of a well developed Canadian biotechnology industry, large multinational firms will purchase the rights to the best Canadian PB&FS technologies, develop them abroad, and license them back to Canadians on a commercial basis.

Job creation potential, biotechnology company profits, contributions to government tax bases, and other economic spinoffs will go to other countries. Part of Canada's opportunity to build a knowledge-based economy will have been lost.

The Allocation Committee, NSERC, and the Canadian gov-

ernment have an opportunity to choose a different and far more appealing future for Canada. Our recommendations will put GSC03 on a track to making PB&FS research a source of knowledge and expertise that can be put to service here in Canada. We respectfully request that GSC03 be given the resources to fulfill its vision as Canada's premiere vehicle for a strategic national investment to fundamental plant biology and food science research.

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