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United States-Israel Binational Agricultural Research and Development Fund

BARD

40 Year External Review

Research Impact Assessment

December 2019

SCHOOL OF MEDICINE

Robert F. Garry, Ph.D.
Professor, Department of Microbiology and Immunology
Assistant Dean, Graduate Program in Biomedical Sciences
Program Manager, Viral Hemorrhagic Fever Consortium

12-1-19

Richard Linton, PhD
Chairman, BARD Board of Directors
Dean, College of Life Sciences
North Carolina State University
Raleigh, North Carolina 27695

RE: The External 40-year Review of BARD

Dear Dean Linton:

On behalf of the External 40-Year Review Committee, I present to you our report of the operations and effectiveness of the United States - Israel Binational Agricultural Research and Development Fund (BARD).

The evaluation was conducted through two complementary pathways: a self-reporting survey among grantees and a detailed analysis of 20 case studies. BARD's cumulative impact on academic outcomes and the economic benefits of the resulting agricultural applications are quantified. In contrast to past reviews that largely measured economic impact only, BARD's present review extends the definition of benefit to outcomes delivering worldwide environmental and social impact, which are integral to its mission.

The Review Committee found that BARD's positive impacts extend well beyond US and Israeli borders to global communities and organizations. To sustain this valuable and effective program into the future, we urge the Board to consider several specific recommendations concerning BARD's operations and financing.

Very sincerely,

Robert F. Garry
For the 40 year Review Committee

Members of the Review Committee:
Stephen O. Duke
James Giovannoni
Jonathan Gershoni
Orly Reiner
Ada Rafaeli

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This report summarizes a comprehensive evaluation carried out in 2019 and available online on BARD's website: www.bard-isus.com

The following appendices are available on BARD's website:

Appendix A: Agreement upon the establishment of BARD
http://www.bard-isus.com/bard40/docs/AppA.pdf

Appendix B: Approved budgets by year (1979-2018)
http://www.bard-isus.com/bard40/docs/AppB.pdf

Appendix C: BARD-funded institutions in the US and Israel
http://www.bard-isus.com/bard40/docs/AppC.pdf

Appendix D: Vaadia-BARD postdoctoral fellows
http://www.bard-isus.com/bard40/docs/AppendixD.pdf

Appendix E: BARD funded workshops 1990-2018
http://www.bard-isus.com/bard40/docs/AppendixE.pdf

Appendix F: List of all board members since 1979
http://www.bard-isus.com/bard40/docs/AppendixF.pdf

Appendix G: Evaluation Compendium
http://www.bard-isus.com/bard40/docs/EvaluationCompendium.pdf

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1 | Members of the BARD 40 Year Review Steering Committee

Chairman: Prof. Robert F. Garry, Tulane University, US

Prof. Garry is a Professor of Microbiology and Immunology and Assistant Dean for the Graduate Program in Biomedical Sciences at Tulane Medical School. He is currently managing the Viral Hemorrhagic Fever Consortium, a public-private consortium developing point-of-care diagnostics, immuno-therapeutics and vaccines against high consequence pathogens. His team has also been developing research and clinical trial infrastructure in West Africa.

Prof. Stephen O. Duke, USDA, University of Mississippi, US

Prof. Duke is a plant scientist who leads a group of USDA scientists involved in the utilization of natural compounds in agriculture, especially for pest management. He is best known for his research on the mechanisms of action of herbicides and natural phytotoxins. Other areas of his research include chemical ecology of plant/plant interactions, weed biology, and mechanisms of herbicide resistance.

Prof. James Giovannoni, USDA, Cornell University, US

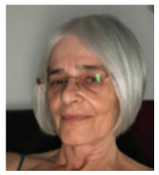
Prof. Giovannoni is a plant molecular biologist, Director of the USDA-ARS Robert W. Holley Center for Agriculture & Health; Adjunct Professor, Section of Plant Biology School of Integrative Plant Science at Cornell University. The focus of research in his laboratory is molecular and genetic analysis of fruit ripening and related signal transduction systems, with emphasis on the relationship of fruit ripening to nutritional quality.

Prof. Jonathan Gershoni, Tel Aviv University, Israel

Prof. Gershoni received his Ph.D. in biochemistry from the Hebrew University of Jerusalem and postdoctoral training at Yale School of Medicine. For 30 years he has investigated the immune response towards viruses such as HIV, HCV and SARS-CoV. He continues to develop novel methods for the computational characterization of the antibody composition in blood and applications towards new immuno-diagnostics and preventive vaccines. Prof. Gershoni has worked as a visiting scientist at the National Institutes of Health in Bethesda MD, and at Boston University - Department of Physics.

Prof. Orly Reiner, Weizmann Institute of Science, Israel

Prof. Reiner's research concerns how brain structure is determined during embryonic development and what goes awry during developmental diseases. Brain development is a very dynamic process that is regulated by way of the concerted action of multiple gene products. Abnormalities in these processes may result in devastating consequences such as severe brain malformations, as well as conditions such as epilepsy, autism spectrum disorder and schizophrenia. Prof. Reiner is currently serving as the incumbent of the Bernstein-Mason Professorial Chair of Neurochemistry at the Weizmann Institute of Science.



Coordinator: Prof. Ada Rafaeli, Agricultural Research Organization, Volcani Center, Israel

Prof. Rafaeli (Emeritus), served as Senior Research Scientist at the Agricultural Research Organization, Volcani Center (ARO); Adjunct Professor in Insect Physiology and Chemical Ecology, Department of Entomology, Hebrew University of Jerusalem Faculty of Agriculture; former Associate Director of Academic Affairs and International Cooperation at ARO. The ultimate goal of Prof. Rafaeli's research is to discover new substances for the control of insect pest populations without using toxic chemicals. She believes that a thorough understanding of the endogenous regulatory mechanisms of key processes crucial to pest survival, such as reproductive behavior, will enable us to design products which will disrupt these mechanisms.

Advisor: Prof. Richard Linton, Dean, College of Life Sciences, North Carolina State University, US; Acting Chairman of BARD's Board

Prof. Linton is currently the Dean of the College of Agriculture and Life Sciences at North Carolina State University. He previously served as Professor of Food Safety and Chair of the Department of Food Science and Technology at Ohio State University. From 2000-2010, Prof. Linton served as the Director of the Center for Food Safety Engineering, which focuses on the development of rapid detection technologies for biological and chemical foodborne hazards.

Review Team:

Mr. Shaul Zaban, Economist, Zenovar, Israel
Dr. Tamar Moise, Scientific and Technology Analyst, Zenovar, Israel
Prof. Uri Mingelgrin, (Emeritus) Institute of Soil, Water and Environmental Sciences, Agricultural Research Organization, Volcani Center, Israel
Mr. Zvi Tropp, Agricultural Economist, Israel
Ms. Sophia Zhao, Economic Evaluations Assistant, Zenovar, Israel

צנובר Zenovar

Zenovar is a leading Israel-based consulting company, specializing in agricultural business development, environment, and sustainable planning. The company has extensive experience in carrying agricultural programs from feasibility studies through full deployment plans. Zenovar is active both in Israel and internationally.
Zenovar's work is characterized by its interdisciplinary approach. Its team of expert consultants includes first-rate economists, specialists in advanced agricultural methods, ecology and the environment, land and water uses, marine biology, geography and regional planning.

Agricultural Economic Analysis Consultants:

Prof. Kenneth A. Foster, Department of Agricultural Economics, Purdue University, US
Prof. Wallace E. Tyner, James and Lois Ackerman Professor of Agricultural Economics, Purdue University, US (deceased)

BARD Coordinator:

Ms. Yehudit Newman, Communications Specialist, Israel

2 | BARD 40 Year Review: Executive Summary

The US-Israel Binational Agricultural Research and Development Fund, or BARD, was established to advance, foster and fund cutting-edge research carried out jointly by the outstanding scientists of both countries, in order to facilitate promising groundbreaking advances in agricultural research for the mutual benefit of both nations and beyond. BARD maintains its position as a flagship of excellence in scientific development in this field, with a rigorous selection process and proven methodology that have become the gold standard in competitive funding in this sphere.

While science, technology and knowledge advance exponentially, BARD's vision and mandate remain constant, to support and advance collaborative research between US and Israeli scientists. This research focuses on key agricultural challenges facing both countries, with the aim of building academic and human capacity, and translating scientific outcomes into scalable agricultural practices and applicable intellectual property for the benefit of the bilateral and global economies.

With BARD marking 40 years of activity in 2019, this milestone serves as an opportune juncture for a comprehensive evaluation of its work. BARD's board of directors appointed a steering committee to oversee and guide an external review, with the twofold objective of assessing its past and present impact, and establishing the next generation benchmarks with the best practices that serve BARD's mission.

BARD has commissioned a comprehensive review to calculate the outcomes of its investments over 40 years. Especially, the review aims to quantify BARD's cumulative impact in terms of academic outcomes and the economic benefits of the resulting agricultural applications. If past reviews largely measured economic impact only, BARD's present review extends the definition of benefit to outcomes delivering worldwide environmental and social impact. With far-reaching global implications, these must be acknowledged as integral to BARD's impact.

Evaluation Methodology and Process: Overseen by the 40 Year Review Committee, the evaluation was conducted through two complementary pathways: a self-reporting survey among grantees, and a detailed analysis of 20 case studies. The methodology is based on a range of Research Impact Assessment (RIA) approaches, particularly proven Agricultural RIA (ARIA) methodologies.

The survey was conducted among 140 Principal Investigators (PIs) who reported on 224 awards granted between 1994 and 2014. The timeframe was chosen both to include ongoing research and to provide the adequate time lag for evaluating mid-to-long term impact. Additionally, 20 case studies representing different disciplines were selected for an in-depth narrative and quantitative impact analysis.

Key Findings

The Big Picture: Over 40 years, BARD has invested $1.06 billion in 1,330 awards that led to the adoption of about 200 new agricultural practices. BARD has delivered economic, environmental and social benefit worldwide, and expanded academic knowledge with more than 5,600 publications. BARD's investment has also contributed an estimated $3 billion to the US and Israeli economies in human resource capacity building.

Investment and Economic Impact: The 20 case studies examined for this review have generated an economic benefit of $2.7 billion to the US economy, $0.5 billion to that of Israel, and another $13.3 billion globally. The return on BARD's investment generated by these 20 case studies is a $16.5 return for every dollar invested—a most favorable Benefit-Cost Ratio of 16.5.

Academic Impact: 1,540 PIs (910 from the US and 630 from Israel) took part in the 1,330 BARD-funded studies. An estimated 3,300 students have been involved in BARD research projects; around 1,200 of these continued to academic positions and some 600 others to employment in Agri-Bio industries. Approximately 80% of PIs continued to collaborate in follow-up studies after the initial grant. Additionally, approximately 70% of PIs received further academic funding based on the outputs from their BARD research award.

Academic Publications: BARD awards have generated more than 5,600 published manuscripts, 42% of which appeared in first quartile (Q1) journals (an impact factor ranking in the top 25% of their specific disciplines). 10% of the publications have over 100 citations, further demonstrating the academic impact generated by BARD.

2 | BARD 40 Year Review: Executive Summary

Practical Applications: With much of the funded research achieving significant scientific advances, BARD-funded research has led to the adoption of approximately 200 new agricultural practices worldwide, as well as around 100 series of patents or breeding licenses. An estimated 40 commercial engagements have been formalized and around a dozen companies were founded based on the outputs of BARD-funded research. The findings indicate that an average of 15 years transpire between BARD's initial investment and the first applications, indicating that the benefit of recent studies is not yet manifest or quantifiable.

Environmental and Social Impact: BARD-funded projects deliver a wide range of environmental and social benefits, ranging from increasing global protein availability at a competitively affordable cost to potentially lessening the burden of waterborne diseases in developing nations and creating employment through new industries. More than half the case studies demonstrate significant environmental impact such as reducing use of chemical pesticides, energy generation and species conservation. These benefits are difficult to quantify in monetary terms, indicating that the current calculations underestimate the full value of BARD research.

The Network Effect: While the immediate stakeholder of BARD-funded research is the scientific community, 80% of awarded researchers engaged with stakeholders beyond the academic sphere, expanding the circle of BARD's impact to industry, government, farmers, venture capital funds and non-governmental organizations.

BARD's Unique Position: From the interviews with scientists and the survey conducted for this evaluation, BARD clearly occupies a unique position within the environment of competitive grants. By investing in research projects in early stages, BARD funding enabled still-basic but promising research projects to develop proof-of-concept and a preliminary applicable usage. BARD's carefully-placed investments in translational research at a critical juncture for projects enabled groundbreaking scientific achievements to reach their potential for academic, economic, social and environmental benefit to the US, Israel, and beyond. BARD adheres to the original selection criteria for proposals, such as scientific merit, benefit to agriculture, mode of collaboration and probability of success. At present, special emphasis is placed on the mode of the collaboration and the anticipated benefits to agriculture. BARD's comprehensive and rigorous process to select the best proposals in every round was highly regarded by the 20-year review committee, and this process has since been maintained consistently. Widely recognized for their meticulous evaluation and vetting, the initial BARD awards often provided a prestigious steppingstone for early-stage research to leverage subsequent funding from additional sources, allowing the seeds planted by BARD to grow to their full impact.

Delivering True Value: The results of this evaluation showcase the value BARD has delivered to the scientific community, the economies of both countries, and the development of advanced, solid, applicable, competitive, lucrative and sustainable agricultural practices. BARD has deepened the partnership between the US and Israel, creating an even closer partnership between stakeholders in both countries from academia on up to industry and government. BARD has consistently held itself to its own high standards, adhered to its values, and constantly examined itself to ensure uncompromising integrity, enduring scientific vision, and sound fiscal responsibility. The 40-year review steering committee members are deeply grateful for BARD's role in creating scientific, social and environmental value, and look forward to equally productive years ahead.

Conclusions: The present evaluation demonstrates clearly that BARD's unwavering dedication has yielded tremendous financial value and return on investment. The findings prove that BARD grants strengthen the academic community and build academic and human capacity through excellent choice of promising projects that address the most pressing global agricultural challenges with innovative science. In addition, the findings support BARD's methods for fostering and supporting innovation through awards and feasibility studies. Results also demonstrate that the awarded amount requires researchers to seek and gain subsequent awards in order to achieve full impact.

BARD's value extends beyond economically quantifiable outcomes. By enabling the most innovative of scientific advances in agriculture, BARD has created a ripple effect of environmental and social benefit. From increasing affordable global protein availability to enhancing food security, reducing the use chemical pesticides and lessening the burden of disease in developing nations, BARD's true impact may well be beyond calculation.

To safeguard BARD's ability to continue generating this positive impact effectively to its full potential, the committee proposes several key recommendations ultimately aimed at increasing funding availabilities while maintaining and further improving current programs and procedures.

Recommendations: To maintain academic and economic achievements, the 40-year review steering committee recommends adhering to selection criteria emphasizing scientific merit, anticipated benefit to agriculture and the environment of both countries, and the potential for fruitful collaboration and success. To drive substantial impact and higher achievements, the review committee recommends extending research projects to a 5-year period, thus enabling more than one award at implementation stages. To enhance reporting and evaluation, the review committee recommends introducing automated updating to supplement final reports, currently submitted too early in the project to record true outputs and outcomes. To focus research objectives to meet market needs, the review committee recommends expanding the "B-Lever" (academia-to-industry) funding track and encouraging commercial entities to engage with researchers early on. To ensure that the current gender balance among submissions and awards is maintained, the review committee recommends that BARD continue close monitoring of this issue.

Key to BARD's continued success and impact is funding. BARD relies heavily on its well-managed endowment but unlike most grant agencies has not raised its annual budgets significantly. Award levels have not been adjusted in 35 years and grants remain $310,000 for a 3-year period. There is urgent need to offset the rising costs of research and the decline in purchasing power in a way that will not undermine BARD's admirable rate of funding. The review committee recommends that the board of directors propose strategies for augmenting disposable funds to bring annual funding close to $20 million ($13 million in addition to the existing $7.1 million in interest on the endowment). The review committee suggests forming an advocacy committee focused on increasing funds for US-Israel Agricultural Research and Development. BARD's operations are managed with extreme efficiency, and there is little room for cost-cutting; rather, the net available funds must be increased. The initial target should be doubling the average award amount.

3 | Acknowledgements

The committee acknowledges the valuable assistance of BARD staff in providing the background information throughout the evaluation process. We would like to sincerely thank Yehudit Newman for coordinating the process, as well as Miriam Green (controller), Haim Katz (scientific research coordinator) and Nitsan Singer (projects administrator), who provided the background for the analysis of BARD's operations included in the report. Throughout the review, Prof. Yoram Kapulnik (BARD's Executive Director) provided additional information on BARD and extended valuable assistance to support the committee's activities.

We would like to thank Prof. Kenneth A. Foster of the Department of Agricultural Economics at Purdue University for his assistance in setting the methodology that was implemented by Zenovar for the economic analysis. His guidance in assessing the probability of the findings and his kind referral to experts in his field are much appreciated. His advice helped us obtain useful inputs and conduct the analysis with the utmost attention to detail.

We note with regret the recent passing of Prof. Wallace E. Tyner, the James and Lois Ackerman Professor of Agricultural Economics at Purdue University. We had the pleasure of working with him. With his smile and generosity, Prof. Tyner created an optimal atmosphere to discuss methodical issues, while holding us all to the highest professional standards.

We also wish to thank Prof. Julian Alston from the Agricultural and Resource Economics Department at UC, Davis for his feedback on the methodology used to calculate BARD's economic value and benefit, and for his referral to sources that served as benchmarks for the evaluation.

Prof. Ada Rafaeli helped us keep on track and made sure we received all the information we needed. We thank her for all the time and effort she has invested in assisting us run the evaluation smoothly.

A special thanks to Prof. Richard Linton, Dean at the College of Life Sciences, North Carolina State University and Acting Chairman of BARD's board of directors, who worked with us as a liaison to the board and gave the committee valuable guidance and advice.

4 | About BARD

The United States-Israel Binational Agricultural Research and Development Fund, or BARD, was established over 40 years ago. The process was efficient and swift, with both the US Congress and Israeli Knesset completing the necessary legislation within a single year. In September 1977, US Department of Agriculture, Agricultural Research Service (USDA-ARS) Administrator T.W. Edminster appointed a steering committee to discuss the matter, and BARD's board of directors convened their first meeting in November 1978. This expeditious action was in no small part thanks to many people both in the US and in Israel, who strongly believed in this important mission and worked to make BARD a reality. The first round of funding for joint US-Israel agricultural research was granted in May 1979.

Also founded in the 1970s were the binational funds of BIRD and BSF. Each of the three joint funds operates according to a binational agreement, supports the majority of its projects though jointly funded endowments, and is governed by a binational board of directors. The joint funds have proven track records for strengthening the relationship between the United States and Israel and generating significant scientific and economic benefits for both countries. The full agreement on the establishment of BARD can be found in Appendix A, available online on BARD's website.

4.1 | BARD's Mission and Vision

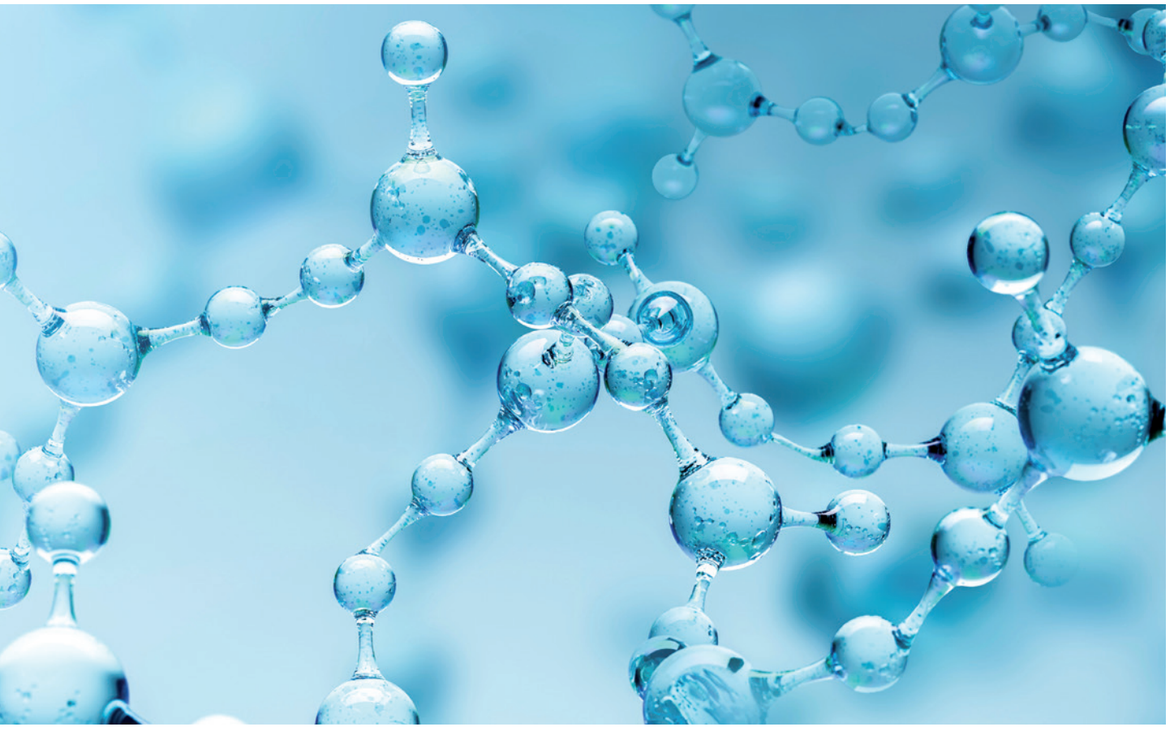
The primary mission of BARD is to bring together US and Israeli scientists to jointly address key agricultural challenges that concern both countries. Fostering this collaboration serves as a force multiplier, and the synergy generates far greater achievements than would have been attained with scientists working separately.

BARD's vision is to fund and promote the translation of scientific excellence into agricultural practice. This is accomplished by supporting joint US-Israel applicable agricultural research & development (R&D).

The majority of BARD-funded research projects focus on increasing agricultural productivity, particularly in hot and arid climates, and emphasize plant and animal health, food quality and safety, and environmental issues. BARD also supports international workshops and offers fellowships for postdoctoral research, senior research scientists and graduate students.

There is an extensive overlap between the challenges facing US and Israeli farmers. Drought, increasingly extreme weather conditions, population growth and diminishing arable land due to urbanization and overuse are only a few of these shared concerns. Driven by necessity, Israel has made great strides in entrepreneurial innovations since its establishment, complementing the vast resources and advanced technologies available in the US. BARD serves as a catalyst, lighting a spark that fires the brilliant minds of US and Israeli scientists, and providing a workspace that synergizes collaborative agricultural research.

The signing ceremony for BARD; Washington DC, November 7, 1978.
Bottom, left to right: Y. Guron, Y. Vaadia, H. Bar-On, G.E. Schuh, D.G. Unger. Top, left to right: E. Raff, P. Zusman, D. Boaz, J. Avni, R.E. Neetz, T.W. Edminster, J.M. Beattie, C. Baxter.



4.2 | BARD's Activities

BARD runs several programs that facilitate joint US-Israel agricultural R&D (section 4.7). The main program funds research proposals that are submitted to the fund on an annual basis and meticulously appraised through a three-tiered evaluation process. These fellowship and workshop applications are reviewed by the Technical Advisory Committee (TAC) during its annual meeting. This process (section 4.3) was set in place by the founders of BARD in order to ensure that funding is granted to the best proposals and that the research topics will promote the agricultural interests of both the US and Israel.

The scope of research projects spans a wide range of fields within agriculture. BARD's research priorities are determined by the board of directors, which reviews them every few years.

The following are BARD's current priorities:

- Increased Efficiency of Agricultural Production: including sustainable development, efficient use of resources, economic evaluation of policies and regulatory issues, and crops that yield higher value per unit.
- Protection of Plants and Animals against Biotic Stress: including monitoring pest occurrence, genetic changes in different biological systems, and tracking invasive species and emerging diseases.
- Agricultural Production Challenges in Increasing Marginal Conditions: such as drought, increased salinity, high temperature and nutrient stress.
- Food Quality, Safety and Security: including improved assessment and detection methods, food nutritive value in relation to human health, functional foods, ensured/increased quantity/supply, and postharvest treatments.
- Water Quality and Quantity: including efficient use of low-quality water (gray, black, saline), improved economic return for water in agriculture, crop response to soil and water quality and constituents, impact of nutrients on water quality.
- Functional Genomics and Proteomics that deal with important agricultural issues: including production and protection traits, genetic optimization and increased yield.
- Sensors and Robotics: linking biological phenomena with sensors or otherwise bridging into the fields of bioengineering, nano-technology, precision agriculture and labor reduction.
- Sustainable Bio-Energy Systems: including biofuel production systems, reduced energy costs, renewable resources, reduced greenhouse gases, and diversified farm economy.

4 | About BARD

4.3 | The Research Proposal Evaluation and Selection Process

The core of BARD's activities is the support of collaborative research projects. Submissions for projects of a three-year duration are called for annually with a closing date in mid-September. Decisions are announced the following May-June. The BARD review process is a three-tiered process consisting of ad hoc reviewers who are experts in the discipline of a given research proposal, independent Israeli and US scientific discipline panels, and the Technical Advisory Committee (TAC).

The selection process provides the opportunity for panels on both sides (US and Israel) to create a list of their priorities based on each country's needs. This enables a thorough review of each proposal and ensures that only the most innovative and scientifically excellent proposals which align with BARD's overall mission are funded.

The TAC consists of 10 prominent scientists, with equal representation of both countries, who are experts from diverse disciplines, and it is they who select the final interdisciplinary portfolio with a prioritized list of recommended proposals. The regular rotation of members within the TAC maintains the integrity of the selection process and keeps it constantly invigorated with fresh perspectives, thereby ensuring it remains open to new ideas and approaches to meet the agricultural challenges of the future.

4.3.1 | The Average Rate of Approved Proposals

BARD has funded 41 rounds of submissions over the past 40 years (1979–2018), with two rounds in 1979 and 1980 each, and annual submissions since then. A total of 5,102 proposals were submitted, of which 1,330 were funded at a total budgetary commitment of $315 million.

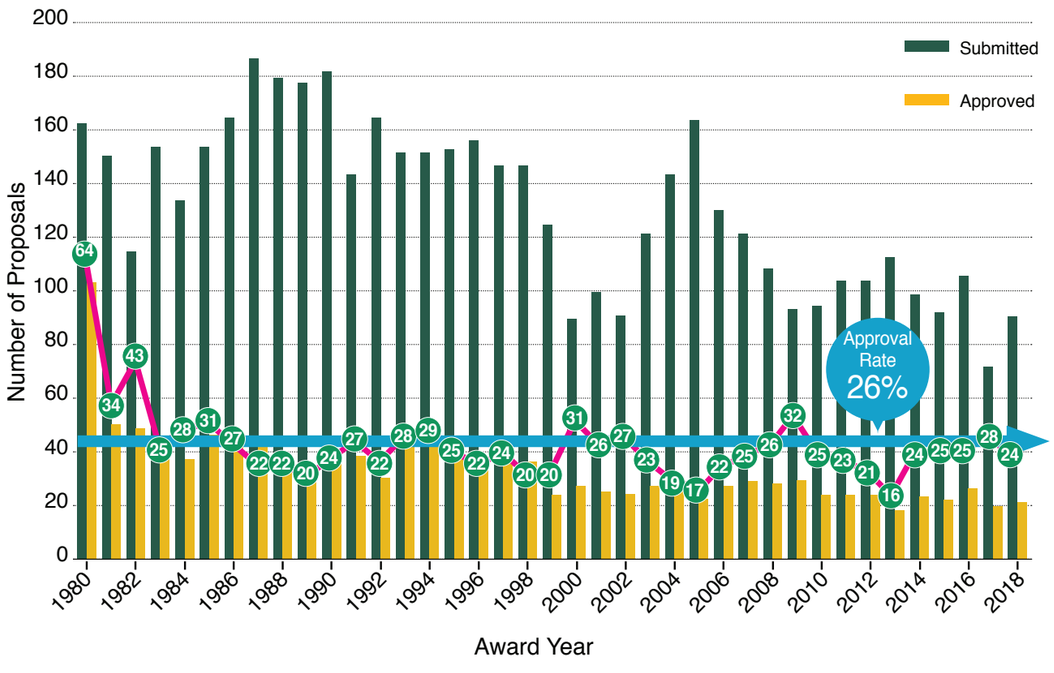


Figure 1: Submitted and Approved Proposals (1979-2018)

The mean research grant approval rate for all 41 rounds of proposal submissions is 26% (Figure 1). The fluctuation in the rate of grant approval is a result of the varying number of applications every year, as well as budget availability. Periodic changes in BARD granting policy have also contributed to fluctuations in the number of submitted proposals, thereby affecting the total number of proposals submitted throughout the 40 years of BARD funding. Changes in the number of researchers in all fields can also impact the number of applications.

4.3.2 | Submitted and Approved Proposals by Research Field

The initial research priority areas were proposed in the "Potential Areas of Mutual Interests" section of the original agreement between the two governments. Over the 40 years, BARD's leadership has redefined the research areas to reflect topics of relevance to both countries and scientific progress in each field. Any suggested change in research areas was discussed and approved or rejected by the board of directors. The present 7 research areas representing BARD's portfolio are listed in Table 1.

Table 1: Summary of Submitted and Approved Proposals by Research Field and Approval Rate (1979-2018)

Area of Research	Number of Projects			Approved Budget	
	Submitted	Approved	%	1,000s USD, Nominal Terms	%
Crop Production	1,525	395	26	96,277	31
Animal Production	741	196	26	47,881	15
Animal Health and Invasive Species	409	103	25	24,229	8
Food Product - Safety, Security and Quality	492	135	27	32,790	10
Crop Health and Invasive Species	970	250	26	59,623	19
Environment, Water and Renewable Resources	581	140	24	32,096	10
Agricultural Innovation and Engineering Technologies	384	110	29	22,163	7
Total	**5,102**	**1,329**	**26**	**315,059**	**100**

Table 1 shows the distribution of submitted and funded proposals across the research fields. As can be seen from the breakdown, the approval rate percentage is virtually identical throughout all areas of research, reflecting an impartial evaluation process that is not biased towards any particular research discipline a priori.

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4.4 | Sources of Funding for BARD Activities

The funds for supporting BARD activities, approximately $8 million annually, are generated by two sources that are contributed in equal parts by the governments of the US and Israel: interest on a fixed $110 million endowment, and an annual direct supplement to the research budget of each country.

The main source of BARD's research budget (Figure 2) is the interest on the endowment fund. This fund was set up within the framework of the original agreement between the two governments, each of which endowed $40 million, creating a total fund of $80 million. With a fixed annual interest of 7%, paid quarterly in arrears, the endowment fund generates an annual $5.6 million.

The full table of approved budgets throughout 40 years can be found in Appendix B, available online on BARD's website.

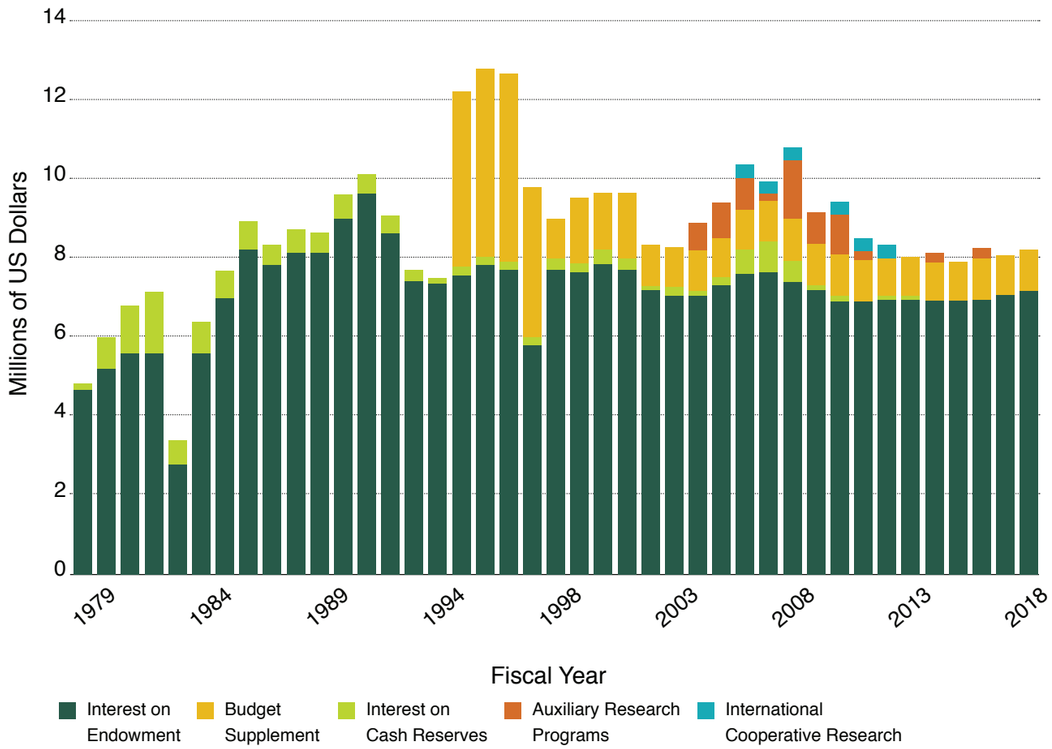

Figure 2: Sources of Income (1979-2018)

The endowment fund was enhanced in 1984 by $30 million, contributed in equal parts by both countries. The formula for calculating the interest on this amount is based on the LIBOR (London Interbank Offering Rate) index and is paid semiannually. Since 1984, this interest rate has fluctuated between 4.5% and 10.5% per annum. In 2018, the interest was 5% a year, yielding $1.5 million.

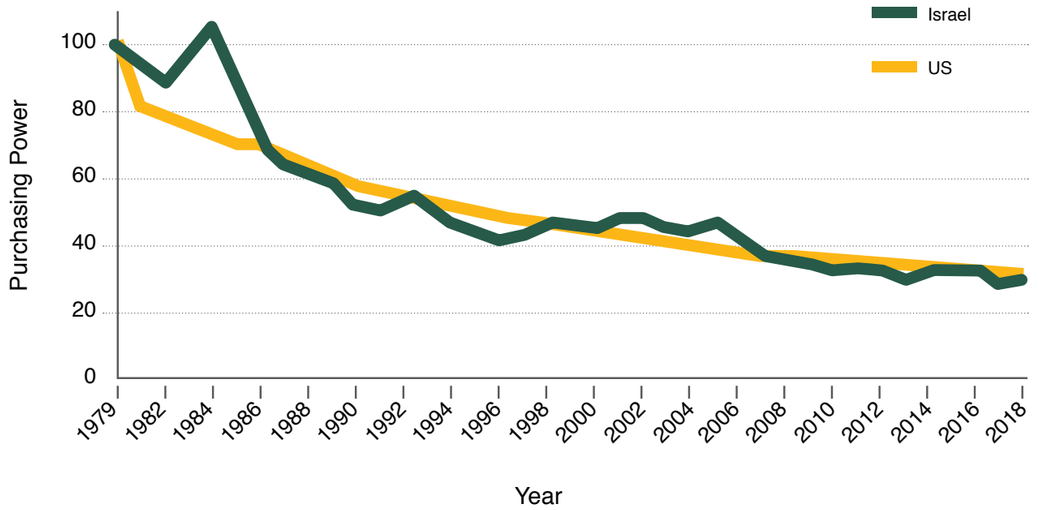

Figure 3: The Purchasing Power of the US Dollar (1979-2018)

The devaluation of currency has direct impact on the value of research grants, as the sum awarded per research grant has not been significantly increased over the years (Figure 3). Similar trends in currency value have been observed in both countries, where USD purchasing power has declined by 70% over 40 years. The percentage of the purchasing power of the dollar is calculated starting in 1979.

4.5 | Distribution of Funds for the BARD Research Grant Program

BARD's research grant guidelines do not require an equal allocation of the research budget between the two countries. The research teams enjoy the independence of deciding how to divide the awarded BARD research grant. As can be seen in Figure 4, a larger share of the budget was allocated to the Israeli teams in the early years; however, for the last 20 years, the budget was split nearly evenly between the two countries. 1999 saw a steep plummet in total funding after both countries cut their annual budgetary supplement from $2.5 million to $500,000 each. Funding has further declined since 2008, as falling interest rates on the US dollar decreased the income from the endowment fund.

4.6 | Funded Institutions

In the US, the majority (73%) of partners in BARD projects are scientists from state universities and land-grant colleges. The remainder are from the USDA-ARS (13%) and other private and public non-profit research institutions (14%). In Israel, almost 50% of the allocations go to research partners at the Agricultural Research Organization, Volcani Center (ARO). Another 23% goes to the Hebrew University of Jerusalem, with the remainder to other universities and non-profit research institutions. The full list of funded institutions can be found in Appendix C, available online on BARD's website.
BARD has been successful in funding projects all over the United States, reaching 47 of the 50 states. BARD has yet to fund projects in North Dakota, Maine and Alaska (Figure 5). The top funded research projects per state are California, New York, Florida, Maryland, Texas and Michigan. California received the highest proportion of funding for nearly 300 research projects, which constitute over 20% of the total number of projects. Over 11% of projects funded were granted to researchers in New York and over 7% to researchers in Florida, with 151 and 97 projects, respectively.

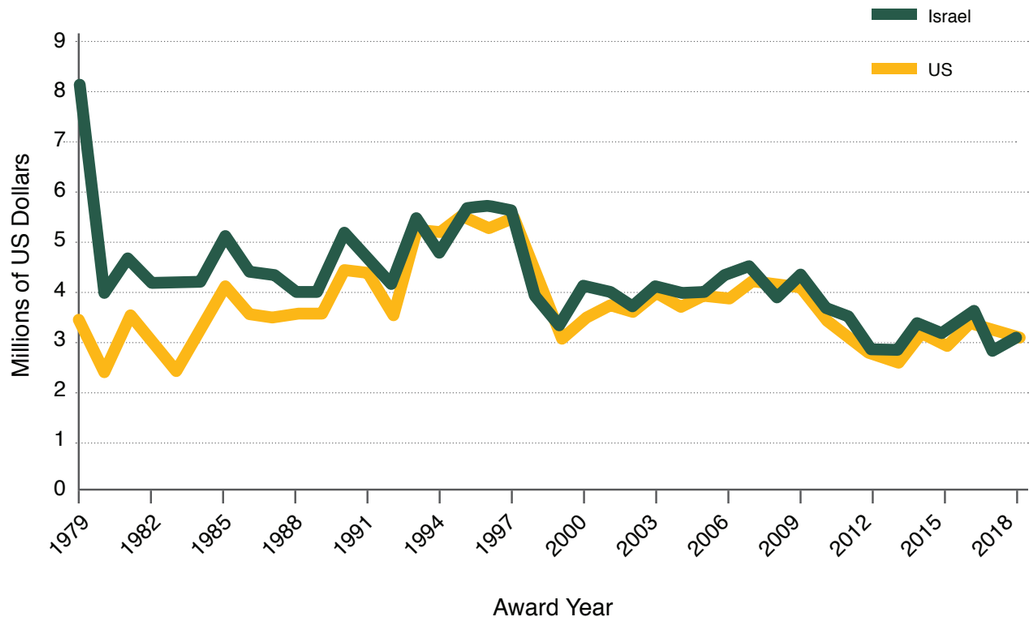

Figure 4: BARD Budget Allocation by Country (US, Israel)

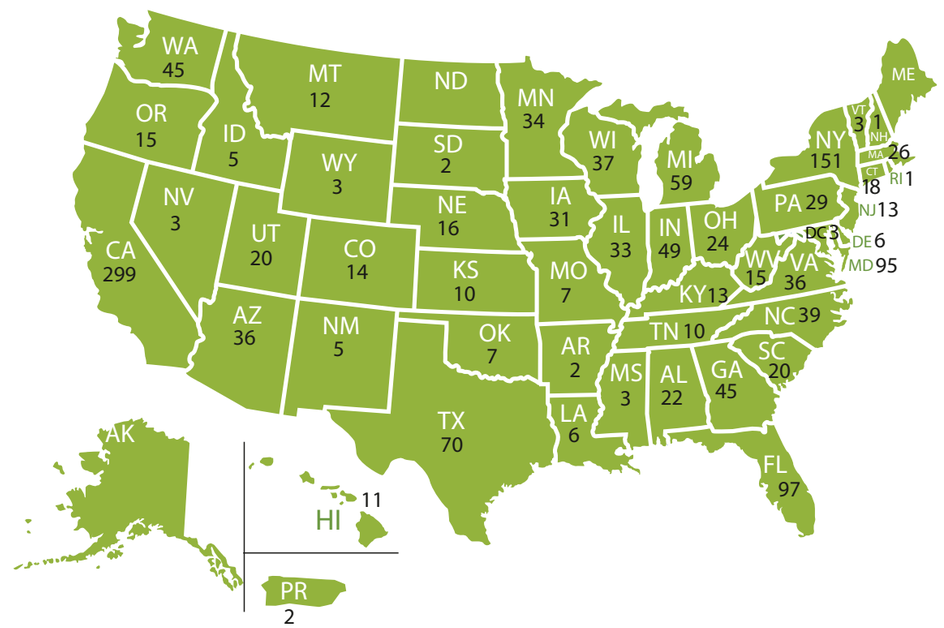

Figure 5: Distribution of Funded Research Projects in the US by State

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Table 2: BARD Allocation of Budget by Type of Expenditure
(BARD Research Grant Program)

	BUDGET (in US Dollars)		
	Israel	**U.S.**	**Total**
Salaries	79,187,537 **47%**	83,686,590 **57%**	162,874,127 **52%**
Equipment	10,744,918 **6%**	3,359,184 **2%**	14,104,102 **4%**
Supplies	44,587,745 **27%**	32,641,627 **22%**	77,229,372 **24%**
Travel Abroad	4,224,821 **3%**	3,678,733 **2%**	7,903,554 **3%**
Overhead	28,688,329 **17%**	24,259,827 **17%**	52,948,156 **17%**
Total	**167,433,350** **100%**	**147,625,961** **100%**	**315,059,311** **100%**

Table 2 shows cumulative funding for the past 40 years and the funds' distribution by budgetary item in each country. In both countries, approximately half of the funding is for personnel. The salaries shown here represent the payments for postdoctoral fellows, graduate students or laboratory technicians involved in the research project (BARD regulations strictly prohibit use of the funding to pay for Investigators' salaries). Approximately one-quarter of the total budget in both countries covers supply procurement. Less than 10% of the budget is allocated to equipment. Overhead claims 17% of the total budget (BARD regulations limit the overhead costs to 20% of direct expenditure). The findings of this analysis show that the allocations by budget item in both countries are similar.

4.7 | BARD Programs

The BARD Research Grant Program funds projects for a duration of three years. It supports all aspects of agricultural R&D including strategic or applied research. Since 1979, the program has funded 1,330 projects with a total of $315 million (see Table 1).
Another avenue for funding is through one-year feasibility studies, which may be granted in one of two situations. In certain cases, TAC may grant one-year feasibility funding to a proposal that has yet to demonstrate preliminary results meriting three-year funding but harbors potential for innovative research. In others, researchers themselves seek funding for a one-year feasibility study in order to establish a basis for pursuing further research on an innovative idea. Applications for feasibility funding follow the same guidelines as other proposals. The funding for a one-year feasibility study is $100,000.

Over the past 40 years, BARD has funded 98 one-year feasibility studies, of which 52 have requested further funding after their initial one-year grant came to an end. Of those, nearly half (22) received additional funding.

The Vaadia-BARD Postdoctoral Fellowship Program, established in 1985, funds postdoctoral fellowships for one to two years for citizens of either the US or Israel to conduct agricultural research mentored by established scientists from the other country. The program identifies and supports these young scientists, who will later become leaders in agricultural R&D. The primary objective of the fellowship is to enable these young accomplished scientists to acquire new skills and techniques while becoming professionally established in the agricultural research community. Since its inception, the program has granted 248 fellowships. Fellows are granted $40,000 per year; fellows with dependents receive $49,000.

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This program allows US and Israeli fellows to travel to their mentor's research facilities and experience different research viewpoints, as well as new and different cultures and academic environments, forging symbiotic relationships and broadening their horizons. In many cases, the teaching programs in agricultural studies are also enriched by techniques, ideas and insights that stem from BARD-supported projects and the research fellows' work. Many of the fellows now hold key positions within the agricultural R&D community in both the US and Israel. Approximately 70% of the postdoctoral alumni have stayed in research or academia, and some 10% currently hold positions in the agricultural-related private or government sector. Table 3 shows the distribution of postdoctoral fellows across research fields. The full list of the 248 postdoctoral fellows since the program began in 1985 can be found in Appendix D, available online on BARD's website.

Table 3: Postdoctoral Fellowship Grants by Research Fields

Research field	Total number of postdoctoral fellows
Animal Health and Invasive Species	9
Animal Production	34
Crop Health and Invasive Species	60
Crop Production	90
Agricultural Economics	5
Agricultural Innovation and Engineering Technologies	2
Food Product- Quality Safety and Security	8
Environment and Renewable Resources	40
Grand Total	**248**

Crop production and crop health are the most popular research fields within the postdoctoral program. Together, they make up 60% of the postdoctoral grants funded by BARD. The fields of agricultural innovation and engineering technologies, agricultural economics and food product combined account for only 6% of the postdoctoral grants.

The Senior Research Fellowship Program allows senior US scientists to visit Israeli research institutions for a period of two to twelve months in order to promote the exchange of ideas and personal interaction between the senior scientist and Israeli scientists and students. The program has funded 21 senior research fellows since beginning in 1990.

The Graduate Student Fellowship Program enables doctoral candidates from the US or Israel to travel to the other country for a period of three to six months to acquire new skills and techniques in their field of study. The program has funded 24 graduate student fellows since beginning in 2007.

Workshops Program supports workshops in areas related to the binational and shared agricultural interests of the US and Israel. The program has funded 52 scientific workshops since beginning in 1990, of which 14 were held in the US, 36 in Israel and another 2 in Europe. The full list can be found in Appendix E, available online on BARD's website.

B-Lever Program was recently launched (December 2018) with the aim to support academia-to-industry collaboration through partnership with the Israel Innovation Authority and the USDA National Institute of Food and Agriculture (NIFA).

4.8 | BARD Auxiliary Programs

Texas-BARD Program (2004-2011, 11 projects, $4 million) promoted mission-oriented, applied, collaborative agricultural research and development activities conducted jointly by scientists in Texas and Israel. Funded projects were expected to be of interest to the relevant agricultural industries and yield applicable results within 3 years, as well as possible public-private partnerships.

The University of Maryland (UMBI)-BARD Aquaculture Research Program (2004-2008, 10 projects, $3 million) promoted and competitively supported mission-oriented, collaborative aquaculture research and development activities between US and Israeli scientists. The research projects addressed issues of mutual benefit to both countries and provided solutions to shared aquaculture and marine biology challenges, opening new horizons for advancing related fields.

UC Davis, Center for Produce Safety-BARD Program (2006-2012, 2 projects, $500,000) provided competitive funding aimed at fostering collaborative, mission-oriented research between agricultural scientists from US universities or research institutions and their Israeli counterparts engaged in joint research relating to food safety.

MARD-Multinational Agricultural Research and Development Program (2003-2014, 11 workshops, 9 projects $700,000) promoted collaborative agricultural research and development in the Middle East region between scientists from Israel, Jordan, the Palestinian Authority and the US. The program funded regional workshops that addressed pressing agricultural concerns common to farmers throughout the Middle East, and provided modest facilitating grants. This enabled the joint teams of scientists to obtain preliminary research results that allowed them to develop proposals and seek funding opportunities with agencies offering more lucrative grants.

NIFA-BARD Program (2014 - present, 5 grants, $3.4 million) enables Israeli scientists to collaborate with US scientists within the framework of a specific request for applications sponsored by the Agriculture and Food Research Initiative (AFRI) Competitive Grants Program of the USDA. To date, $887,000 have been allocated to Israeli scientists as a match to the NIFA grants allocated to the US scientists.

5 | The 40 Year Evaluation

5.1 | Objectives of the 40 Year Review

This review aims to assess and quantify BARD's historic and cumulative impact in terms of academic outcomes as well as the resulting agricultural applications. This includes both applied know-how with limited commercial impact, as well as projects that have proven and achieved significant commercial and economic impact.

The organizational structure of BARD and its evaluation mechanisms themselves were not evaluated for the purpose of this current review. These were meticulously defined and reviewed closely during the process of the 20-year evaluation conducted in 2000, as were the values and assets of all collaborative research projects, review panels process in both countries, TAC activities and responsibilities, and the effectiveness of administrative process. Since then, BARD has continued to adhere to the original selection criteria for proposals, such as scientific merit, benefit to agriculture, mode of collaboration and probability of success. At present, special emphasis is placed on the mode of the collaboration, and the anticipated benefits to agriculture. BARD's comprehensive and rigorous process to select the best proposals in every round was highly regarded by the 20-year review committee, and this process has been maintained consistently since.

5.2 | Methodology of the 40 Year Evaluation

The methodology employed for the evaluation is based on the range of Research Impact Assessment (RIA) approaches reported in literature across different disciplines, and specifically, on previously implemented and proven Agricultural RIA (ARIA) methodologies[1].

The chosen methodology is derived from methods implemented by INRA (French National Institute for Agricultural Research)[2], CSIRO[3] (Commonwealth Scientific and Industrial Research Organization), CGIAR[4] (Consultative Group on International Agricultural Research) and EMBRAPA[5] (Brazilian Agricultural Research Corporation), among others. These bodies use case study impact analysis as a means of assessing impact of the organization. In the case studies, the pathway between the research activities and outcomes and the eventual impacts are analyzed, most often according to categories defined in the OECD glossary of terms for evaluation[6]. For the 40-year evaluation analysis, BARD adopted impact categories and indicators used by the institutions and organizations cited above, as well as those from the impact statements of the USDA-NIFA. The main categories of impact for which indicators have been selected are academic, environmental, social, and economic.

The evaluation was conducted by two complementary pathways: a survey and case studies. Both applied mutual indicators for assessment of impact.

1 A comparison between some of the implemented ARIAs can be found in Joly, P. et al. (2016), OECD Food, Agriculture and Fisheries Papers, No. 98, http://dx.doi.org/10.1787/5339e165-en

2 ASIRPA guide to analyzing the impacts of research, 2013, INRA; can be found at http://inra-dam-front-resources-cdn.wedia-group.com/ressources/afile/238248-a43fa-resource-asirpa.html

3 a) CSIRO. (2014). How CSIRO ensures it delivers impact (Vol. 9) and (b) CSIRO. (2015). Impact Evaluation Guide. Recent impact evaluation reports for specific projects can be viewed and downloaded from https://www.csiro.au/en/About/Our-impact/Our-impact-in-action

4 (a) Stevenson, J. et al., 2018. The Rigor Revolution in Impact Assessment: Implications for CGIAR. (b) Raitzer et al., Benefit–cost meta-analysis of investment in the International Agricultural Research Centers of the CGIAR, Agricultural Systems 96 (2008) 108–123.

5 Avila, F. et al., (2016). EMBRAPA Experience on the Impact Assessment of Agricultural R&D: 15 Years Using a Multidimensional Approach.

6 OECD. (2002). Glossary of key terms in evaluation and results-based management. Development Assistance Committee (DAC), Working Party on Aid Evaluation.

5.2.1 | Survey

This component of the evaluation carried out a broad assessment of research studies conducted by Principal Investigators (PIs) who were awarded funding and began their research between the years 1994-2014. This 20-year timeframe provides an effective window for evaluation. It allows inclusion of researchers who are currently still active in research, while also providing a time lag during which the mid-to-long term impact of research outcomes has had time to evolve and manifest. The survey was conducted in a self-reporting format, in which the researchers were provided an online questionnaire containing a set of key impact indicators. The questionnaire is presented in the Evaluation Compendium, available online on BARD's website.

5.2.2 | Case Studies

Twenty case studies were selected for an in-depth research impact analysis that provides both a narrative and quantitative analysis of selected indicators. The materials were retrieved from multiple sources: personal interviews with the researchers, stakeholders and beneficiaries of any practical outcome, as well as publications, written reports, databases and websites. The information collected from the different sources was triangulated and cross-referenced. The following describes the process of selecting the case studies for analysis.

Step 1: BARD approached 13 Israeli academic and research institutes and requested that their respective research authorities nominate projects with outstanding research outcomes. Following the provided guidelines (detailed in the Evaluation Compendium, available online on BARD's website) as well as their respective internal process, the research authorities returned a list totaling 120 Israeli PIs, whose joint projects with US researchers were considered the most outstanding and impactful.

Step 2: The 120 nominated projects were screened by the BARD evaluation team, which subsequently compiled a short-list of 60 projects for case study analysis, based on (i) the research authorities' selection (ii) input from experts in the fields of the proposed projects (iii) the self-reported survey evaluations, and (iv) prior knowledge.

5 | The 40 Year Evaluation

The two main categories used to assess the projects were (i) academic advances and impact and (ii) practical agricultural application.

Step 3: The short-list of 60 projects was narrowed down by the steering committee to 20 projects chosen to serve as case studies. Most of the projects selected had begun within a time window that enabled a measurable outcome to evolve. Several others were conducted in more recent years and were included for scientific advances that have already achieved substantial international impact, despite not yet attaining full impact potential. While diversity of disciplines was not in itself a criterion for selection, the number of projects from any specific discipline was limited.

5.2.3 | Economic Analysis

Using 2018 Dollar-Terms

The economic calculations go back to 1979, the first active year of BARD. Since each project has a different starting point between 1979 and the present, the calculations in this review are expressed in present value terms. Therefore, all flows of money were adjusted to real dollars using the US Consumer Price Index (CPI). For past flows of money, we calculated the real rate of return of 10-year treasury bonds for the years 1979 – 2017, which is 3%. However, in the last 20 years this measure is lower, and we also calculated the long-term real GDP growth rate for the years 1979 – 2017, which is 2.7%. Therefore, past flows are compounded to 2018 dollar-terms using an interest rate of 2.7%.[7]

Regarding future projections, our working assumption is that most projects will generate additional competitive practical agricultural solutions within the coming decade. Therefore, we limited calculations to 2028 and capped the benefit calculation period for all projects at 30 years from first implementation. An exception to this rule was case study 7 (see Appendix 1), the research outcomes of which provided the basis for the emergence of a new industry. As with the other projects, the benefit for this case study was calculated through 2028 but sums to a total of 38 years of benefit since the project began.

Future flows of money were discounted to 2018 dollar-terms using the same rate of 2.7%. All results and calculations in this document are expressed in 2018 discounted dollar-terms, unless otherwise stated.

The Investment

For all projects, BARD's investment is calculated according to the sums of the awards connected to the research project, and the specific years of the grants. Any additional investments from academic, governmental and private funds are also included in the calculation. The total amount is adjusted to 2018 dollar-terms.

In most cases, BARD invested in the initial and hence most risky stage of the project. BARD provided funding for both fundamental as well as translational research, positioned at a stage where the research was able to demonstrate a preliminary applicative character. This early stage precedes scale-up and entrance of the private sector, since proof of concept has yet to be demonstrated and uncertainty is still high, making BARD's investment at this point critical.

We estimated the risk premium attributed to BARD and to the other foundational investors by bringing their investments to 2018 dollar-terms using a real interest rate of 7.7% per annum. This figure combines the 2.7% rate and a 5% risk premium to reflect the risk interest rate in the last decade.[8] Any additional investments by commercial and industry players that followed up on the BARD-funded research were calculated using the standard 2.7% rate as the interest rate. These calculations were conducted only for the purpose of quantifying BARD's share in the overall economic benefit from the projects it funded. We limited the results of this calculation to attribute no more than an extra 15% to BARD's share in the benefit.

In several case studies, (6, 7, 16 and 18; see Appendix 1) we were unable to obtain information on the additional investment made by academic and governmental funds that were active in the foundational research phase. In these cases, we evaluated BARD's share through personal interviews with the researchers and relevant experts, and by extrapolating from previous evaluations.

The Benefit

Certain projects generated value added by improving productivity and yield, while others did so by reducing damage and loss to agricultural production and products. Others yet generated value added through developing a new product.

The benefit was calculated according to farmgate prices plus its effect on the retail price. In order to calculate the value added, we compounded the farmgate prices with the impact on retail prices. The two components of the supply chain that are relevant to this calculation are the revenue of the wholesaler and that of the retailer, which are a set percentage of the ultimate retail price of a given product. Our working assumption is that the cost of other components throughout the value chain are not affected by fluctuations in farmgate price.[9] For example, if the price of an agricultural product was reduced by $4/ton because of BARD's project, and we know that the retail and wholesale revenue is 30% of the consumer price, then we calculated the benefit of the project as $4/(1-0.3) = $5.7/ton.

We estimated the benefit to the relevant global activity and to all players throughout the value chain. We did not address the breakdown of the benefit throughout the value chain, such as how it is distributed between producers and consumers. However, a number of projects benefited the US or Israel as consumer parties. For example, the US and Israel consumption of tilapia is mainly generated from imports. In this case, the US and Israel do not enjoy the producer's benefit, but do enjoy the consumer's surplus. For these case studies, we estimated the consumer surplus in both countries in order to estimate their share of the overall benefit.[10]

While we described environmental and social benefits, these are excluded from the calculation.

7 See the internet site of the US government Bureau of Economic Analysis: https://search.bea.gov/search?affiliate=u.s.bureauofeconomicanalysis&query=Table+1.1.1.+Percent+Change+From+Preceding+Period+in+Real+Gross+Domestic+Product
Alston et al used a discount rate of 3% as a base scenario, see: https://pdfs.semanticscholar.org/1cfa/7d94983ebedc0f94c67b9eb4b33fbb4b98a9.pdf

8 A. Damodaran analyzed financial indicators and found that since 2008, the expected return on stocks has stagnated at about 8%. See: http://pages.stern.nyu.edu/~adamodar/
We calculated expected inflation according to the average US-CPI in the last three years: 1.2%.

9 The information about retail and wholesale dollar share in the supply chain is obtained from: https://data.ers.usda.gov/reports.aspx?ID=17885

10 Main source for the demand and supply elasticity is: https://data.ers.usda.gov/reports.aspx?ID=17825#P532c0294132b4f87986b398505db6d5f_4_214
And the book: A Database for Trade Liberalization Studies, published in 1989 by ERS, USDA

5.3 | The Results

We regard BARD's funding of research projects as an investment and aim to quantify the returns on these investments by employing a set of key indicators. In order to measure the returns, we deducted the initial investment from the economic benefit attributed to BARD, arriving at the Net Present Value (NPV), which reflects the return.

Additionally, we calculate the Internal Rate of Return (IRR), which is the rate at which the NPV of a given project cash flow equals the present value of the initial investment. A high IRR is an indicator of a gainful project.

Another indicator is the Benefit-Cost Ratio (BCR), here calculated to reflect the ratio between the benefit attributed to BARD and the cost of the initial investment in 2018 dollar-terms. We note that typically, governments pay the costs of the foundational research, while benefits accrue to producers and consumers of farm products.[11]

Availability of relevant data is essential to conducting economic analyses. However, in certain cases, the data and price estimates of key parameters available to us were incomplete. To address this caveat, we presented baseline results along with a sensitivity analysis including low and high estimates of the benefit and attribution to BARD in different scenarios.

The distribution of projects across the 7 BARD topic panels was analyzed for all components of the report, including the awarded BARD projects, the projects reported on in the online survey, and the chosen case studies, as shown in Figure 6. With the exception of the Animal Production panel, the selection of case studies per panel corresponded to their proportional share within the full BARD portfolio.

11 On the influence of that observation on the way to calculate the IRR indicator, see Alston et al: https://academic.oup.com/ajae/article-abstract/93/5/1257/176597?redirectedFrom=fulltext. However, we used a simple IRR

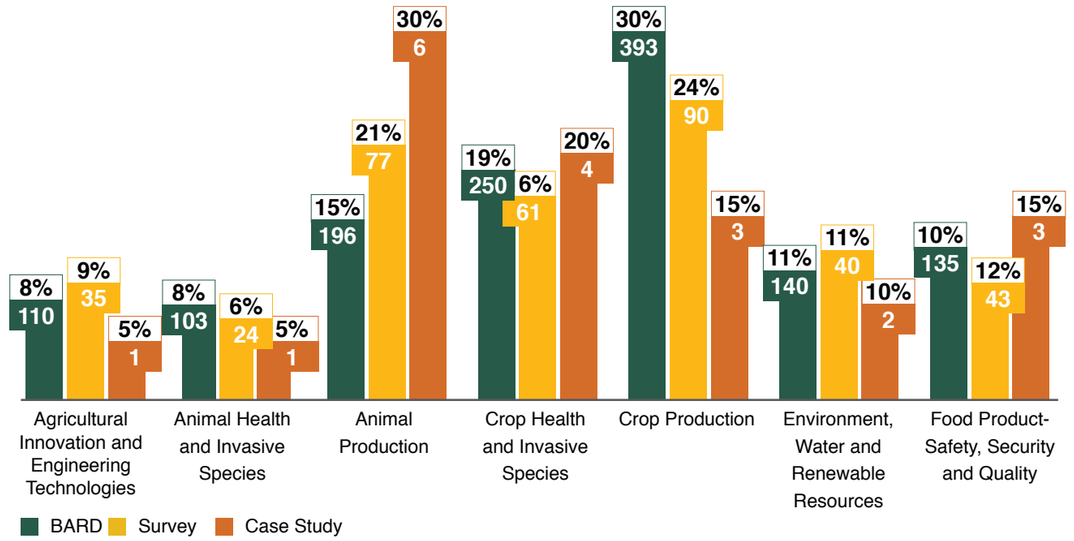

Figure 6: Distribution of Projects Across BARD Panels

*The project "GOSSYM Cotton Model" is classed under Crop Production in the BARD documentation but has since been transferred to the more suitable Environment, Water and Renewable Resources.

5.3.1 | Evaluation of BARD's Impact Derived from the Survey

Over the 40 years of its activity, BARD has funded 1,330 research awards involving a total of 1,540 PIs, 910 from the US and 630 from Israel. The self-reporting online questionnaire was circulated to 640 US and Israeli PIs on awards received in the period of 1994–2014. The PIs were asked to respond on a single award, or on multiple awards related to a single research project that they regarded as their most impactful. A total of 140 PIs completed the survey, 66 from the US and 74 from Israel, relating in their answers to 224 BARD awards. Of the respondents, 18 US-Israeli pairs reported on the same awards. The main results of the survey are presented in Figure 7 and are described in brief according to the pathway of the research from initial input to final impact.

5.3.2 | Inputs

1. Research projects are often comprised of multiple awards. The average number of awards per project among the survey respondents was 1.6. From this we calculated that a total of 830 research projects emerged from the 1,330 granted awards. This estimate is used later in the analysis.
2. The overwhelming majority of researchers, 88%, continued research on the topic of their BARD project after termination of the award.
3. A solid majority, 67% of the respondents, reported that the BARD grant facilitated further funding via BARD and other academic funding programs, and another 21% reported securing continued funding from commercial entities.

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Main Results from 140 Survey Respondents

Inputs	Activities	Academic Impact	Stakeholder Engagement	Agricultural Outcomes	Impact Beyond Agriculture
Inputs 1.6 BARD Awards/PI	**BARD Research Activities**	**Publications** 6.1 Per Award **Research Output** Scientific Advances: 72%	**Non-Academic Engagements** **Overall** 80% Technical: 45% Industry: 52% Government: 33% Farmers: 35% VC funds: 7% Extension: 35% NGOs: 11%	**Agr. Implementation** Agr. Practice: 60% Regulation: 5% **Adoption** Adopted: 24% Ready to adopt: 7% **IP** Patents submitted: 12% Patents issued: 11% Breeding rights: 4% **Industry** Commercial signing: 3% Spin-off: 1%	**Social** 6%
BARD as Catalyst for Further Funding	**Follow-up Studies** 88% Commercial: 21% Academic: 67%	**Students** 2.5 Per Award **Follow-up Collaboration** US and IS BARD PIs: 82% Workshops: 43% Consortia: 18%			**Environmental** 35%

Figure 7: The Main Results of the Online Survey

The % values represent the percentage of 140 respondents that answered positively to the indicator.

5.3.3 | Academic Impact and Capacity Building

1. To date, the 1,330 awards funded by BARD have generated more than 5,600 published manuscripts. These were an outcome of approximately 925 awards, or 70% of all awards, which yielded an average of 6.1 publications per project. This figure is a low estimate, as data on publications from the early years of BARD (chiefly the 1980s) is incomplete, and not all researchers maintain updated records of their BARD-associated publications.
2. 10% of the publications have over 100 citations, and 42% appeared in the first quartile (Q1) journals, i.e. those with an impact factor that ranks in the top 25% of journals in their particular research discipline.
3. On average, 2.5 graduate students participated in the research for each award. Currently, 40% of the students and postdoctoral researchers are in academia and 22% hold positions in Agri- and Bio- industries. These figures represent the lowest estimate, as in several cases PIs were unable to provide information about the students' current occupation.
4. 72% of respondents reported that significant scientific advances were achieved during the research. 43% participated in academic workshops and 18% in consortia on the topic of their BARD research.
5. 82% of all respondents continued to collaborate with their US or Israeli Co-PI in subsequent follow-up studies.

5.3.4 | Stakeholder Engagement

More than 80% of the respondents participated in sharing of their findings with non-academic stakeholders. Many respondents engaged with more than one stakeholder category (see Figure 7).

5.3.5 | Practical Agricultural Outcome

1. 65% of the respondents reported that the research project had practical implications for agricultural practice and policies.
2. 24% of the respondents reported that their research output had already been adopted; another 7% reported that their findings were ready for adoption.
3. 12% of the respondents applied for patent registration, of which 11% have been issued patents. 4% have been assigned breeding rights, 3% have signed commercial agreements related to the BARD-funded research outcomes, and 1% founded a spin-off company based on the BARD-funded research output.

5.3.6 | The Selected Case Studies

The 20 selected case studies are listed in Table 4.

Table 4: Selected Case Studies for In-depth Analysis

The projects are listed within their respective BARD panel in chronological order of the years of research activity.

20 Selected Case Studies for In-Depth Analysis				
	Subject	**PIs**	**# Awards**	**Time Span of Awards**
		Crop Production		
1	Magical Nebula	A. Schaffer (ARO), M. Pharr (NC State U), A. Bennett (UC Davis)	5	1987-1997
2	High Brix Tomatoes	S.D. Tanksley (Cornell U.), D. Zamir (HUJI)	4	1995-2002
3	Power Wheat	J. Dubcovsky (UC Davis), T. Fahima (Haifa U.), A. Blechl (USDA), P. San Miguel (Purdue U.)	5	2001-2016
		Animal Production		
4	Chicken Feed	S. Hurwitz (ARO), J.P. McMurtry (USDA), H. Talpaz (ARO)	2	1984-1990
5	Sheep Prolificacy	E. Gootwine (ARO), W.C. Foote (Utah U.), D. Thomas (Wisconsin U.)	3	1985-1993
6	Genetic Improvement of Dairy Herd	J.I. Weller, M. Ron, E. Seroussi (ARO), D. Gianola, H.A. Lewin (Illinois U.), G.R. Wiggans, P M. VanRaden (USDA), I. Misztal (Georgia U.)	6	1985-2018
7	Hatchery Spawning	Y. Zohar (IOLR), Y. Koch (Weizmann Inst.), R.S. Langer (MIT), W.W. Dickhoff (Washington U.)	2	1985-2002
8	In-ovo Feeding	Z. Uni (HUJI), P.R. Ferket (NCSU), E.A Wong (Virginia Tech)	3	2002-2018
9	Monosex Prawns	A. Sagi (BGU), A. Elizur, (Dept. of Ag. & Fisheries. Queensland), S. Du, Y. Zohar (UMD)	2	2006-2015
		Animal Health & Invasive Species		
10	Tilapia Virus	W.I. Lipkin (Columbia U.), E. Bacharach (TAU), A. Eldar (Isr. Vet. Institute)	2	2013-2019

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20 Selected Case Studies for In-Depth Analysis				
	Subject	**PIs**	**# Awards**	**Time Span of Awards**
Food Product – Safety, Security & Quality				
11	Ornamental Foliage	R.T. Poole, C.A. Conover (Florida U.), J. Ben-Jaakov (ARO)	1	1980-1983
12	Biocontrol Agents	C.L. Wilson, W.J. Janisiewicz, M. Wisniewski (USDA), E. Chalutz, S. Droby (ARO)	5	1985-2003
13	Mango Treatment	D. Prusky (ARO), N. Keen (UC Riverside), J. Rollins (Florida U.), L. Vaillancourt (Kentucky U.), T. Mengiste (Purdue U.), R. Fluhr (Weizmann Inst.)	5	1995-2014
Crop Health & Invasive Species				
14	Trichoderma Biocontrol	R.D. Baker (Colorado St. U.) G.E. Harman (Cornell U.), I. Chet (HUJI)	8	1981-2004
15	Bombus for Crop Pollination	A. Hefetz (TAU), G.E. Robinson (Illinois U.), J.O. Schmidt (USDA), S.L. Buchmann (Arizona U.)	2	1994-2002
16	Citrus Greening Immunity	M. Bar-Joseph (ARO), R.F. Lee, W. Dawson (Florida U.)	4	1994-2006
17	Basil Resistance	J.E. Simon (Rutgers), Y. Cohen (Bar-Ilan U.)	1	2016-2019
Environment, Water & Renewable Resources				
18	GOSSYM Cotton Model	D. Baker (USDA), A. Marani (HUJI)	1	1981-1984
19	Aquaculture Waste Treatment	K. Sowers, Y. Tal (UMD), A. Gross (BGU)	2	2004-2014
Agricultural Innovation & Engineering Technologies				
20	Robotic Stress Detection	S. Nof (Purdue U.) Y. Tao (UMD), A. Bechar (ARO)	1	2016-2019

5.3.7 | Main Economic Outcomes of the Selected Case Studies

The results are expressed in 2018 discounted dollar-terms, unless otherwise stated.

Appendix 1 showcases the 20 projects chosen as case studies, with summaries outlining the main outcomes of each. The more detailed analysis of each project appears in the Evaluation Compendium. BARD awarded 64 grants across the 20 case studies totaling $49 million in 2018 dollar-terms, with an average of 3.2 grants per project. The summaries include BARD's share in the total investment required for research and development, and its share of the attributed benefit. The 20 case studies produced 502 publications, an average of 25 publications per project and 7.8 per grant. A total of 128 graduate students and postdoctoral fellows were involved in the research, an average of 6 students per project and 2 per grant. From Table 5, it can be concluded that, on average, a successful case study would need 3.2 grants to reach implementation or commercialization, yield 25 publications and employ 6.25 postgraduate students.

Table 5: 20 Selected Case Studies: Capacity Building and Investment

#	The Research	Capacity Building		Investment					
		Publications	**Students involved**	**# Awards**	**Years**	**BARD ($M)**	**Further funding ($M)**	**BARD funding share (%)**	**Benefit attributed to BARD (%)**
1	Magical Nebula	26	12	5	1987-1997	4.8	9.1	34	49
2	High Brix Tomatoes	33	5	4	1995-2001	3.6	6.4	36	51
3	Power Wheat	28	20	5	2001-2016	2.4	1.2	67	67
4	Chicken Feed	19	2	2	1984-1990	1.9	6.3	23	38
5	Sheep Prolificacy	17	1	3	1985-1993	3.2	0.3	90	90
6	Genetic Improvement of Dairy Herd	79	15	6	1985-2017	4.3	NA	NA	4
7	Hatchery Spawning	30	3	2	1985-1991	2	NA	NA	40
8	In-ovo Feeding	13	5	3	2002-2018	1.0	Too early to determine		
9	Monosex Prawns	12	7	2	2006-2014	0.8	1.3	37	52
10	Tilapia Virus	4	3	2	2013-2018	0.5	2.0	20	22
11	Ornamental Foliage	7	NA*	1	1980-1982	1.3	0	100	75
12	Biocontrol Agents	56	9	5	1985-2003	3.7	4.2	46	61
13	Mango Treatment	41	9	5	1995-2013	3.3	0.6	86	89
14	Trichoderma Biocontrol	50	7	8	1981-2007	8	37	17	32
15	Bombus for Crop Pollination	5	4	2	1994-2001	1.5	0	100	Non-monetary benefits
16	Citrus Greening Immunity	66	11	4	1994-2006	3.0	Too early to determine		
17	Basil Resistance	3	5	1	2016-2018	0.3	0.5	37	37
18	GOSSYM Cotton Model	2	2	1	1981-1984	2.8	NA	NA	25
19	Aquaculture Waste Treatment	4	4	2	2004-2014	1	3	20	20
20	Robotic Stress Detection	7	4	1	2016-2019	0.4	Too early to determine		
	TOTAL	502	128	64		49.8			

*NA – information not available

5 | The 40 Year Evaluation

Table 6 presents the results of the economic analysis for each case study, calculated both to the present, i.e. 2018, as well as projected until 2028. The analyses show that approximately 60% of the Net Present Value (NPV) has already been attained. Four case studies have not yet achieved a positive NPV. Of these, 3 are promising projects expected to yield high results, but it is too early to evaluate the benefit (case studies 8, 16 and 20). Additionally, case study 15 has indirect benefits that are outside the scope of our evaluation methodology.

Table 6 shows the distribution of the benefit between three entities: the US, Israel and Other Countries. The allocation is calculated according to the location of the agricultural implementation and of the consumption of the produce.
The lag column in Table 6 represents the time between the first year of BARD's investment to the first practical application of the research outcomes. This varies between case studies, ranging from 2 to 33 years, with an average time lag of 15 years.

Table 6: 20 Selected Case Studies: Main Economic Results

		NPV Attributed to BARD Projected to 2028			NPV Attributed to BARD Already Attained				Allocation of the NPV			
	Research	NPV $M	IRR (%)	BCR	NPV $M	IRR (%)	BCR	Lag	US $M	IS $M	Other $M	Total $M
1	Magical Nebula	220	16%	47	24	10%	6	28	2	-2	221	220
2	High Brix Tomatoes	261	28%	74	166	28%	48	14	263	-2	0	261
3	Power Wheat	118	32%	50	20	27%	9	12	37	-1	82	118
4	Chicken Feed	788	28%	410	382	28%	199	12	168	3	617	788
5	Sheep Prolificacy	204	18%	65	76	16%	25	19	-2	206	0	204
6	Genetic Improvement of Dairy Herd	1,135	25%	264	248	22%	59	25	534	2	599	1,135
7	Hatchery Spawning	12,050	143%	5,883	7,522	143%	3,673	6	156	240	11,654	12,050
8	In-ovo Feeding	-1	Too early to determine					-0.5	-0.5	0	-1	
9	Monosex Prawns	38	21%	51	4	14%	6	26	0	0	38	38
10	Tilapia Virus	46	83%	91	1	47%	3	4	2	1	43	46
11	Ornamental Foliage	119	89%	90	119	89%	90	5	119	-1	0	119
12	Biocontrol Agents	12	9%	4	12	9%	4	33	6	-2	8	12
13	Mango Treatment	54	21%	17	26	20%	9	15	6	29	19	54
14	Trichoderma Biocontrol	647	17%	85	190	15%	26	17	618	-4	33	647
15	Bombus Crop Pollination	-1.5	Indirect benefits not calculated					-0.7	-0.7	0	-1.5	
16	Citrus Greening Immunity	-3	Too early to determine					-1.5	-1.5	0	-3	
17	Basil Resistance	10	144%	34	0	56%	2	2	4	4	3	10
18	GOSSYM Cotton Model	813	98%	288	813	98%	288	5	766	47	0	813
19	Aquaculture Waste Treatment	28	31%	44	0	9%	2	14	6	0	22	28
20	Robotic Stress Detection	Too early to determine										
	Total	**16,538**		**340**	**9,603**		**198**	**15**	**2,683**	**517**	**13,337**	**16,538**

NPV = Net Present Value
IRR = Internal Rate of Return
BCR = Benefit-Cost Ratio

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Table 7: Evolvement of Each Case Study Research Project Over Time

#	Case Study	Awards	1979 - 1990	1991 - 2000	2001 - 2010	2011 - 2018
1	Magical Nebula	5				
2	High Brix Tomatoes	4				
3	Power Wheat	5				
4	Chicken Feed	2				
5	Sheep Prolificacy	3				
6	Genetic Improvement of Dairy Herds	6				
7	Hatchery Spawning	2				
8	In-ovo Feeding	3				
9	Monosex Prawns	2				
10	Tilapia Virus	2				
11	Ornamental Foliage	1				
12	Biocontrol Agents	5				
13	Mango Treatment	5				
14	Trichoderma Biocontrol	8				
15	Bombus for Crop Pollination	2				
16	Citrus Greening Immunity	4				
17	Basil Resistance	1				
18	GOSSYM Cotton Model	1				
19	Aquaculture Waste Treatment	2				
20	Robotic Stress Detection	1				

BARD + Other Research Funds Industry Funds Benefit

Table 7 details the evolvement of each case study project over time, illustrating the time span for the initial academic research, industry investments, and the ensuing benefit yielding implementation. The red cells represent research grant funding by BARD; yellow cells represent industry funding; green cells represent the benefits derived from the projects. In several cases, there is overlap between funding sources and the yield of benefits. These are marked as either red and yellow, or green and yellow, depending on the particular project's progress.

This table shows that an average project needs numerous awards during its lifespan. Slightly more than half (53%) of the successful projects have a hiatus between granted BARD awards. This hiatus can slow or even prevent progress on the project and its implementation through engagement of commercial entities. It can be noted that two-thirds of the projects that have engaged with commercial entities began this engagement at least 9 years prior to commercialization.

5.3.8 | The Growth in Benefits over Time

The US

The total estimated benefit to the US economy is $2.7 billion, thereof 60% already attained in 2018. Six case studies contributed over 90% of the benefits to the US economy that emerged from the 20 case studies, as detailed below and illustrated in Figure 8:

- Cotton Model, case study 18: Estimated contribution of $766 million between 1984 – 2013.
- Trichoderma, case study 14: Anticipated contribution of $618 million between 2010 – 2028.
- Dairy Herd, case study 6: Anticipated contribution of $534 million between 2011 – 2028.
- Brix Tomatoes, case study 2: Anticipated contribution of $263 million between 2004 – 2028.
- Chicken Feed, case study 4: Anticipated contribution of $168 million between 2009 – 2028.
- Hatchery Spawning, case study 7: Anticipated contribution of $156 million between 1990 – 2028.
- All the other case studies contributed together $178 million.

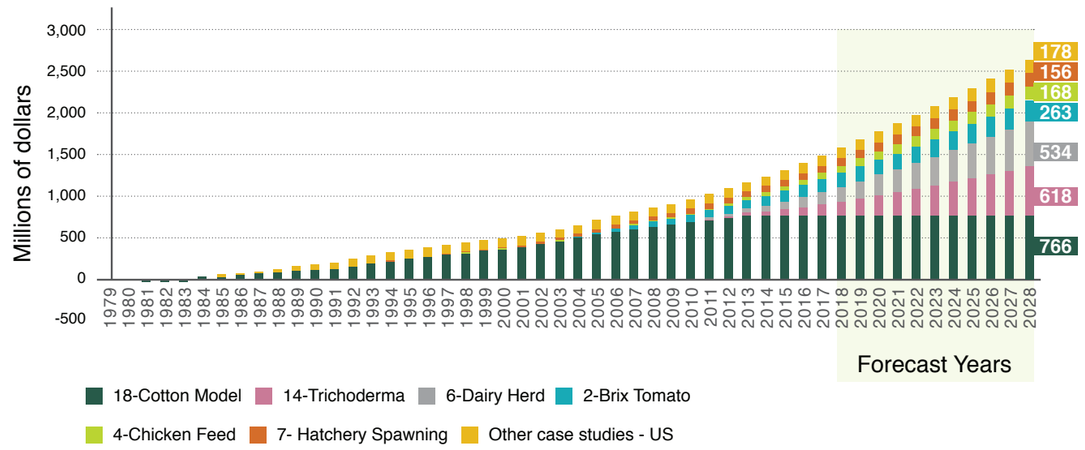


Figure 8: The 6 Main Contributing Projects to the US Economy, cumulative and per project, $ million.

5 | The 40 Year Evaluation

Israel

The total estimated benefit to the Israeli economy is $0.5 billion, thereof 53% already attained in 2018. Four case studies contributed almost all the benefits to the Israeli economy that emerged of the 20 case studies, as detailed below and illustrated in Figure 9:

- Hatchery Spawning, case study 7: Anticipated contribution of $240 million between 1990 – 2028.
- Sheep Prolificacy, case study 5: Anticipated contribution of $206 million between 2006 – 2028.
- Cotton Model, case study 18: Estimated contribution of $47 million between 1984 – 2013.
- Mango Treatment, case study 13: Anticipated contribution of $29 million between 2010 – 2028.

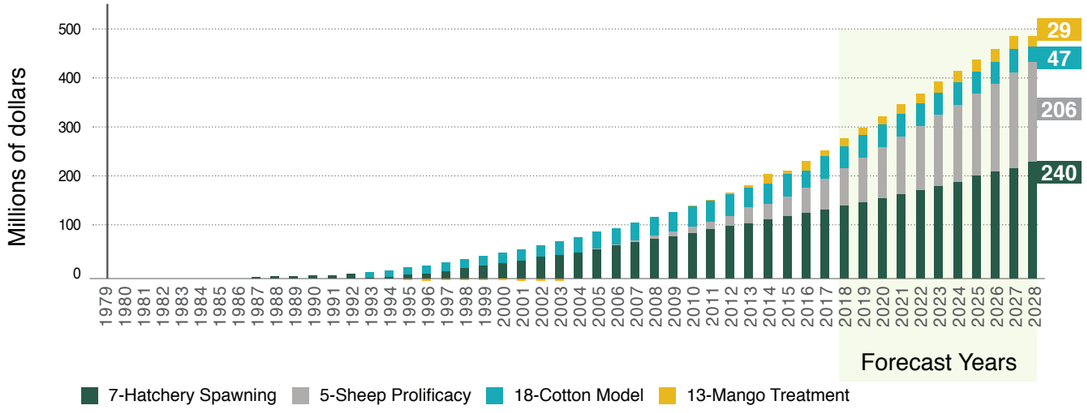


Figure 9: The 4 Main Contributing Projects to the Israeli Economy, cumulative and per project, $ million.

Other Countries

The total estimated benefit to the economy of countries other than the US and Israel is $13.3 billion, thereof 58% already attained in 2018. Four case studies contributed over 95% of the benefits to the other countries' economy that emerged of the 20 case studies, as detailed below and illustrated in Figure 10:

- Hatchery Spawning, case study 7: Anticipated contribution of $11.6 billion between 1990 – 2028.
- Chicken Feed, case study 4: Anticipated contribution of $617 million between 2009 – 2028.
- Dairy Herd, case study 6: Anticipated contribution of $599 million between 2011 – 2028.
- Magical Nebula, case study 1: Anticipated contribution of $221 million between 2017 – 2028.
- All the other case studies contributed together $248 million.

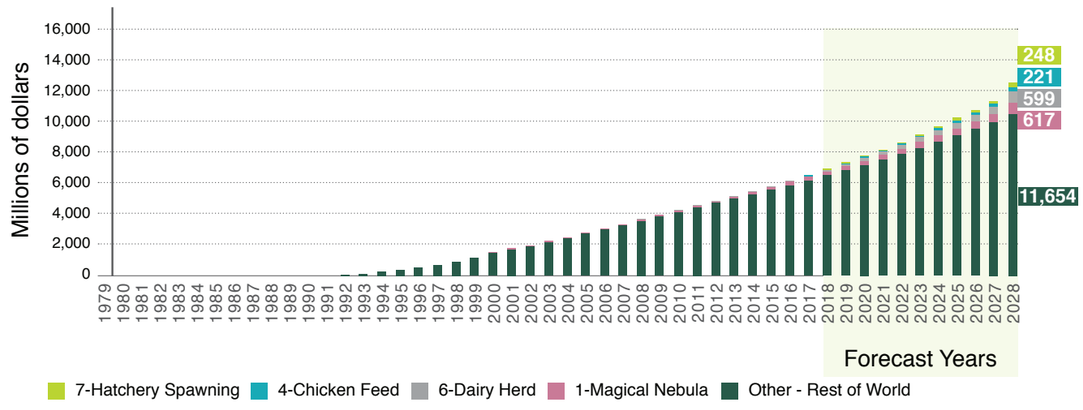


Figure 10: The 4 Main Contributing Projects to the Economy of other countries, cumulative and per project, $ million.

6 | Net Present Value

The Net Present Value (NPV) generated by the 20 case studies is estimated at $16.5 billion. Thereof, a $2.7 billion contribution to the US economy, a $500 million contribution to the Israeli economy and a $13.3 billion contribution to other countries.

These 20 selected case studies account for only a fraction of BARD funded projects. Nonetheless, the direct returns on these selected case studies have well-exceeded the total compounded value of BARD's investment since 1979, which totals $1.06 billion in 2018 dollar-terms. In terms of Benefit-Cost Ratio (BCR), comparing the global benefit generated only by these 20 projects to the total of BARD's research investment yields a BCR of 16.5. This BCR is 60% higher than the median BCR value documented in a recent study that reviews more than 600 agricultural research projects worldwide spanning 50 years of activity[12].

The economic benefit from the full portfolio of BARD's 1,330 awards is undoubtedly greater than that quantified for the 20 case studies. Based on the responses of the broader set of 140 researchers that responded to the survey, we extrapolate to the full BARD portfolio of projects, and estimate that these resulted in the adoption of approximately 200 new agricultural practices, around 40 commercial engagements, and approximately 100 series of patents and breeding rights licenses. Based on this, we assume that additional projects, beyond those included in the case studies, have generated significant economic benefit.

12 Pardey P.G., Chan-Kang C., Dehmer S., Beddow J.M., Hurley T.M., Rao X., and Alston J.M. Investments in and the Economic Returns to Agricultural and Food R&D Worldwide. In: Neal Van Alfen, editor-in-chief. Encyclopedia of Agriculture and Food Systems, Vol. 4, San Diego: Elsevier; 2014. pp. 78-97

6.1 | Applications in the Pipeline

In analyzing the case studies, we find that on average, 15 years are required between the initial investment in a BARD agricultural research study and its first practical application. Accordingly, we assume that only a fraction of the potential applications and benefits stemming from research projects conducted during the last 15 years has been manifest at this point. Our current results, therefore, are by definition an underestimation of the benefit generated by BARD-funded research.

6.2 | Economic Contribution of Capacity Building

The OECD recently conducted a comprehensive economic analysis of higher education in its member countries, analyzing the private and public costs and benefits per person attaining tertiary education[13]. The study calculated the average public and private investment for a single person attaining higher education in the US and Israel at $100,000 and estimated the benefit at $717,000, yielding an estimated BCR of 7, i.e. a sevenfold return on investment. See also an analysis of skills, education, and the rise in earnings among US high school graduates, undergraduates and postgraduates in the period of 1964 – 2012.[14]

Over the past decade, the Australian government has commissioned several studies dealing with evaluations of capacity building in the agriculture sector. These studies indicated for capacity building a BCR between 13 and 28 (Mullen et al[15], Gordon and Chadwick[16]).

We used the OECD values to estimate, as a reference, the benefit of BARD's investment in fellowships and salaries. We applied the BCR of 7. Based on these parameters, we estimated the Net Present Value attributed to BARD's $550 million investment in human resource capacity building at $3 billion, contributed in equal parts to the US and Israeli economies.

13 https://www.oecd-ilibrary.org/docserver/eag-2018-en.pdf?expires=1548334007&id=id&accname=guest&checksum=AF3AF19A76C5A37E485FB0B5C1CE2BB2

14 http://piketty.pse.ens.fr/files/Autor2014.pdf
15 https://www.aciar.gov.au/node/13571
16 https://www.aciar.gov.au/node/8901

7 | Additional Indicators of Impact

From personal interviews with PIs and from survey respondents we learned that BARD occupies a unique position within the competitive grants' environment, making its investments at a critical juncture. BARD funding enabled translational research, positioned at the stage where fundamental research was able to demonstrate a preliminary applicative usage. This critically-timed support allowed many of the research projects to demonstrate proof of concept for an applied outcome, ultimately facilitating commercial interest and investments.

We wish to stress that the economic benefit calculated for this review is only one of many identified long-term benefits of BARD-supported research. Additional benefits, including environmental and social impact, are acknowledged and described in this review, but not quantified economically.

7.1 | Further Funding

Extrapolating from the survey to BARD's full portfolio of projects, we estimate that approximately 500 awards leveraged further funding from other academic funds, and another 170 awards procured further funding from commercial entities.

7.2 | Additional Economic Benefits

Several projects, such as prolonging the quality of tropical foliage for export (case study 11), or the use of a virus as a carrier of genes against the citrus greening disease (case study 16), carry outcomes that have far-reaching state-wide gains in employment, trade and new affiliated industries that are not accounted for in the quantitative analysis. Benefits associated with the establishment of new companies in the US and Israel have not been quantified either. In other cases, benefits can have regional effects, such as the development of all-female prawn (case study 9), which created employment in a geographic periphery region of Israel and increased the retention of academic talent in that particular area.

Some of the innovations have had spill-over effects that have similarly not been quantified. We know that the introgression lines for higher Brix incorporated into commercial tomato varieties by Monsanto/Bayer (case study 2) have been implemented by additional industry players in their tomato breeding programs. Specific details are not available, and the benefits are not accounted for in the analysis. Similarly, the model for improved chicken feed (case study 4) has also been applied in the turkey industry, which was not included in the analysis.

Another factor contributing to conservative estimates of economic benefit has been limited data availability from industry players, such as for the improvements in chicken feed (case study 4), the commercializing of the sweet Nebula tomato (case study 1) and development of mildew-resistant basil lines (case study 17).

Lastly, we have most likely overlooked additional benefits gained from the adoption of improved knowledge-based agricultural practices, such as the post-harvest treatment of mango (case study 13), where dissemination and adoption of technique are more difficult to monitor and gauge.

7.3 | Environmental Benefits

The environmental benefits delivered by the research projects and embedded within the case studies have, for the most part, not been quantified economically. While the reduction in pesticide use was in fact quantified for the power wheat (case study 3), this was done in the context of calculating monetary savings on herbicide use. Overall, the environmental benefits emerging from the case studies are highly prolific and impactful.

Power wheat, the greenhouse robotic system, the use of a virus as a carrier of genes against the citrus greening disease, use of Trichoderma and additional biocontrol agents (case studies 3, 20, 16, 14, and 12, respectively) all contribute to reduction of pesticide use.

Sludge treatment (case study 19) directly reduces the detrimental environmental impact of aquaculture waste products from land-based aquaculture, and self-generates energy.

Fish spawning in captivity (case study 7) eliminated the bottleneck for conducting aquaculture in captivity, directly led to conservation of overexploited marine species, and provided an applied tool for gene rescue and population amplification of threatened and endangered fish species.

The implemented chicken feed software (case study 4) and in-ovo feeding (case study 8) play a crucial role in lowering Feed Conversion Ratios (FCR), thereby delivering a positive environmental impact.

It is likely that many more of the diverse projects across all BARD panels have had direct and indirect positive impact on the environment.

7.4 | Social Benefits and Food Security

The research projects leading to increased crop and animal productivity all contribute to global food security. We specifically note the three aquaculture projects on monosex prawns, hatchery spawning and treatment of land-based aquaculture waste (case studies 9, 7 and 19, respectively) as having led to increased global protein availability and animal productivity with a relatively low FCR.

Power wheat (case study 3) has already impacted grain availability in India, where the new varieties are being grown on an area comparable in size to the growing areas in all the US and Europe, and is likely to increase further in coming years.

Identifying the Tilapia Lake Virus (case study 10) has mobilized global organizations such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) to provide management tools and research objectives towards diminishing the potentially extensive negative impact of the virus on global food security as well as the nutrition and livelihood of countless small stakeholders.

The potential use in African rivers of all-male prawns (case study 9) as a biocontrol agent for freshwater snails which host the parasitic worm that causes Schistosomiasis (Bilharzia) could dramatically reduce the burden of disease in African countries.

7.5 | Academic Impact and Capacity Building

The 1,330 grants funded by BARD have generated more than 5,600 published manuscripts, serving as another important vehicle for increasing the academic impact by disseminating the knowledge BARD has facilitated.

Based on the survey results, we estimate some 3,300 students have been involved in BARD research projects to date. At least 1,200 of them later held academic positions, and 600 were employed in Agri- and Bio- industries.

In many instances, the collaboration between US and Israeli PIs extended far beyond the scope of the initial research, continuing throughout their academic careers and those of their respective students to create a ripple effect and widen BARD's circles of impact. Funding within the BARD award has often facilitated student exchange between the PIs, thereby broadening the reach of impact and contributing to capacity building of the younger generation of researchers.

Additionally, many technicians, staff members and in many cases undergraduate students took part in the research projects, each carrying their experience onwards into their respective fields.

3% of BARD's research budget was allocated to financing international travel for the investigators. This is an integral part of the investment and serves as a measure of the scientific exchange between US and Israeli investigators, while reflecting BARD's commitment to achieving the maximal benefits of cross-pollination of ideas and knowledge.

Of the PIs engaged in the 20 selected case studies, 4 had received BARD postdoctoral fellowships at notably early stages of their scientific careers.

7.6 | Stakeholders Collaboration

Of the 20 case studies, 5 projects engaged with farmer organizations and cooperatives already during the research stage in order to provide a solution to a particular farming sector, and 4 worked closely with governmental entities. Another 7 attained commercialization through existing companies, and 6 led to the establishment of new companies. Of these, 5 were founded by the BARD researchers, together with 3 co-founders that were the Ph.D. researchers on the BARD awards. Three of the new companies were later integrated into leading international corporations.

8 | Conclusions: Insights on BARD's Impact as Derived from the Evaluation

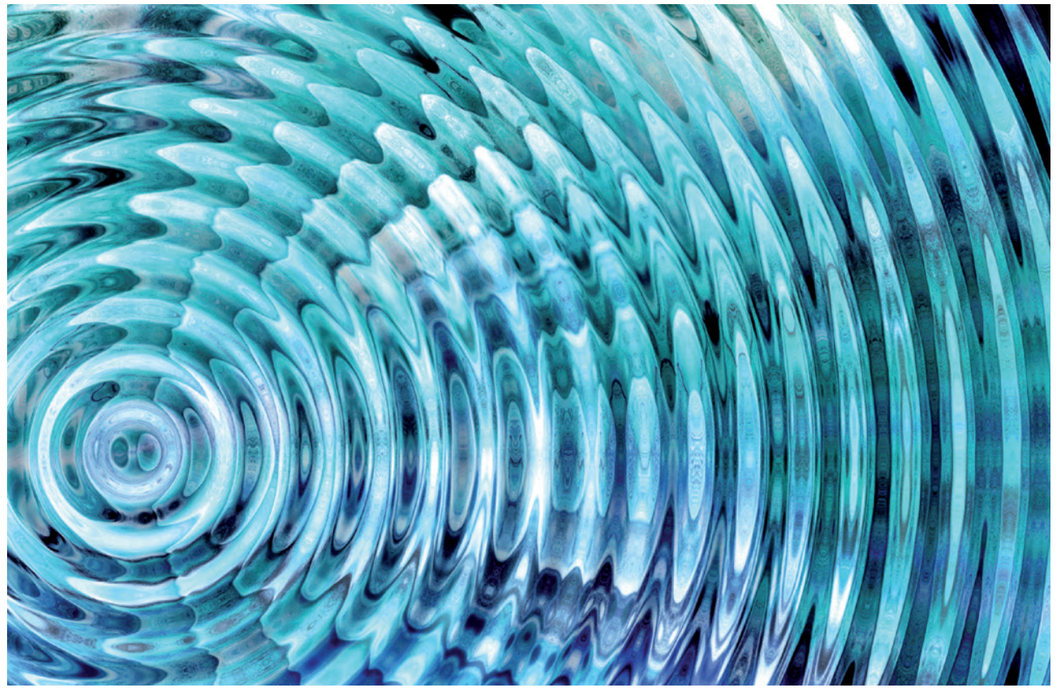
Over 40 years of BARD activities, the number of researchers receiving awards grew to 910 US and 630 Israeli researchers from state universities, land-grant colleges, government research institutes (USDA-ARS and ARO), as well as other private and public non-profit research institutions. These scientists and institutions benefited from collaborative US-Israeli research encompassing the array of agricultural research disciplines covered by the BARD topic panels. Of these researchers, over 80% continued to collaborate with their co-investigators after the termination of the award, both via additional BARD awards as well as by external leveraged funding. BARD awards have thus led to the forging of strong ties and a network of collaborative research spanning between researchers at the top institutions across 47 US states and Israel that has proliferated and borne fruit well beyond a single granted award.

While the immediate stakeholder of BARD-funded research is the scientific community, a large portion of awarded researchers engaged with stakeholders beyond the academic sphere, expanding the circle of BARD's impact to industry, government, farmers, venture capital funds and non-government organizations. An array of practical agricultural applications emerged following these engagements, and the positive impact of the collaborative research is revealed both by the significant scientific advances, as well as these practical applications that have benefited the US, Israeli and global economies and societies.

Scientific advances, collaborations and novel agricultural practices have emerged also from the subsequent accomplishments of the thousands of graduate students and postdoctoral fellows who took part in the research funded by BARD awards over the years. More than half of the engaged researchers continued to hold positions in academia and agricultural-biological industries, providing a foundation for advances and productivity both in academic as well as industry settings. The case studies demonstrated the instrumental role some of these students had in the transformation of the scientific advances to practical innovations, as well as the foundational role the BARD-funded research had in their subsequent research advances, and in the diffusion of the gained knowledge amongst the broader scientific communities as well as additional stakeholders. Moreover, a number of principal investigators of the selected case studies received dedicated BARD postdoctoral fellowships at early stages of their careers that crucially contributed to their research development and direction and to the ensuing innovations that came later in their career.

The quantitative benefits attributed to the 20 selected case studies reveal that BARD has, at a minimum, generated an economic benefit of $2.7 billion to the US economy, $0.5 billion to that of Israel, and another $13.3 billion globally. The economic benefits yield a Cost-Benefit Ratio of 16.5, meaning a $16.5 return on every dollar of the total BARD investment of $1.06 billion (all monetary values are expressed in 2018 dollar-terms). As discussed in the evaluation report, this is undoubtedly an underestimate, as it focuses on selected case studies only, constituting <5% of the total number of awards.

The positive impact derived from the fruition of the collaborative research of the BARD-funded projects extends to a wide range of environmental and social benefits that are not quantified in monetary terms in this evaluation. These range from increasing global protein availability at a competitively affordable cost to potentially lessening the burden of waterborne diseases in developing nations and



creating employment through new industries. More than half the case studies demonstrate significant environmental impact such as reductions in the use of chemical pesticides energy generation, as well as species conservation. Monetary benefits of BARD have been extended both to the US and Israel, as well as to many additional countries worldwide. In today's world, where food safety and security are pressing global issues and sustainability for future generations is often a driver for advances and progress, the diffusion of BARD's impact beyond the borders of the US and Israel to global communities and organizations provides further testimony to the positive impact of the program and its ability to meet the challenges facing society in the modern world.

9 | Committee Recommendations

1 Due to BARD's successful academic and economic achievements, it is evident that the criteria used by BARD for selection of most projects are thorough. A recent emphasis on "anticipated benefit to agriculture and the environment" was also implemented and was adopted by review panels and TAC members to highlight those projects that were directly relevant to agricultural practice. It is recommended that the selection of fundable proposals continues to be based on scientific merit, the benefit to agriculture and the environment of both countries, as well as the the potential of fruitful collaboration and probability of success.

2 The cost of conducting research in both Israel and the US has increased considerably compared to its cost 40 years ago. Yet, BARD, which relies heavily on its well-managed endowment, has not received significant increases in its annual budget. Unlike most other granting agencies, BARD has not adjusted its award level for the last 35 years: BARD grants are still $310,000 per 3 years, shared by both US and Israeli partners.

There is urgent need to seek a solution that does not significantly reduce BARD's admirable rate of funding. It is recommended that BARD prioritize securing additional/supplemental funds to cover deviations such as the increase in research costs and the decline in purchasing power. It is recommended that BARD's board of directors propose options and devise strategies for augmenting disposable funds to bring annual funding close to $20 million annually ($13 million in addition to the existing $7.1 million which comes from interest on the endowment). It is suggested that the board of directors form an advocacy committee of consultants that will focus on increasing funds for US-Israel Agricultural Research and Development activities.

The initial target should be an increase in average award value of $150,000 for each partner, or an approximate doubling of the average award amount. There should also be an effort to increase the number of fellowships for postdoctoral students, as well as workshops and administrative overheads. BARD's operations are managed very efficiently (see recommendation 8), so there is little room for creating additional research through cost cutting. Rather, the net available funds for BARD should be increased.

The evaluation of the economically beneficial projects in this 40-year report showed that to make a substantial impact, a researcher must receive more than one award. Moreover, the evaluation showed that it takes an average of 15 years to develop an innovative idea from seed to a product that can benefit agriculture. Successful projects had to compete and secure funding in subsequent rounds in order to obtain sufficient resources. It is recommended that the board of directors consider extending the research projects up to 5 years to allow some projects sufficient time to carry out the research and achieve higher accomplishments.

3 In this respect, it is recommended to expand the "B-Lever" (academia-to-industry) funding track of proposal applications and to encourage companies and commercial entities to be involved in the early research stages, thus allowing focus of some research objectives to meet the market needs.

4 A large proportion of the approved expenditure in BARD grants is currently allocated to salaries, supplies and overhead, but not to equipment. It is recommended that when budget permits, application for support equipment purchasing will be permitted together or separately from the grant application.

5 The committee was concerned about gender imbalance. However, the ratio of projects awarded to the total submissions among women was identical (even slightly higher) to that among men (Appendices C and D, available online on BARD's website). It is recommended that BARD should continue to carefully monitor this issue.

6 The committee recommended that BARD should generate a scientific publication to describe the findings from its 40-year evaluation process, preferably in a highly ranked journal.

7 It was noted that the electronic submission and reporting procedures that were recommended by the 20-year review committee were adopted. Also, the final report format was improved accordingly. However, the submission deadline for the final report is usually too early in the project to allow recording of true outputs and outcomes. A supplementary report from completed projects can assess the scientific merit. It is recommended that BARD will further improve its follow-up (publications and patents) to update the outcomes arising from completed projects. BARD is encouraged to introduce automated updating of information to its current electronic reporting system. These will enhance the evaluation of the fund at any future time.

8 The steering committee commends the current and prior program staff for their excellent, efficient and effective administration of the program.

10 | List of Figures

11 | List of Tables

12 | Abbreviations

USDA-APHIS	Animal and Plant Health Inspection Service, United States Department of Agriculture
USDA-ARS	Agricultural Research Service, United States Department of Agriculture
ARO	Agricultural Research Organization, Volcani Center, Ministry of Agriculture and Rural Development (Israel)
BARD	United States – Israel Binational Agricultural Research and Development Fund
BCR	Benefit-Cost Ratio
BGU	Ben Gurion University (Israel)
BIRD	Israel – US Binational Industrial Research and Development
BSF	US – Israel Binational Science Foundation
Committee	BARD External 40 Year Review Steering Committee
CPI	Consumer Price Index
FAO	Food and Agriculture Organization of the United Nations
FCR	Feed Conversion Ratio
GDP	Gross Domestic Product
HUJI	The Hebrew University of Jerusalem (Israel)
IRR	Internal Rate of Return
LIBOR	The London Inter-bank Offered Rate
MARD	Multinational Agricultural R&D
MIF	Ministry of Finance (Israel)
NIFA USDA NIFA AFRI	National Institute of Food and Agriculture Agriculture and Food Research Initiative
NPV	Net Present Value
NSF	National Science Foundation (US)
OECD	The Organization for Economic Cooperation and Development
PI, Co-PI	Principal Investigator, Co-Principal Investigator in BARD Collaborative Research Projects
RIA/ ARIA	Research Impact Assessment / Agricultural Research Impact Assessment
TAC	BARD's Technical Advisory Committee
TAU	Tel Aviv University (Israel)
WHO	World Health Organization of the United Nations

Appendix 1:

Summaries of the 20 Case Studies

The summaries of the 20 case studies are presented below. The detailed analysis of each project appears in the Evaluation Compendium available for further reading on BARD's website.

Case Study 1: Magical Nebula: A New Sweet Snack Tomato

Principal Investigators: IS: Ari Schaffer, (Agricultural Research Organization, Volcani Center); US: Mason Pharr (North Carolina State University), Alan Bennett (University of California, Davis)

Goal: To generate a superior tasting tomato through natural genetic manipulation.

Activities: The genetic and biochemical basis for sucrose accumulation was studied first in melons and then in wild tomatoes. Genes that determine greater sucrose and fructose content in wild tomatoes were successfully transferred to domestic cultivars through breeding in order to produce sweeter tasting tomatoes.

Outcomes: Subsequent R&D was carried out in conjunction with Zeraim Gedera, later bought by Syngenta. The first of 5 planned commercial varieties is the Nebula cherry snack tomato that entered the market in 2015 and is now grown in Europe, Canada and California.

Economic Benefit: Net Present Value of BARD's investment is $220 million, thereof $24 million already attained. The Internal Rate of Return is 16%. Benefit-Cost Ratio is 47, thereof 6 already attained.

Capacity Building: At least 12 postgraduates were involved in the research supported by 5 BARD awards between 1987 and 1997. Currently, 7 of these are in academia in the US, Israel and China; 3 are in the biotechnology industry and another 1 at the Israeli Ministry of Agriculture.

Case Study 2: Brix Quantitative Trait Loci for Processing Tomatoes

Principal Investigators: US: Steve Tanksley (Cornell University); IS: Dani Zamir (Hebrew University of Jerusalem)

Goal: To discover QTL (quantitative trait loci) alleles associated with soluble solid content (TSS) in wild tomatoes and transfer them to elite processing cultivars. Higher TSS results in a higher utilization of the tomato (more kg of paste per ton) for the processor.

Activities: Chromosome segments of the wild tomato *l. Penelli* introgressed with the cultivated tomato enabled the mapping of 23 QTLs that increased Brix, a measure of TSS. The line with the highest increase in TSS (fructose and glucose) with no negative effects on yields was identified.

Outcomes: The high Brix line was incorporated into breeding programs for processing tomatoes at A.B. Seeds, later bought by Monsanto/Bayer. These varieties today comprise ~ 80% of the "thin viscosity" segment of processing tomatoes in California.

Economic Benefit: Net Present Value of BARD's investment is $261 million, thereof $166 million already attained. The Internal Rate of Return is 28%. Benefit-Cost Ratio is 74, thereof 48 already attained.

Capacity Building: 5 postgraduates were involved in the research supported by the 2 BARD awards between 1995 and 2002. Currently, all 5 hold academic positions, 4 in Israel and 1 in the US.

Case Study 3: Power Wheat: Genes for Improvement of Modern Wheat

Principal Investigators: US: Jorge Dubcovsky (The University of California Davis); IS: Tzion Fahima (University of Haifa)

Goal: To identify genes that increase grain protein content, micronutrients and stripe rust resistance in wild emmer wheat and to transfer them to commercial varieties.

Activities: Successful cloning and breeding programs led to high protein wheat varieties without loss of yield and wheat varieties introgressed with two stripe rust resistant genes.

Outcomes: Genetic maps, DNA markers and gene sequences were made publicly available and germplasm has been shared with wheat researchers all over the world. In the US and Canada, between 2013 – 2018, commercial introgressed cultivars were grown on ~ 110,000 hectares and a similar acreage was grown in India in 2018. To date, all wheat in California is grown without fungicides thanks to the incorporation of these genes.

Economic Benefit: The Net Present Value of BARD's investment is estimated at $118 million, thereof $20 million already attained. Internal Rate of Return is 32%. Benefit-Cost Ratio is 50, thereof 9 already attained.

Capacity Building: 20 postgraduates were involved in the research supported by the 5 BARD awards between 2001 and 2016. Currently, at least 10 of these are in academia in the US, Israel, China, Argentina and the UK, and 1 is in the biotechnology industry.

Case Study 4: Improved Feed Efficiency in Chickens

Principal Investigators: US: John. P. McMurtry (USDA-ARS); IS: Shmuel Hurwitz (Agricultural Research Organization, Volcani Center)

Goal: To improve feed efficiency and carcass quality in broiler production and to develop a mathematical model to simulate and determine the optimal daily feed intake.

Activities: Feeding models that optimized broilers' feed intake and monitored the Food Conversion Ratio (FCR) were developed and tested.

Outcomes: It was shown that birds subjected to feed restrictions early in life exhibited "compensatory growth" and surpassed the final weight of unrestricted birds whilst also decreasing their FCR. An algorithm named ChickOpt (Chicken Optimization), which simulates the broiler growing curve and yields an economically optimal feeding regime, has been incorporated into a commercial software package and is implemented in more than 130 countries.

Economic Benefit: Net Present Value of BARD's investment is $788 million, thereof $382 million already attained. The Internal Rate of Return is 28%. Benefit-Cost Ratio is 410, thereof 199 already attained.

Capacity Building: 2 postgraduates were involved in the research supported by the 2 BARD awards between 1984 and 1990. One is currently working in the broiler industry.

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Case Study 5: Increased Prolificacy in Domestic Sheep

Principal Investigators: IS: Elisha Gootwine (Agricultural Research Organization, Volcani Center); US: Dave Thompson (University of Wisconsin-Madison)

Goal: To increase prolificacy and lamb production in domestic sheep breeds.

Activities: Introgression of the Booroola sheep fecundity mutation by crossbreeding to the Awassi and the Assaf breeds in Israel and the Rambouillet breed in the US.

Outcomes: Introgression resulted in two new prolific strains, the Afec Awassi and the Afec Assaf. With an average annual increase of 0.6 live births per ewe, the Afec Awassi has been successfully integrated into the Bedouin sector under intensive management. This has led to improvements in flock productivity and economic gains, as well as additional social benefits to the community such as increased literacy through documentation and tighter collaboration with veterinary services.

Economic Benefit: Net Present Value of BARD's investment is estimated at $204 million, thereof $76 million already attained. Internal Rate of Return is 18%. Benefit-Cost Ratio is 65, thereof 25 already attained.

Capacity Building: 4 postgraduates were involved in the research projects supported by the 3 BARD awards between 1985 and 1993. Currently, 3 of them hold research positions in US academia and agricultural research stations.

Case Study 6: Genetic Improvement of Economic Traits in Dairy Cattle

Principal Investigators: IS: Joel Weller (Agricultural Research Organization, Volcani Center); US: Daniel Gianola (University of Illinois), George Wiggans (USDA ARS), Ignacy Misztal (University of Georgia)

Goal: To map quantitative trait loci (QTL) that affect traits of economic importance in dairy cattle, such as milk, fat and protein production, by means of genetic markers. The aim was to introduce the genetic information into cattle breeding selection schemes.

Activities: Novel designs to identify QTL-marker linkages for genes with relatively small quantitative effects were developed using genotypes and phenotypes of sire and offspring. The research led to the understanding that genetic improvement can be enhanced through genomic selection using genetic markers covering the whole genome, a methodology made possible by the advent of SNP (Single Nucleotide Polymorphisms) arrays and adoption of genomic evaluation in the US and Israel since 2009 and 2015, respectively.

Outcomes: Genomic evaluation has increased rates of genetic improvement of over 30 major traits included in the dairy cattle selection indices. The annual milk gain has increased twofold.

Economic Benefit: The attribution to BARD is based on the degree to which the genomic selection technique was expedited due to the research outcomes. Collection of DNA from all bulls in the US and Canada was evaluated as hastening genomic implementation by one year. The experience with marker assisted selection advanced the statistical methods used for genomics by 6 months. Based on these 2 outcomes, the benefits attained to date were reached 1.5 years earlier than a counterfactual scenario without BARD. This part of the total Net Present Value of the benefits was attributed to BARD.
Net Present Value of BARD's investment is estimated at $1,135 million, thereof $248 million already attained. Internal Rate of Return is 25%. Benefit-Cost Ratio is 264, thereof 59 already attained.

Capacity Building: 18 postgraduates were involved in the research supported by the 6 BARD awards between 1985 and 2018. Currently, 5 of them have academic positions, 3 in Israel and 2 in the US. Another 1 is in the biotech industry.

Case Study 7: Full Life-Cycle Hatchery-Based Aquaculture

Principal Investigators: US: Robert Langer (Massachusetts Institute of Technology), Martin P. Schreibman (Brooklyn College); IS: Yonatan Zohar (then Isr. Ocean Res., now at University of Maryland), Yitzhak Koch (Weizmann Institute of Science)

Goal: To establish tools to control fish reproductive processes and their timing in captivity, and to acquire high-quality gametes (i.e. eggs and sperm) and seeds (i.e. fertilized eggs and larvae) for grow-out to the marketable product.

Activities: Investigation of GnRH regulation and receptor affinity and additional neuropeptides involved in sexual maturation, ovulation and spawning.
Optimization of sustained release delivery systems for GnRH analogs. Development of techniques for early onset of puberty in fish.

Outcomes: The polymer-based GnRH delivery systems have provided the global aquaculture industry with a tool to induce fish to spawn in captivity, enabling the rapid development of fish farming that did not exist before. The technique is used in fish hatcheries around the world to induce spawning and egg/juvenile production in scores of fish species (salmon, sea bass and recently bluefin tuna). Full cycle farming in captivity both provides a protein source for the world population and also enhances conservation of overexploited marine species. The technique is an applied tool for gene rescue and population amplification of threatened and endangered species.

Economic Benefit: Net Present Value of BARD's investment is $12,000 million, thereof $7,500 million already attained. The Internal Rate of Return is 143%. Benefit Cost Ratio is 5,800, thereof 3,600 already attained.

Capacity Building: 3 postgraduates were involved in the research. 1 currently holds an academic position in Greece.

Case Study 8: In-Ovo Feeding: Jump-Starting the Development of the Chick

Principal Investigators: US: Peter R. Ferket (North Carolina State University), Eric. A Wong (Virginia Polytechnic Institute and State University); IS: Zehava Uni (Hebrew University of Jerusalem)

Goal: To determine the effect of in-ovo feeding (feeding to the embryo) on growth performance and economically valuable production traits of broiler and turkey flocks.

Activities: The research demonstrated that supplementing the chick embryo amnion with carbohydrates and amino acids enhances neonatal development. The role of the yolk sac in the mediation and transport of nutrients to the embryo for optimal development was studied as were in-ovo feed ingredients (nutrients and probiotics) that upregulate the number of cells expressing nutrient transporters.

Outcomes: A new science of neonatal chick nutrition was established. More than 15 research groups in industry and academia now use the in-ovo feeding concept. Research groups around the world have continued to study feed and stimulant injection of nutrients and biologics (immunostimulants, antibodies, live beneficial bacteria, prebiotics) and have shown many positive outcomes such as faster growth and higher final weights, enhanced expression of nutrient transporters, support of bone development, advanced intestine development and digestive capacity and improved chick health.

Economic Benefit: The method has not yet been commercialized by the poultry industry and we have not included an economic benefit analysis.
Some barriers to adoption are now being overcome and we anticipate a high probability of commercial implementation.

Capacity Building: At least 5 postgraduates were involved in the research. Currently, 1 is in academia in the US, another 1 holds a research position in the USDA-ARS working on human nutrition for at-risk populations, and 3 work in Agri/Biotech industries in Israel.

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Case Study 9: Monosex Prawns: Exploiting Androgenic Gland Function for Sex Reversal

Principal Investigators: IS: Amir Sagi (Ben Gurion University of the Negev); AUS: Abigail Elizur Dept. of Ag. & Fisheries. Queensland; US: JimShao Jun Du (University of Maryland)

Goal: To develop a monosex culture for crustacean aquaculture, specifically for the commercially important giant freshwater prawn, *Macrobrachium Rosenbergii*, and to improve production efficiencies.

Activities: cDNA libraries of the insulin-like AG gene (IAG), responsible for male sexual differentiation, were compiled. The first application of RNAi (gene silencing) in the field of aquaculture was applied to induce functional sex reversal.

Outcomes: The induction of sexual reversal was translated into agro-biotechnologies for monosex culture of prawns supporting higher yields around the world with two Israeli companies providing the seed for all-male culture (Tiran Group) and all-female technologies (the startup company Enzootic).

Economic Benefit: Net Present Value of BARD's investment is $38 million, thereof $4 million already attained. The Internal Rate of Return is 21%. Benefit-Cost Ratio is 51, thereof 6 already attained.

Capacity Building: 7 postgraduates students were involved in Israel in the research supported by the 2 BARD awards between 2006 and 2015. Currently, 3 of them have academic positions in Israel and 1 in Australia, 2 are in algae and pharmaceutical industries, and another 1 is a patent attorney.

Case Study 10: Tilapia Lake Virus: A Threat to the Global Tilapia Industry

Principal Investigators: US: W. Ian Lipkin (Columbia University); IS: Eran Bacharach (Tel Aviv University)

Goal: To identify the causal agent of a disease-causing mortality to Tilapia fish in Israel that was not identified as any known parasites, bacteria, viral pathogens or toxins.

Activities: Isolation and identification of a novel viral agent, Tilapia Lake Virus (TiLV), as the disease agent. Genomic sequencing of TiLV and development of a diagnostic assay for TiLV detection.

Outcomes: TiLV has since been identified around the globe. As food security of millions of people depends on Tilapia farming in developing countries, the World Organization for Animal Health (OiE) and the Food and Agriculture Organization (FAO) have initiated dissemination of information, promoted diagnostics and are assessing procedures for disease containment. The intellectual property (IP) has been licensed to one of the large international companies for their development of an inactivated virus against TiLV.

Economic Benefit: Net Present Value of BARD's investment is $46 million, thereof $1 million already attained. The Internal Rate of Return is 83%. Benefit-Cost Ratio is 91, thereof 3 already attained.

Capacity Building: 1 postdoctoral researcher, 2 graduate students, and 1 pre-graduate trainee were involved in the research supported by the 2 BARD awards between 2013 and 2019. Currently, 1 is in academia, 1 has progressed to a post-doctorate fellowship and 2 are conducting graduate studies.

Case Study 11: Prolonging the Quality of Ornamental Foliage Plants

Principal Investigators: US: C. A. Conover, Richard T. Poole (University of Florida); IS: Jaacov Ben-Jaacov (Agricultural Research Organization, Volcani Center)

Goal: To determine the environmental conditions for maintaining quality of foliage potted plants during long distance shipping and storage.

Activities: Laboratory and simulated shipping experiments to determine the effects of temperature, soil mixes, humidity and phytohormones on several genera of foliage plants during dark storage.

Outcomes: The initiation of shipping transportation of foliage (and later flowering) potted plants to Europe. An immediate growth in the tropical foliage plants industry in Florida (also creating job opportunities) followed upon the large increase in shipped exports and development of the international market for foliage potted plants. The success later decreased as other international competitors entered the market and shipments from the US declined.

Economic Benefit: Net Present Value of BARD's investment is $119 million, and it has already been attained. The Internal Rate of Return is 89%. Benefit-Cost Ratio is 90 and it has already been attained.

Capacity Building: Due to the early date of this BARD award, we are not able to provide information on the students involved in this research project.

Case Study 12: Biocontrol Agents for Pre and Post-Harvest

Principal Investigators: US: Michael Wisniewski (USDA-ARS); IS: Samir Droby (Agricultural Research Organization, Volcani Center)

Goal: To identify yeast antagonists effective against pre and post-harvest pathogens and to develop biocontrol agents.

Activities: Isolation and screening of new biological control antagonists found on fruit surfaces. Identification of molecular traits and research on additives to enhance performance of yeast biocontrol agents.

Outcomes: Two identified yeast antagonists were the base for 2 commercial biocontrol products, one of which was the very first ever commercial biological control product (AspireTM), based on the yeast *Candida oleophila*. This yeast is now the base of a Syngenta biocontrol product that provides protection of banana crops worldwide. The second identified yeast, *M. Fructicola*, has been licensed by Koppert Biologicals and has just received EU permits for application on grapes, strawberries and stone fruit.

Economic Benefit: Net Present Value of BARD's investment is $12 million. The Internal Rate of Return is 9%. Benefit-Cost Ratio is 4, thereof already attained 0.

Capacity Building: At least 2 postdoctoral and 7 graduate students were involved in the research supported by the 5 BARD awards between 1985 and 2003. Currently 3 are in academia, of which 2 in Turkey and 1 in Italy; 4 are in industry, 1 is a teacher and 1 works at the Israeli Ministry of Agriculture's Extension Services.

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Case Study 13: Mango Treatment: Extending Shelf Life Using Fewer Chemicals

Principal Investigators: IS: Dov Prusky, (Agricultural Research Organization, Volcani Center); US: Jeffrey Rollins (University of Florida), Lisa Vaillancourt (University of Kentucky), Tesfaya Mengiste (Purdue University)

Goal: To develop methodologies to reduce post-harvest loss of mango fruit by fungal pathogens.

Activities: The researchers discovered that the fungi pathogenicity was modulated by the pH levels of the fruit, and that pH changes were induced by the pathogen itself.

Outcomes: A post-harvest acid-prochloraz treatment of mango fruit was established that modifies the pH of the fruit environment and inhibits fungal colonization. The treatment reduced fruit loss from Alternaria fungi by several percent and improves safety by reducing the concentration of prochloraz applied as a post-harvest fungicide. The treatment has been adopted in Israel and in Northern Sinaloa, Mexico.

Economic Benefit: Net Present Value of BARD's investment is $54 million, thereof $26 million already attained. The Internal Rate of Return is 21%. Benefit-Cost Ratio is 17, thereof 9 already attained.

Capacity Building: At least 9 postgraduates were involved in the research supported by the 5 BARD awards between 1995 and 2014. Currently, 3 of these are in academia in the US and Israel, 1 is in medical research, 3 are in the agritech industry and another 1 at the Standards Institution of Israel.

Case Study 14: Trichoderma: A Potent Fungus as Biological Control Agent

Principal Investigators: US: Gary Harman (Cornell University); IS: Ilan Chet (Hebrew University of Jerusalem)

Goal: To control pathogenic fungi in field crops through root colonization by Trichoderma, an endophytic fungus. The role of Trichoderma in inducing multiple benefits to plants, such as root growth promotion, resistance to abiotic stress and increased nitrogen use efficacy was also examined.

Activities: Protoplast fusion was conducted to obtain highly rhizosphere competent Trichoderma strains that are effective against pathogens and promote plant growth. Strongly antifungal enzymes generated by Trichoderma were identified and isolated. Gene expression studies were conducted to elucidate the plants' systemic changes leading to enhanced productivity and resilience.

Outcomes: Two commercial companies were established based on the research results. BioWorks produces Trichoderma products for biocontrol of root disease for greenhouse (ornamental) and vegetable crops. Advanced Biological Marketing (ABM) produces and markets mixes of proprietary strains of Trichoderma as root and soil inoculants and biostimulators for wheat, corn, cotton, soy and vegetables.

Economic Benefit: Net Present Value of BARD's investment is $647 million, thereof $190 million already attained. The Internal Rate of Return is 17%. Benefit Cost Ratio is 85, thereof 26 already attained.

Capacity Building: 7 postgraduates were involved in the research supported by the 8 BARD awards between 1981 and 2007. Currently, 4 of these are in academia in the US, Israel and Taiwan; 2 are in the biotechnology industry, 1 in Israel and 1 in the US.

Case Study 15: Bumblebees for Crop Pollination: Social Behavior

Principal Investigators: US: Gene Robinson (University of Illinois); IS: Avraham Hefetz (Tel Aviv University)

Goal: To understand the colony development, social behavior and reproduction of the *Bombus Terrestris* (buff-tailed bumblebee) and to implement the findings of the basic research into successful rearing of the *B. Terrestris* for industrial crop pollination.

Activities: The key biological functions of the *B. Terrestris* with respect to colony growth and social behavior; e.g. worker bee reproduction regulation, queen dominance and development from larvae to adult were investigated.

Outcomes: The understanding of the biology and social behavior of the *B. Terrestris* paved the way to facilitate colony manipulation for year-round and specific pollination requirements. Israel was the fourth country (after Belgium, Holland and Canada) to commercially use bumblebees for tomato pollination. It leads to higher fruit quality and increased total yield, reduces costs in comparison to manual labor, and necessitates reduction in pesticides application. Today, commercial greenhouse tomatoes are pollinated worldwide by bumblebees, including most European countries, North America, Chile, several Asian countries such as Japan, South Korea and China, and also Turkey.

Economic Benefit: The contribution of the project to crop pollination is indirect and difficult to estimate. Therefore, we did not attribute any monetary benefit to BARD.

Capacity Building: 3 postgraduates and a number of graduate students were involved in the research. Currently, 2 are in academia, 1 in the US and 1 in Israel; another 1 established a bumblebee rearing and research facility.

Case Study 16: Creation of a Transient Expression Vector for Citrus: An Effective Immunity against Citrus Greening

Principal Investigators: US: William Dawson (University of Florida); IS: Moshe Bar-Joseph (Agricultural Research Organization, Volcani Center)

Goal: To manipulate the Citrus tristeza virus (CTV) genome for transient expression of foreign genes in citrus trees.

Activities: A manipulatable genetic system with the full-length cDNA copy of the CTV genome was created. The most successful CTV vectors were shown to be unusually stable and suitable for long-lived woody trees. The CTV expression vector was used to test efficacy of antimicrobial peptides against citrus greening.

Outcomes: The IP was licensed to Southern Gardens Citrus who are using the CTV vector to express one or more spinach defensin genes that have been shown to induce resistance to citrus greening. Efficacy trials were conducted over 10 years in which young citrus trees were inoculated with CTV. A regulatory permit is currently being evaluated by the USDA. The CTV expression vector is at the core of 7 USDA research projects.

Economic Benefit: As the USDA APHIS multisite permit for use of the CTV vector with the defensin gene is still pending, we did not calculate any benefits to this project yet. However, Florida's citrus industry has been devastated by citrus greening, with damage costs estimated at $658 million annually and the potential benefits of using the CTV vector to lessen the impacts of the disease could be immense.

Capacity Building: 11 postgraduates were involved in the research supported by the 4 BARD awards between 1994 and 2006. Currently, 8 are in academia in Israel, the US, Spain and Uruguay. 1 established a biotech company, 1 is in the biological industry in Russia and 1 is in government service in Israel.

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Case Study 17: Basil Lines Highly Resistant to Downy Mildew

Principal Investigators: IS: Yigal Cohen (Bar-Ilan University); US: James Simon (Rutgers University)

Goal: To develop basil strains that would be resistant to downy mildew, a disease prevalent since the last decade in epidemic proportions both in the field and in greenhouses and constituting a threat to the US and Israeli basil industry.

Activities: Domestic and wild basil accessions from around the world were screened for resistance to downy mildew. Introgression between resistant lines and sweet basil have created partially (from domesticated accessions) and fully (from wild accessions) resistant basil varieties. Embryo rescue was employed in the backcrossing breeding to enable the development of fertilized abnormal gametes into plantlets.

Outcomes: Genesis Seeds Ltd. facilitated the breeding program in Israel and began marketing two resistant varieties under the trademark "Prospera®" in 2019. Four commercial varieties that emerged from the US research group are produced and sold since 2018 by VDF Specialty Seeds. Rutgers University is due to release an additional 4 downy mildew resistant basil varieties for consumers and home gardeners.

Economic Benefit: Net Present Value of BARD's investment is $10 million, thereof $0.1 million has already been attained. The Internal Rate of Return is 144%. Benefit-Cost Ratio is 34, thereof 1 has already been attained.

Capacity Building: 5 postgraduates are and have been involved in the research supported by this single BARD award that began in 2016.

Case Study 18: GOSSYM Cotton Model

Principal Investigators: US: Donald Baker (USDA-ARS); IS: Avishalom Marani (Hebrew University of Jerusalem)

Goal: To evaluate the quantitative effects of drought stress on the rate of photosynthesis of cotton plants. To incorporate the information into the process-driven dynamic simulation model, GOSSYM, to aid in cotton crop irrigation management.

Activities: Constants and rate coefficients for processes such as photosynthesis and organ growth were obtained for water stress conditions under closely controlled and monitored environmental conditions. The results were incorporated into the GOSSYM model and validated in field experiments. A second model, Cotton 2K, was later derived from GOSSYM, with adaptations specifically for arid and dry regions.

Outcomes: The GOSSYM model was used in commercial cotton farms in the US between 1984-2008 as a decision support system for determining crop termination, nitrogen utilization, and irrigation practices in efforts to maximize profit, minimize risk and optimize input. In Israel, the full model was not applied but the coefficients derived for the irrigation simulations have been routinely utilized from 1985 until today. Both the GOSSYM and Cotton 2K cotton simulation models are widely used in research programs for testing hypotheses and for providing policy makers with economic and policy decisions (e.g. to assess decline in yields, effects of climate changes, the potential effect of fertilizer replacements, changes in drainage patterns, and assessing precision agriculture and integration of sensor data with models).

Economic Benefit: Net Present Value of BARD's investment is $813 million, already attained. The Internal Rate of Return is 98%. Benefit-Cost Ratio is 288, already attained.

Capacity Building: 2 postgraduates were involved in the research supported by the BARD award in 1980. Currently, 1 is in the USDA-ARS – Beltsville, MD., US, and 1 works at the Israel Ministry of Agriculture's Extension Services.

Case Study 19: Marine Aquaculture Solid Waste Treatment

Principal Investigators: US: Kevin Sowers (University of Maryland); IS: Amit Gross (Ben Gurion University of the Negev)

Goal: To develop an integrated aquaculture wastewater treatment system for simultaneous microbial reduction of sludge mass, nitrate/nitrite removal, and biomethane production from varying organic loads throughout the fish growth cycle.

Activities: Laboratory studies to identify a marine methanogenic consortium and system factors influencing methanogenic activity.
Upscaling of laboratory reactors to a semi-commercial marine and brackish recirculating system with integrated modified large volume USAB (Upflow Anaerobic Sludge Blanket) bioreactors fed with saline sludge.

Outcomes: Development of a system that leads to an overall reduction of organic saline waste at inland mariculture farms, generates energy, and consequently leads to an improved system efficiency and a reduction in operating costs.
The first commercial application of a methanogenic consortium, developed by the US PI together with industry partners using the same principles developed in the BARD projects, was established at an inland salmon farm in Norway in 2018 to convert its salmon smolt solid waste into fuel-grade methane.

Economic Benefit: Net Present Value of BARD's investment is $28 million. The Internal Rate of Return is 31%. Benefit-Cost Ratio is 44, thereof 1 already attained.

Capacity Building: 5 graduate students, 8 undergraduates and 1 high school student. 5 are currently in academia, of which 3 in the US, 1 in Israel and 1 in Armenia. Another 6 are in industry, of which 3 in the US and 3 in Israel.

Case study 20: Integrated Robotic System for Stress Detection in Greenhouses

Principal Investigators: US: Shimon Nof (Purdue University), Yang Tao (University of Maryland); IS: Avital Bechar (Agricultural Research Organization, Volcani Center)

Goal: To develop an effective and affordable high frequency and high resolution human robotic integrated (HRI) monitoring and inspection system to detect biotic and abiotic stress in greenhouse environments as soon as they emerge.

Activities: Determination of narrow spectral bands (at wavelengths greater than the visible spectrum) that identify crop disease upon emergence and as it develops (different signatures).
Development of deep-learning algorithms to successfully map the plants stress status. Development of mobile robotic system and arm to successfully navigate within crop rows and access all relevant plant elements (e.g. top and bottom foliage, stem, variable heights and depth).

Outcomes: A human integrated robotic system that will replace manual monitoring for greenhouse crop disease (at this stage including Powdery Mildew, Cucumber Green Mottle Mosaic Virus (CGMMV) and Tomato Spotted Wilt Virus (TSWW)) enabling high resolution, dynamic mapping of the crop area. Early detection will lead to improved crop management (by preventing uncontrolled spreading of stresses causing irreparable damage), support attainment of or exceedance of crop yields and quality targets, enable precise applications of pesticides, nutrients and water and mitigation of crop disease.

Economic Benefit: This unique HRI innovation is in early stages of development and we do not assign monetary value.

Capacity Building: 3 graduate students and 1 postdoctoral researcher are currently involved in the research.