

August 2019

## Basil Lines Highly Resistant to Downy Mildew

### Case Study 17

Research goal	To develop basil lines resistant to basil downy mildew.
Beneficiaries	Farmers, Seed companies.
Activities conducted in order to achieve the objectives	<p>Identification of genes associated with basil downy mildew resistance in wild and domesticated basil accessions.</p> <p>Introgression of these genes to develop basil breeding lines resistant to basil downy mildew. Embryo rescue was implemented for backcrossing between wild accessions and sweet basil.</p> <p>Sequencing of the resistant lines to generate a high-resolution linkage map with desired traits; e.g. resistance, aroma, appearance and essential oil content.</p> <p>Epidemiological studies of basil downy mildew.</p>
Funding	BARD award US-4947-16 R \$300,000; Israeli Plant Production and Marketing Board invested \$100,000. USDA: \$400,000
Publications	6 journal publications.
Students involved	3 M. Sc students, 1Ph.D and one post-doctoral fellow.
Stakeholders' collaboration	Ministry of Agriculture Extension Services; Rutgers Agricultural Experimental Station
Environmental impact	Reduction in fungicide applications
Social impact	None
Commercial engagement	Genesis Seeds, IL; Van Drunen Farms.
Patents	<p>WIPO Application No. PCT/IL2018/050048</p> <p>Prospera F1® is a trademark protected by the CPVO (Community Plant Variety Office), the European agency for the protection of plant patents where it is registered.</p>
Practical agricultural applications	Basil hybrids resistant to downy mildew and fusarium have entered the US, European and Israeli markets.
Economic impact	<p>Net present value of the BARD's investment is \$10 million, thereof \$0.2 million has already been attained.</p> <p>The Internal rate of return is 144%.</p> <p>Benefit cost ratio is 34, thereof 2 already attained.</p>

## 1 Objective: Basil Lines Resistant to Basil Downy Mildew

Basil is one of the most economically important and widely grown herbs in the world. Basil downy mildew, caused by *Peronospora belbahrii*, has become a major disease in sweet basil (*Ocimum basilicum*) production worldwide in the past decade, appearing in Europe, the US and Israel in 2001, 2007 and 2011 respectively. The research aimed to develop basil strains that would be resistant to downy mildew.

## 2 Research Activities

In 2016 a BARD award was granted to James E. Simon (Rutgers) and Yigal Cohen (Bar-Ilan) for basil gene pool enrichment for Downy Mildew resistance and Quantitative trait locus (QTL) development using genotyping by sequencing (US-4947-16R).

### 2.1 Israel:

Domestic basil accessions from around the world were screened for resistance to basil downy mildew (BDM). No resistance being found, the researchers then examined a large collection of wild basil species and found highly resistant wild types. Introgression between 4 resistant wild accessions and the elite, susceptible cultivar “sweet basil” successfully transferred the *Pb1* gene controlling resistance to the first generation cross (F1). However, due to lack of chromosomal homology between the parents, the cross is sterile. To overcome this, the first-generation plants (F1) were pollinated with the sweet basil parent and *in vitro* embryo rescue techniques were employed. The use of these techniques enabled the development of fertilized abnormal gametes into plantlets from the first backcross generation (BCs1).

About 100 highly resistant first backcross generation (BCs1) plants were rescued from ~7000 flowers and 28,000 embryo rescues. The breakthrough enabled the researchers to obtain genetic material that constituted the foundation for a broad breeding program. BCs1 were partially fertile but the next generation back-crossed plants, BCs2, displayed restored fertility. Backcrossing was conducted for 6 generations.

Selection of crosses was based on full resistance to downy mildew as well as resistance to Fusarium. Selection was also based on appearance, flavor and the aromatic profile of the cross.

### 2.2 USA

USDA/SCRI support starting in 2011 enabled the development of inbred Basil Downy Mildew and Fusarium resistant plant material used in the BARD supported research. A Downy Mildew Resistant (DMR) non-domesticated sweet basil line was discovered and introgression between this accession and sweet basil led to 20 resistant varieties through combinations of self-pollination. Of these resistant varieties, 4 lines have been chosen for

commercialization and release based on their high resistance to BDM and ideal horticultural traits (size, yield, aroma and flavor).

### 2.3 Marker Development:

Phenotyping of the US inbred lines is being conducted in field trials in 3 US locations and in Israel (for BDM resistance, oil content, color, leaf morphology and more). The inbred lines (US and Israeli) will be sequenced and genotyped with SNPs and SSR markers in the Rutgers lab and will be used to generate high resolution linkage maps and to identify QTL for the phenotype traits.

## 3 Academic Impact

### 3.1 Publications

6 peer-reviewed journal publications were published based on research from this single BARD award.

### 3.2 Capacity Building

3 M.Sc, 3 Ph.D. students and 1 post-doctoral researcher were and are currently involved in the BARD supported research.

The BARD research has leveraged funding for a new 4-year USDA/SCRI on basil (began 2019) and a USDA/NIFA grant examining activated plasma water on basil health and safety (\$600,000).

## 4 Stakeholder's Collaboration

Personnel from the Extension services at the Israel Ministry of Agriculture first approached the Israeli research group to aid in the quest for genetic resistance to downy mildew following the epidemic onset in 2011.

## 5 Commercial Engagement

The IP that emerged from the research in Israel has been licensed to the Israeli company, Genesis Seeds, one of the world's largest producers of certified organic vegetable, herb & flower seed. Genesis provided further funding and facilitated the breeding program.

Bar-Ilan University and Genesis Seeds are now commercializing the new sweet basil cultivar under the trademark "Prospera®".

The Rutgers *O. basilicum* experimental lines were released and introduced into the market in 2018 as 'RutgersPassion DMR', 'Rutgers Devotion DMR', 'Rutgers Obsession DMR' and 'Rutgers Thunderstruck'. Seed production is conducted by Van Drunen Farms through

a new division, VDF Specialty Seed, established as part of the collaboration between Rutgers and Van Drunen Farms.

## 5.1 Patents

*Downy mildew resistant/tolerant sweet basil varieties*; James E. Simon, Robert Michael Pyne, Christain Andrew Wyenandt, US159,212, Granted: 25-12-2018 to Rutgers, The State University of New Jersey.

BIRAD, the commercial arm of Bar-Ilan University, has submitted a PCT. WIPO Application No. PCT/IL2018/050048

## 6 Practical Agricultural Applications

Damages from downy mildew have caused economic havoc to the basil industry in the US, Israel and worldwide. Chemical fungicides cannot be applied close to the harvesting of basil and moreover, *Peronospora belbahrii*, the fungal cause of BDM, is displaying resistance to many fungicides, including the prominent mefenoxam. Other techniques to minimize infection, including red light radiation ( $\lambda_{max}$  625 nm), day-time solar heating, and improving air flow by the use of fans, can be costly and not always easy to adopt.

Sales of “Prospera®” began across Europe and Israel in 2019. Sale of the 4 Rutgers commercial varieties began in the US in 2018. Rutgers is due to release an additional 4 downy mildew resistant basil varieties for consumers and home gardeners.

## 7 Social Impact

Basil is considered to be a leader in the fresh herb category. Reduction in consumption of basil could negatively affect other categories of herbs as well if growers were to decide to forfeit their herb growing areas due to basil disease. Increased consumption of herbs is a mitigating factor in salt intake, serving as a substitute flavor enhancement, which is important from a public health standpoint.

## 8 Environmental Impact

The need to find alternatives to fungicides is derived both from the evidence that their efficacy is inadequate, as well as from the ramifications for health and environmental concerns that have led to strict pesticide use regulation, especially in the EU<sup>1</sup>. Although large scale planting of downy mildew resistant basil varieties has just begun, we can

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<sup>1</sup> [https://www.cbi.eu/sites/default/files/market\\_information/researches/product-factsheet-europe-fresh-herbs-2016\\_final\\_approved.pdf](https://www.cbi.eu/sites/default/files/market_information/researches/product-factsheet-europe-fresh-herbs-2016_final_approved.pdf)

assume that the market will increasingly grow which will lead to a reduction in pesticide applications and exposure.

## 9 Economic Impact

### 9.1 Investment Cost

BARD contributed \$300,000 in research funds between 2016-2019. Industry investments in Israel totaled \$100,000. The US group received funding of ~ \$400,000 from the USDA prior to the BARD award.

### 9.2 The Benefits

#### Fresh Produce Market

In the United States, basil is grown commercially in western and southern states where the climate is favorable including Arizona, California, Florida, New Mexico, and North Carolina. As downy mildew affects the marketable part of the plant (i.e. the leaf) there is very low tolerance for the disease. There are no definitive figures quantifying the damages caused by the disease. Losses incurred by the fungus are estimated as "tens of millions of dollars" in the US alone from 2007 to 2014, and the investment in fungicides at "tens of millions of dollars" annually<sup>2</sup>.

The demand for fresh-market basil has grown in recent years due to increased consumer demand, which has led to more intensive field and greenhouse production systems. Quantitative information on the basil market is difficult to obtain. Official statistics from the FAO, and the USDA give total aggregated data for the whole fresh herb market (including several other herbs). The industrial and medicinal uses of basil, and potted plants for home gardening are not included in these databases, and the estimates of basil production from these data are thus an underestimate for the "all-use" basil market.

The US 2016 retail market for fresh fruit and vegetable produce has been valued at between \$61 to \$105 billion. The fresh herb market was estimated to constitute 2%-4% of the total fresh produce market with an annual growth rate of 10-15%, with basil comprising 40-45% of the herb market<sup>3,4</sup>. The total US market for fresh basil may then be estimated to be over \$1 billion annually. Annual acreage for basil production in New Jersey alone is approximated to be about 11,000 acres (pers. Communication, Dr. Andy Wyenandt), while states such as Florida and California cultivate substantially more basil and over a greater proportion of the year

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<sup>2</sup> <https://apsjournals.apsnet.org/doi/10.1094/PHYTO-02-15-0032-FI>

<sup>3</sup> <https://www.grandviewresearch.com/industry-analysis/us-fruit-vegetables-market>  
<https://www.fmi.org/newsroom/news-archive/view/2016/06/22/fmi-report-fresh-produce-growth-driven-by-mega-trends>

<sup>4</sup> <https://www.producebusiness.com/herbs-are-trending-upward/>

Western Europe is a growing market for fresh herbs with relatively stable prices. Basil is the most popular culinary herb, making up between 60% to 75% of the total European herb consumption.<sup>5</sup> Estimates of the UK annual herb market in 2016 ranged between £100 to £145 million, with an annual growth rate of 18%. Assuming that the average per capita consumption in the UK may be applied also to France, Italy and Germany, then the fresh basil retail market for those four countries alone can be estimated at \$400 million annually. Including the rest of Europe and Russia, the total developed countries consumption of fresh basil may be estimated at \$1.5-\$2 billion in annual retail value.

### Seed Market

There are no official statistics for the herb seed market. Genesis, a leading Israeli seed provider that is a partner to the commercialization of the Prospera® made available their figures for 2019, the first year of marketing the Prospera® varieties. Multinational orders of the modified seeds totaled \$1 million. The estimated premium for these seeds as compared to other “non-resistant” varieties is 35%. i.e. \$350,000 for the first introductory year. Assuming similar sales and premium for the Rutgers varieties, we estimate a \$700,000 premium for 2019. Along the supply chain, the retailers 2019 selling price for the Prospera and Rutgers varieties are 10-fold the price of commonly grown basil varieties such as Genovese and Italian large leaf basil

Demand for fresh herbs is increasing in both the US and EU at an annual growth rate of approximately 15%<sup>3,4</sup>. Calculating a compounded annual growth rate of the retail market for the penetration of the new downy mildew resistant basil seeds, we derive an annual premium of \$1.6 million for 2024, and \$2.8 million for 2028. We assume that the farmers benefit is at least twice the seed premium they pay. Thus, we estimate \$1.4 million benefit attributed to this project in 2019, and the benefit grows to \$5.6 million in 2028.

This is a very conservative estimate in comparison to the evaluation of damages and of annual expenditures on fungicides previously cited. It does not consider the damages caused by current repression of market growth. For example, in a US 2013 survey, 30% of basil growers cited disease as the greatest obstacle to expanding basil production, with 92% of those surveyed placing downy mildew at the top of the list for diseases that affect basil production<sup>6</sup>.

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<sup>5</sup> <https://www.producebusinessuk.com/insight/insight-stories/2016/05/12/new-ways-of-using-herbs-tipped-to-fuel-market-growth-further>  
[https://www.cbi.eu/sites/default/files/market\\_information/researches/product-factsheet-europe-fresh-herbs-2016\\_final\\_approved.pdf](https://www.cbi.eu/sites/default/files/market_information/researches/product-factsheet-europe-fresh-herbs-2016_final_approved.pdf)

<sup>6</sup> R. Govindasamy, Agricultural, Food and Resource Economics. Rutgers.  
<https://www.youtube.com/watch?v=LbUhmOCISg0>

### 9.3 Economic Results

According to the calculation described in the methodology section we attribute 37% of the benefit to BARD.

- Net present value of the BARD’s investment is \$10 million, thereof \$0.2 million has already been attained.
- The Internal rate of return is 144%.
- Benefit cost ratio is 34, thereof 2 has already been attained.

**Table 1: Economic Results for the Case-Study, 2018 Million Dollar-Terms**

	The Project	BARD	BARD Attained	Thereof to the US	Thereof to Israel	Other Countries
BARD's Share in the Cost	37%					
Share in the Benefit		37%				
Cost	0.9	0.3	0.3	0.2	0.2	
Benefit	29	11	0.5			
Net Present Value	28	10	0.2	4	4	3
Internal Rate of Return	59%	144%	56%	112%	112%	
Benefit Cost Ratio	34	34	2	23	23	

### 9.4 Sensitivity Analysis

The low and high alternative assumptions used in the sensitivity analysis were brought together to estimate the Net Present Value (NPV) for BARD’s share in the benefit under pessimistic and optimistic scenarios. The NPV ranges between a low result of \$4 million to a high result of \$20 million (see Table 2).

**Table 2: NPV - Sensitivity Analysis, 2018 Million Dollar-Terms**

			<u>BARD's Share in the Benefit</u>		
			Low	Central	High
			27%	37%	47%
<u>Change in Benefit</u>	Low	50%	4	5	6
	Central	100%	8	10	13
	High	150%	11	16	20

## 10 Appendix A: BARD Awards

Table 3: Details of the BARD award.

Project No	Full Title				
	Investigators	Institutes	Budget	Duration	Start Year
US-4947-16 R	Basil gene pool enrichment for Downy Mildew resistance and QTL development using genotyping by sequencing				
	J. E. Simon Y. Cohen	Rutgers Bar-Ilan University	\$300,000	3 years	2016

## 11 Appendix B: Information providers: Personal communication

Yigal Cohen – PI of BARD grant, Plant Genetics, Bar-Ilan University, Israel

James E. Simon - PI of BARD grant, Plant Biology, Rutgers, NJ, USA

David Silverman – Ministry of Agriculture, Israel

Dr. Isaac Nir – President, Genesis Seeds