Mango Treatment: Longer Shelf Life Using Less Chemicals
Case Study 13

Research goal	Developing methodologies to reduce post-harvest mango fruit loss.
Beneficiaries	Mango packing houses, Mango exporters
Activities conducted in order to achieve the objectives	The researchers discovered that the pathogenicity of the rot inducing fungi was modulated by pH levels of the fruit, and that pH was induced by the pathogen itself. Later research clarified the enzymatic activities and gene expression that regulate alkali or acidic secretions by each pathogen.
Funding	5 BARD awards: IS-2435-95, IS-2686-97C, IS-3363-02, IS-3945-06 R, IS-4469-11 R, with $1.6 million between 1995 – 2011. GIARA, US-Israel CDR, Israel Mango Desk: $325,000 between 2002 – 2011.
Publications	41 publications, 50% in the top IF quadrant..
Students involved	At least 9 graduates. Current positions: 2 at the Agricultural Research Organization, Volcani Center; 1 in US Academia, 3 in industry; 1 at the Standards Institution of Israel; 1 in medical research.
Stakeholders' collaboration	Collaboration with a research group at Spanish National Research Council (CSIC).
Environmental impact	75% - 90% decrease of fungicides usage in the post-harvest treatment.
Social impact	Food waste reduction.
Commercial engagement	Collaboration with the Mango Desk and with Westfalia, a South African avocado grower/exporter.
Patents	No patents
Practical agricultural applications	Adoption of a post-harvest acid treatment of mango fruit in Israel and in Northern Sinaloa, Mexico. Mango fruit loss from *Alternaria* was reduced to close to 0%.
Economic impact	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.

Green- Academic information; Yellow - Social and environmental information; Blue - Economic information

1 Objective: Reduction in Post-Harvest Mango Loss

In the 1990's, post-harvest mango loss was identified as a major problem. The dominant mango disease affecting Israeli mangos is *Alternaria*, caused by the fungal pathogen *Alternaria alternata* that is quiescent in the fruits growing stage and regains virulence after its ripening. Globally, the dominant mango disease is Anthracnose, caused by the fungal pathogen *Colletotrichum gloeosporioides.* The research projects studied signaling pathways and regulatory factors involved in the awakening of quiescent fungal spores with the goal of developing methodologies to reduce post-harvest fruit loss.

2 Research Activities

Between 1995 and 1997 two BARD awards were granted to Dov Prusky (ARO) and Noel Keen (UC Riverside). Their studies focused on the plant's biosynthesis of antifungal dienes and the role of CO_2 and ethylene in the regulation of enzymatic processes in the fruit. A discovery that the pathogenicity of the fungi was modulated by the pH levels of the fruit, and that pH was induced by the pathogen itself led to a new research direction.

As a result, between 2002 and 2011 three BARD awards were granted to Dov Prusky (ARO), Jeffrey Rollins (U. Florida), Lisa Vaillancourt (U. Kentucky) and Tesfaya Mengiste (U. Purdue). Robert Fluhr (Weizmann Institute) was a coinvestigator on the three projects.

Their research focused on mechanisms of local pH modulation and molecular pathways for pH-responsive gene expression of virulence factors. The secretion of compounds that regulate the pH by the pathogen was shown to be a universal mechanism for many fungal pathogens, each awakening from dormancy with different conditions of acidity or alkalinity. The research elucidated the enzymatic activities and gene expression that regulate alkali or acidic secretions by each pathogen.

Research also revealed a role for pH manipulation in the maize anthracnose disease, although the alteration in pH apparently occurs by a different method than in the *Colletotrichum* fruit rots. This was a novel finding that contributed to understanding the mechanism of post-anthesis maize stalk rot and demonstrating that it shared some common biochemical characteristics with post-harvest fruit rots.

The effect of secreted molecules on fruit/host pathogen interaction is central also to other fields such as food technology and human fungal pathogens.

3 Academic Impact

3.1 Publications

One book chapter and forty-one peer-reviewed publications have been published based on research from the 5 BARD awards. 20 of these publications were published in the top impact factor quadrant journals.

3.2 Capacity Building

Eight graduate students were involved in the five research projects in Israel. Currently two of them have positions in ARO, one works for the Standards Institution of Israel, one manages the bio-chemical laboratory of a hospital, and three work in the biotechnology industry.

One graduate student from the group of Lisa Vaillancourt at U. Kentucky was involved in the research project and currently holds a position in US Academia.

3.3 Stakeholder's Collaboration

A strong collaboration ensued with a research group in Madrid, Spain (Eduardo Espeso and Miguel Penalva, at the Spanish National Research Council (CSIC)) that is at the forefront of research on the role of ambient pH as a regulator of growth and development of non-pathogenic fungi.

4 Commercial Engagement

The transformation from scientific progress to an applied methodology was facilitated by funding from the Israel Mango Desk. Following the successful implementation in Israel, Westfalia, one of the biggest South African avocado growers and exporters, conducted a series of trials using the acid prochloraz treatment to reduce post-harvest avocado loss from anthracnose. The commercial adoption was however unsuccessful due to acid induced corrosion of the pack line and sticky residues on the fruit, and was thus terminated.

No commercial agreement has ensued between innovator and users. That might be one of the reasons that the protocol was adopted to a limited extent out of Israel.

5 Practical Agricultural Applications

Close cooperation with the Israeli "Zemach" and "Shoham" packing houses enabled successful trials and near immediate adoption of acid treatment of mango fruit during the packaging process. The post-harvest loss of mango fruit from *Alternaria* following treatment, was close to zero according to Ami Keinan (The professional manager in Zemach packinghouse), who led the practical implementation. Optimization of the protocol was swift, and it was fully adopted by all 13 mango packinghouses in Israel during 2006 – 2010, and is still being implemented today. The acid treatment protocol led to superior quality of both exported mangoes and those sold locally.

In the US, mango is grown in Florida and Puerto Rico. Packinghouses in both areas have not adopted the acid protocol. Mango imports into the US must comply with quarantine regulations against the fruit fly, for which the mango is treated in a bath of hot water at 116°F (47°C) for 90 minutes. This makes the acid treatment redundant.

A total of 60,000 tons of mango are exported to the US from Mexico. They are grown in Northern Sinaloa, a fly -free zone that does not need to adhere to the hot bath phytosanitary measures. According to an importer to US, who also owns packinghouses in this region, the acid protocol is implemented for at least 15,000 tons of the exported produce in Northern Sinaloa.

6 Social and Environmental Impact

The new treatment has a potential effect of reducing food waste, but it is more of a potential benefit, as the protocol is not adopted globally. The new treatment brought a 75% - 90% decrease in fungicides use. According to packinghouse experts, a container of 1,000 liter containing 0.12% Prochloraz could treat 30 tons of mangoes. After adopting the protocol, the Prochloraz concentration was reduced to 0.03% Prochloraz. For an average annual production in Israel and Mexico of 45,000 tons, this leads to a reduction in 1,350 liters of Prochloraz. This saves $250,000 per annum, only for material costs, not including the positive environmental externalities[1]. For the purpose of a conservative calculation, we assume adoption in Israel in 2010 and adoption in Mexico in 2014. We assume that until 2028 no growth will occur, and the treated amount will stay at 45,000 tons.

[1] Based on the catalog price for Israeli farmers, after discount

7 Economic Impact

7.1 Investment Cost

BARD contributed around $1.6 million in research funds between 1995 to 2011. Additional $325,000 was received between 2002 to 2011 through German-Israel Agricultural Research Agreement (GIARA), US-Israel Cooperative Development Research (CDR) Program and from the Israel Mango Desk.

7.2 The Benefit

To calculate the benefit, we first estimate the worldwide tonnage of Mango that undergoes the Acid-Prochloraz treatment, and then calculate the producers benefit on this tonnage based on the current mango retail price averaged for the US, Israel and Europe.

Worldwide Implementation of the Acid Prochloraz Treatment

Mango growers in Israel and in Northern Sinaloa, Mexico implemented the acid Prochloraz treatment. According to the Ministry of Agriculture and the Mango Desk, average mango production in Israel is 30,000 tons per year, half exported, and half retailed locally, and all is treated according to the new protocol. A US importer who owns several packinghouses in N. Sinaloa informed us that his produce, 15,000 tons, is treated using the new protocol. Altogether, around 45,000 tons are treated with the new protocol every year. One third is sold in the US, 1/3 in Europe and 1/3 in Israel.

Mango's Retail Price

Average retail price in Europe is $1.7 - $2.2/unit, which is $3.5/kg[2]. In Israel, according to StoreNext's data for the years 2011 - 2015, the retail price is $2.4/kg. Average retail price in the US is $0.91/unit, which is $1.8/kg[3]. We calculate the average retail price for Israeli mango treated with acid prochloraz as $2.5/kg (0.33×3.5+ 0.33×2.4+0.33×1.8 = 2.5)

Producer's Benefit

Throughout the 90's the mango exported from Israel suffered from A*lternaria* rot. According to Ami Keinan, the produce loss reached 15% when arriving to European destination ports. It cut the amount sold and reduced the willingness to pay for Israeli mangoes. In the local market, the loss was expressed by a shortened shelf life of the produce and the necessity of packinghouses to quickly get rid of the produce.

A hot water brushing system reduced the damage to around 6% loss. After that, Zemach and Shoham packinghouses implemented the acid Prochloraz protocol. The new treatment costs were negligible since the added acid is cheap and the washing infrastructure was already established. The benefit was immediate: according to Ami Keinan losses were

[2] See as an example: https://www.cbi.eu/market-information/fresh-fruit-vegetables/mangoes/europe/
[3] See: https://www.mango.org/wp-content/uploads/2018/09/1st-Half-resultsEnglish.pdf

reduced close to 0%. There is no written evidence as to the exact loss before and after the introduction of the protocol. However, it was implemented very quickly, and nobody thinks today of working without it[4]. According to packinghouse owners interviewed, this project had an essential contribution in developing the "ready to eat" marketing concept, that gave Israeli exporters an important advantage in the market. In Mexico, effectiveness of the treatment was never measured, as far as we were informed.

We assume 3% savings from the reduced post-harvest loss. It generates a producer's value added of $3.37 million, distributed along the value chain in the US, Mexico, Europe and Israel ($2.5/kg*45,000 tons * 3% = $3.37 million).

Worldwide Mangoes Market Size

According to FAO, the global mango production increased by 70% from an estimated 25 million tons in 2001 to 43 million tons in 2013. The international trade of mango showed a 2.3-fold increase, from 0.7 million tons in 2001 to 1.6 million tons in 2015. Throughout the same period, the average FOB price of internationally traded mangoes increased by a factor of 1.7, from 0.9 $/Kg to 1.5 $/Kg. This is an indicator of a long-lasting demand surplus.

Anticipated Growth in protocol implementation

For conservative calculation reasons, we assume no growth of the protocol implementation worldwide.

7.3 Economic Results

BARD invested in the initial and hence risky part of the project. According to the calculation described in the methodology section we attribute 89% of the benefit to BARD.

- Net present value of the BARD's investment is $57 million, thereof $26 million already attained.
- The Internal rate of return is 21%.
- Benefit cost ratio is 17, thereof 9 already attained.

The US and Israel economy benefit is calculated according to the production in these two countries and according to their import, and import prices

[4] See in Hebrew: http://www.snapcall.org/alon/201503/mobile/index.html#p=20
http://www.snapcall.org/alon/201511/mobile/index.html#p=23
http://www.snapcall.org/alon/201512/mobile/index.html#p=36

Table 1: Main Results, 2018 Million Dollar-Terms

	The Project	BARD	BARD Attained	Thereof to the US	Thereof to Israel	Other Countries
BARD's Share in the Cost	86%					
Share in the Benefit		89%				
Cost	4	3	3	1.7	1.7	
Benefit	64	57	29			
Net Present Value	60	54	26	6	29	19
Internal Rate of Return	22%	21%	20%	12%	22%	
Benefit Cost Ratio	17	17	9	4	17	

7.4 Sensitivity Analysis

The low and high alternative assumptions used in the sensitivity analysis were brought together to estimate results under pessimistic and optimistic scenarios. Table 2 displays the net present value sensitivity results, between the low result: $22 million, to the high result: $92 million.

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

			BARD's Share in the Benefit		
			Low	Central	High
			79%	89%	99%
Change in Benefit	Low	50%	22	25	28
	Central	100%	47	54	60
	High	150%	73	82	92

8 Appendix: BARD Awards

Table 3: List of 5 BARD awards granted between 1995 - 2011

Project No	Full Title				
	Investigators	Institutes	Budget	Duration	Start Year
IS-2435-95	Elicitation of Preformed Antifungal Compounds by Non-Pathogenic Fungus Mutants and their Use for the Prevention of Postharvest Decay in Avocado Fruits				
	Prusky, D Keen, N.T. S. Freeman	ARO, Min. Ag UC, Riverside ARO, Min. Ag	$300,000	3 years	1995
IS-2686-97C	Regulation of Avocado Resistance to Postharvest Pathogens by Modulation of the Biosynthesis of Antifungal Compounds				
	Prusky, D. Keen, N.T. Browse, J. Leikin-Frenkel A.I.	ARO, Min. Ag WA State U UC, Riverside ARO, Min. Ag	$341,000	3 years	1997
IS-3363-02	Modulation of Pathogenicity of Postharvest Pathogens by Environmental pH				
	Prusky, D. Rollins, J. Fluhr, R.	ARO, Min. Ag. U Florida Weizmann Inst.	$320,000	3 years	2002
IS-3945-06 R	Host Ammonification by Postharvest Pathogens and its Contribution to Fungal Colonization and Symptom Development				
	Prusky, D. Vaillancourt, L.J Fluhr, R.	ARO, Min. Ag. U Kentucky Weizmann Inst.	$330,000	3 years	2006
IS-4469-11 R	Mechanisms activated by Fungal-Based Host pH Modulators During Quiescent Infections and Active Postharvest Disease Development				
	Prusky, D. Mengiste, T.D.	ARO, Min. Ag. Purdue	$310,000	3 years	2011

	Fluhr, R	Weizmann Inst			

9 Appendix: Information providers: Personal communication

- Dov Prusky – PI for BARD grants
- Nir Yakoby - Molecular Biosciences, Rutgers
- Zelda van Rooyen, Research Manager Westfalia, SA
- Zilungisele Mavuso, Plant pathologist, Westfalia
- Yair Aron, Martex farms, Puerto Rico
- Amichai Rozenfeld, Pachamama Farms, Peru
- Noam Elkan, Researcher, ARO
- Reuven Dor, head of Israeli Mango Desk
- Extension service mango and economic experts
- Richard Campbell – CSO, Ciruli Brothers, growers-importers of Mango to the US own packing houses in Mexico)
- Shaul Klauzner, Mor packing house
- Menachem Shoham, Shoham mango packing house
- Ami Keinan, Zemach packing house