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

Research goal	To generate a superior tasting tomato through natural genetic manipulation
Beneficiaries	Seed companies, Growers, Consumers
Activities conducted in order to achieve the objectives	Studies focused on the soluble solid content of wild tomato. Molecular genetic strategies were initiated to develop tomato genotypes with modified carbohydrate metabolism and enhanced sucrose/fructose accumulation.
Funding	5 BARD awards: IS-1063-87, US-1321-88, US-1872-91C, IS-2270-94C, US-2451-95. $1.32 million between 1987 to 1998. Syngenta: $5.4 million, between 1997 to 2015.
Publications	26 publications, 19 of them in the top impact factor quartile (Q1).
Students involved	More than 12 graduates. Current positions: 7 in Academia of which 5 at the Agricultural Research Organization, Volcani Center, 1 in the US and 1 in China, 3 in the biotechnology industry and 1 at the Israeli Ministry of Agriculture.
Stakeholders' collaboration	The ARO “Center for the Genetic Enhancement of Cucurbit Fruit Quality”. Abundant follow -up academic collaborations on sugar function as a regulator of processes related to fruit growth and ripening.
Environmental impact	None
Social impact	A new healthy snack added to the health snack market.
Commercial engagement	Collaboration with 2 companies: Syngenta and BreedX.
Patents	7 patents approved.
Practical agricultural applications	Nebula, a premium cherry tomato entered the market in 2015 and is estimated to be grown over 90 Ha worldwide, especially in Europe and North America
Economic impact	Net present value of the 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.

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

1 Objective: Breeding for Flavor and Taste

Modern tomato varieties have evolved within a single species, *Solanum lycopersicum*. Breeding goals in tomato have been directed to increasing yields, disease resistance, uniform ripening, extending shelf-life, and visual appeal. The traits of aroma and taste progressively declined in cultivated varieties, leading to a growing demand by consumers for enhancement of these "lost" traits.

The study researched the genetic pathways that control the sweetness of the tomato fruit in genetically diverse wild tomato species. The goal was to transfer traits and generate superior tasting cultivated tomatoes through natural genetic manipulation.

2 Research Activities

Between 1987 and 1995 five BARD awards were granted to Ari Schaffer of the Agricultural Research Organization (ARO Israel), Mason Pharr (N Carolina St. U) and Alan Bennett (UC Davis).

One set of studies characterized the genetic and biochemical basis for sucrose accumulation and the pathway of galactosyl sucrose metabolism in melon fruit, from before flowering until fruit maturity.

The other studies focused on the soluble solid content of wild tomato fruit. The inheritance of the sucrose accumulation gene (*sucr*) was shown to be conferred by a single recessive gene, and three major factors were identified as controlling the sucrose accumulation. The genes and enzymatic pathways that lead to greater sucrose and fructose content were successfully transferred to cultivars through breeding. Based on the research findings, molecular genetic strategies were launched to develop tomato genotypes with modified carbohydrate metabolism and enhanced sucrose/fructose accumulation.

3 Academic Impact

3.1 Publications

Three book chapters and twenty-six peer-reviewed journal publications were published based on research from the five BARD awards. Of these, 19 of the publications were published in the top impact factor quartile journals (Q1).

3.2 Capacity Building

Two graduate students and one post doctorate researcher in the group of Alan Bennett at UC Davis were involved in the research. Currently, one is in Academia, and one in industry.

Five Ph.D. students and four post-doctorate researchers were involved in these five research projects in Israel. Currently six of them have academic positions, five in Israel and one in China, one works for the Ministry of Agriculture and two work in the biotechnology industry.

3.3 Stakeholder's Collaboration

The research results laid a foundational role in follow up collaborations:

- Additional studies on sucrose metabolism in various fruits, other than melons, both by the BARD researchers as well as additional laboratories.
- The ARO "Center for the Genetic Enhancement of Cucurbit Fruit Quality" was established in 2003 with an initial $500,000 funding from the Israeli Ministry of Science. The group has received funding of over $10 million during its activity and has developed novel melon varieties, which are soon to be launched.
- Research on sugar function as a regulator of processes related to fruit growth.
- Research on the role of saccharides in cell wall disassembly during ripening of fruits
- An additional collaboration between Ari Schaffer and Alan Bennett continued with a later BARD grant in 2013, "Manipulating fruit chloroplasts as a strategy to improve fruit quality" (US-4636-13)

4 Commercial Engagement

A pre-breeding and breeding R&D program were conducted between 1996 to 2015 in partnership with the Israeli seed company "Zeraim Gedera" (ZG), purchased by Syngenta in 2008. ZG/Syngenta allocated ~ $5.4 million to the R&D preprogram.

ARO and A. Schaffer will develop new tomato varieties in a partnership with a new Israeli-based company, BreedX while collaborating with Syngenta.

4.1 Patents

Seven patents have emerged from these research projects:

- *Tomato acid invertase gene,* Alan B. Bennett**,** Ellen M. Klann, US5658773A, Granted: 1997-08-19 to University of California
- *Method for breeding tomatoes with superior taste characteristics and product of the method,* Arthur Schaffer, US5817913, Granted: 1998-10-06 to Peri Development Applications, Ltd. (Bet Dagan)
- *Fructokinase genes and their use in metabolic engineering of fruit sweetness.* Alan B. Bennett, Yoshinori Kanayama, US6031154A, Granted: 2000-02-29 to University of California.

- *Sucrose accumulating tomato cultivar*. Alan B. Bennett, Serge Yelle, US6072106A, Granted: 2000-06-06 to University of California.
- *Controlling starch synthesis*, Arthur Schaffer, Ilan Levin, Marina Petreikov, Moshe Bar, US6720485B1, Granted: 2004-04-13 to Israel Ministry of Agriculture
- *Plant-derived alkaline alpha-galactosidase*, Arthur Schaffer, Gao Zhifang US7514254B1, Granted: 2009-04-7 to Agricultural Research Organization, Volcanic Center.
- *Use of fructokinases and sucrose synthases for increasing cell wall polymers.* David Granot, Marcelo Ariel German, Rakefet David-Schwartz, Nir Dai, Arthur Schaffer, Marina Petreikov, US9556421B2, Granted: 2017-01-31 to Agricultural Research Organization, Volcanic Center.

5 Practical Agricultural Applications

The first successfully commercialized variety, of five planned varieties, is the Nebula tomato ("Red cherry TT80154"), a superior cherry tomato that entered the market in 2015. In addition to its unique sweetness, the nebula has a crunchy texture, favorable consistency and good shelf life. Nebula is grown in Northern and Southern Europe, Canada, California, and more. In Israel, less than 1 experimental hectare is grown.

6 Economic Impact

6.1 Investment Cost

BARD contributed $1.32 million in research funds between 1987 to 1997. Syngenta invested around $5.4 million between 1997 to 2015.

6.2 The Benefits

We estimate the economic benefit of the Nebula tomato based upon the cultivated area on which it is grown, its production per hectare of greenhouse, its retail price and the producer surplus. To project the increase in cultivated area in the near future we refer to market analysis of the snack cherry tomato market and its expected growth in the years to come.

Based on knowledge of royalties paid to ARO and additional commercial information received, we estimate that in 2015 there were several hectares of Nebula cultivated greenhouses. The area increased to 14 ha in 2016 and we estimate a growth to 90 ha in 2017.

Based on discussions with experts and farmers, yield is assumed to be 90 ton/ha, of which 70 ton is high quality fruit in conventional plastic greenhouses. However, when very sophisticated glass greenhouses with climate control systems are used, the yield reaches

210 ton/ha. To be conservative, we assume an average global high-quality yield as 90 ton/ha. As such, the 2017 global production is estimated as 8,100 tons.

Nebula's retail price in Europe ranges between $7.5/kg to $8/kg. This is $4.25/kg higher than the price of commodity cherry tomatoes, which is $2.5-$4.5/kg. In Canada, we found documentation of Nebula prices at $10/kg[1].

According to growers and experts, the Nebula variety yields 70% produce compared to regular cherry tomatoes when grown in plastic greenhouses. If it is grown in a sophisticated glass house then the yield is the same as other cherry tomatoes. The highest quality Nebula are obtained under very specific conditions and require an experts hand. Based on discussions with farmers and experts, we estimate the farm operational cost at $3.0/kg, compared to $1.5 – 2.0/kg[2] for the regular cherry tomato, i.e. the cost of production is around $1.25/kg more expensive. This generates the producer's value added of $3/kg ($4.25 - $1.25), distributed along the value chain worldwide.

Consumer's surplus is a measure of economic well-being. It represents the value to consumers who value the tomato at a price higher than the cost to buy it. Two studies conducted during recent years analyzed demand patterns for tomatoes in specific US. These studies found that price elasticity of tomatoes ranges between -0.15 to -7.7, and depends on the fruit's specifications[3]. Even if we attribute the greatest elasticity, -7.7, to the Nebula, which in turn generates the lowest consumer surplus, its value is still significant. Nonetheless, to maintain conservative estimates consumer surplus is not included in the monetary benefit calculations.

European consumption of fresh tomatoes is estimated as 7.2 million ton annually, and cherry tomatoes are an estimated 18% of this, which is 1.3 million tons[4]. According to experts we asked, the snack tomato market is estimated to be about 10% of the cherry

[1] See a sample of real time price information:
https://www.tesco.com/groceries/en-GB/products/300284636,
https://az870929.vo.msecnd.net/product/tomazing-cherry-tomato/00000_000000081623901377,
https://www.ah.nl/producten/product/wi434653/ah-nebula-cherrytomaat,

[2] see as an example, cost of production in Italy: https://www.mdpi.com/2071-1050/6/11/7967

and in Israel, in Hebrew:
https://www.moag.gov.il/shaham/professionalinformation/documents/calculations_yerakot/agvanyot_sheri.pdf

[3] See as an example, two studies published during last years:
https://www.researchgate.net/publication/23515367_Demand_Analysis_of_the_US_Fresh_Tomato_Market
https://ageconsearch.umn.edu/bitstream/196847/2/2015-SAEA-Paper-Lopez-Davis-01-14-2015.pdf

[4] See pages 64 – 66 in:https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/agricultural-outlook-2017-30_en.pdf

and in Hebrew:
https://www.moag.gov.il/yhidotmisrad/research_economy_strategy/publication/2014/documents/Tomatoes_in_israel.pdf

tomato market which is a growing sector of tomatoes sales. A 2015 survey found that snack tomatoes comprise 30% of Dutch tomatoes supermarkets revenues[5]. We assume that the current snack tomato market in Europe is 130,000 tons per annum, and the global market to be twice that size, i.e. 260,000 tons per annum.

According to our estimations, Nebula production in 2017 was 8,100 tons which is equivalent to 3% of the estimated snack tomato market. Syngenta is promoting this variety and we assume that sales will rise 10% annually. The production is anticipated to be 23,000 tons per annum in 2028 which is less than 8% of the global snack tomato market assuming a slight global increase.

We assume other competitive varieties are in the pipeline, thus future calculation terminates at 2028. To maintain a conservative calculation, we did not include the residual value of the Nebula after 2028. Also, not included in the calculation are four more tomato varieties in Syngenta's pipeline that emerged from this research.

6.3 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 49% of the benefit to BARD.

- Net present value of the 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.

The US economy benefit is calculated according to its import of Nebula, and the early stages of production of Nebula in the US.

Benefits attributed to the project that were not included in the calculation:

- Contribution to the Israeli economy by the activity of the new companies established in the country.

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	34%					
Share in the Benefit		49%				

[5] See: http://www.hortidaily.com/article/24910/A-global-look-at-greehouse-tomato-prices/

Cost	14	5	5	2.4	2.4	
Benefit	459	225	29			
Net Present Value	445	220	24	2	-2	221
Internal Rate of Return	18%	16%	10%	5%		
Benefit Cost Ratio	33	47	6	1	-1	

6.4 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: $52 million, to the high result: $509 million.

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

			BARD's Share in the Benefit		
			Low	Central	High
			39%	49%	59%
Change in Benefit	Low	50%	85	108	131
	Central	100%	174	220	266
	High	150%	264	333	402

7 Appendix A : BARD Awards

Table 3: List of 5 BARD awards granted between 1987-1995

Project No	Full Title				
	Investigators	Institutes	Budget	Duration	Start Year
IS-1063-**87**	Study of Carbohydrate Metabolism and Partitioning as Controlling Factors of Fruit Quality in Sweet Melon				
	Schaffer, A Pharr, D.M. Aloni, B Rylski, I Nerson, H Huber, S.C.	ARO, Min. Ag N Carolina St. U ARO, Min. Ag ARO, Min. Ag ARO, Min. Ag USDA, ARS;	$240,000	3 years	1987
US-1321-**88**	Sucrose Metabolism in Developing Fruits of Cultivated and Wild Lycopersicon Species				
	Bennett, A.B Schaffer, A.	UC, Davis ARO, Min. Ag.	$220,000	3 years	1988
US-1872-**91C**	Sucrose Metabolism in Developing Fruits of Cultivated and Wild Lycopersicon Species				
	Bennett, A.B Schaffer, A.	UC, Davis ARO, Min. Ag.	$260,000	3 years	1991
IS-2270-**94C**	Aspects of Sugar Metabolism in Fruit as Determinants of Fruit Quality				
	Schaffer, A Pharr, D.M Burger, J Zamski, E Burton, J.D	ARO, Min. Ag N Carolina St. U ARO, Min. Ag Hebrew U N Carolina St. U	$300,000	3 years	1994
US-2451-**95**	Genetic and Biochemical Characterization of Fructose Accumulation: A Strategy to Improve Fruit Quality				
	Bennett, A.B Schaffer, A. Granot, D. Zamski, E	UC, Davis ARO, Min. Ag. ARO, Min. Ag. Hebrew U	$300,000	3 years	1995

8 Appendix B: Information providers: Personal communication

- Ari Schaffer – PI and Co-PI for BARD grants
- Alan B. Bennett – U. C Davis
- Moshe Bar – former head of Tomato Breeding Program, Zeraim Gedera, CTO at BreedX
- Mark JJ van Haaren, Global Licensing Vegetables, Syngenta
- Rik Lootens, Portfolio Manager, Solancae, Syngenta
- Ohad Zuckerman – former CEO at Zeraim Gedera, Partner at BreedX
- Lior Kushnir - Territory Marketing Head Vegetables., South East Europe at Syngenta
- Experts of Nebula production in Israel
- Jacob Mualem, Kidum - R&D Applications and Technology Transfer, ARO
- Andy Roe – Production Manager, Flavourfresh, U.K
- David Bell – CMO, at Houweling Group, Canada