Increased Prolificacy in Domestic Sheep
Case Study 5

Research goal	Increased prolificacy and lamb production in domestic US and Israeli sheep breeds.
Beneficiaries	Sheep growers, Mutton industry.
Activities conducted in order to achieve the objectives	Introgression of the Booroola sheep fecundity mutation by crossbreeding to the improved- Awassi and the Local Awassi breeds. Implementation and development of methodologies to identify *FecB* genotypes. Development of new management techniques for the higher prolificacy sheep
Funding	3 BARD awards: IS-797 -85, US-1153-86, IS-1817-90C $ 692,000 Additional funding: $160,000
Publications	29 publications of which 20 in the top impact factor quartile (Q1).
Students involved	1 Ph.D and 3 M.Sc. students
Stakeholders' collaboration	Israeli dairy and meat sheep producers
Environmental impact	none
Social impact	Impact on the traditional Bedouins sheep production in transition from extensive to intensive production, changes to social structure and economic status of Bedouin communities.
Commercial engagement	Commercial genotyping by Bactochem
Patents	Trade Mark “Afec”
Practical agricultural applications	Introgression resulted in two new prolific strains, the “Afec Awassi” and the “Afec Assaf”. In Israel today, there are ~ 55,000 ewes carrying the FecB+ genotype
Economic impact	Net present value of the BARD’s investment is $204 million, thereof $76 million already attained The Internal rate of return is 18% Benefit cost ratio is 65, thereof 25 already attained.

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

1 Objective: To Improve the Prolificacy of Sheep Breeds

The long-term objective was to improve the prolificacy of the breeds by introgressing the "Booroola" mutation at the Fecundity (FecB) locus to the Awassi and the Assaf breeds in Israel and the Rambouillet breed in the U.S. An essential part to the strategy was to produce BB homozygous rams and establish Awassi, Assaf and Rambouillet nuclei breeding flocks homozygous for the FecB gene.

2 Research Activities

Between 1995-2002 three BARD awards (IS-797 -85, US-1153-86, IS-1817-90C) were granted to Elisha Gootwine (ARO, Min, of Agr.), Warren C. Foote (U. Utah) and Dave Thomas (U. Wisconsin). See Appendix A for full details of the awards.

The main two sheep breeds in Israel are Awassi and Assaf. The local improved Awassi is an outstanding breed that has remarkably high milk production - about 550 liters per lactation. However, the Awassi and its improved strain have low prolificacy, an average of 1.2 lambs born/ewe lambing with on average one lambing/year. To improve prolificacy, the improved Awassi was crossed in the 1960s with the East Friesian Milk sheep imported from Germany, resulting in the formation of the "Assaf" with improved prolificacy of 1.6 lambs born per lambing and with 3 lambing events over 2 years.

The research studies of the three BARD awards aimed to further increase the prolificacy of the Improved Awassi and Assaf ewes by the introduction of the "Booroola' mutation at the FecB locus, the first major gene for prolificacy identified in the early '80s in Australian Booroola-Merino sheep.

Research steps: Israel

1) Introgression of the Booroola mutation by crossbreeding to the Improved Awassi and the Assaf resulting in two new strains, the Afec-Awassi and the Afec-Assaf.

The breeding work started by crossing the Booroola Merino ram, homozygous (BB) for the FecB locus with the local Awassi and Assaf non- carrier ewes (++). This led within 6 generations to new strains with 97% identity to the local strains, yet more prolific.

The Afec-Awassi and the Afec-Assaf strains have a prolificacy of about 2.0 and 2.4 lambs born per ewe lambing, respectively.

2) The desired genotype at the *FecB* locus for Afec ewes is *B+*, as homozygous *BB* ewes bear some disadvantages in terms of prolificacy and growth. To identify the *B+* ewes , the rate of induced ovulation was monitored in ewe lambs at 5 months of age.

3) At a later stage, this physiological methodology to identify *B+* ewes was replaced by direct genotyping for the *FecB* locus.

A B+ carrier creates on average an additional 0.6 live lamb a year: the multiple of 0.5 additional live ewes per lambing and 1.2 lambings a year[1]

Research steps: US

Introgression of the B allele into a Rambouillet flock was initiated with the support of the BARD grant at the Dixon Springs Agricultural Center of the University of Illinois in 1985. The project was moved in 1991 to the Arlington Agricultural Research Station of the University of Wisconsin-Madison.

Production of commercial Rambouillet *B+* was achieved in the Wisconsin flock by the same methodology applied by the Israel partners, by continual backcrossing of Rambouillet–BM ewes to Rambouillet rams and differentiation of heterozygous ewes from wild-type ewes on the basis of laparoscopy, and nowadays, DNA testing. Introgression of FecB into a Rambouillet genetic background resulted in a flock that is currently > 93.75% Rambouillet ancestry.

The negative effects of lambs born to *B+* ewes (higher litter size, lower survival rates and weaning weights, and a similar weight of lamb per ewe exposed when compared to ewes of similar breed composition without the FecB allele) led to limitations on the opportunity for future use of FecB in commercial sheep production in the USA[2]. This outcome mainly reflects the relatively high prolificacy levels already present in several US sheep breeds.

In Israel, the lack of local prolific strains led to further studies on flock management of the Afec in order to overcome the negative effects associated with the FecB mutation and to ensure overall gains by the FecB introgression. Generally, the problem of feeding high prolific ewes and treating pregnancy toxemia have been solved. Still, there is ongoing research to find better energetic feeds.

3 Academic Impact.

3.1 Publications

29 peer-reviewed journal publications and several US research station reports were published based on research from the 3 BARD awards. 20 of these publications are in the top impact factor quartile (Q1) journals.

[1] Gootwine et.al., Animal Reproduction Science 108 (2008) 402–411

[2] Biological and economic consequences of the FecB mutation in the USA; D.R. Notter, D.L. Thomas and D.F. Waldron, pp 150-158 in S.W. Walkden-Brown, J.H.J. van der Werf, C. Nimbkar and V.S. Gupta (eds) 2009. Use of the *FecB* (Booroola) gene in sheep-breeding programs. ACIAR Proceedings No. 133.

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3.2 Capacity Building

One Ph.D. students and 2 M.Sc students were involved in the research projects. The three US students wrote their thesis on aspects of FecB allele introgression into a Rambouillet Flock. The three continued to successful scientific careers within US universities and agricultural research stations.

4 Stakeholder's Collaboration

For development of the Afec-Awassi strain the researchers collaborated closely with the Ein Harod sheep farm, and during the mid to late 90's with many additional Israeli sheep farms. The Afec-Assaf was developed at the Volcani Center in collaboration with many dairy and non-dairy sheep growers. Subsequent to the BARD research, the Afec Awassi were integrated into Bedouins' flocks with collaboration of many flock owners.

In 2005, E. Gootwine collaborated with the Nimbkar Agricultural Research Institute (NARI), India, to aid in introgression of the FecB mutation into Deccani sheep reared locally in Maharashtra, Karnataka and Andhra Pradesh states of India by smallholders. The introduction of the FecB mutation in Deccani sheep proved to be successful in increasing both lamb production and income.

5 Commercial Engagement

Dissemination of the Afec sheep from the breeding nuclei at the Volcani Center and the Kibbutz Ein Harod Awassi flock has been achieved mainly by selling homozygous *BB* rams to mostly non-dairy intensive commercial flocks. Managerial means to support the maintenance of high-prolific sheep, including a new treatment for pregnancy toxemia, were also developed by the group of E. Gootwine[3].

The genotyping for commercial flock has been transferred to the commercial company, Bactochem. E. Gootwine is a consultant for the company and oversees the validation of the results. At present, around 4500 tests are conducted each year.

5.1 Intellectual Property

The Afec strains are protected by an Israeli Trade Mark (#101075).

6 Practical Agricultural Applications

In Israel, rams of Afec-Awassi and Afec-Assaf carrying FecB are bred in the ARO and have been widely disseminated to industry. The improved genotypes have been most

[3] Zamir, S., Rozov, A., Gootwine, E. (2009). Treatment of Pregnancy Toxaemia in sheep with flunixin meglumine. Veterinary Records 165: 265-266.

successful to date in fully intensive non-dairy production systems with artificial rearing of lambs.

To date, there are ~ 55,000 B+ ewes in the Israeli sheep industry (see section 8.2). Sheep farmers in the Palestinian Authority also cross breed their flocks with the Afec breed.

In the USA there has been very little use of the Booroola mutation due to the naturally high prolificacy of many of the more commonly used breeds of sheep. At the University of Illinois, 10 of the Rambouillet-Booroola B+ rams were distributed to commercial sheep producers, but the large number of triplet and higher order births among the progeny of these rams were detrimental to overall production and profitability. A few high percentages Rambouillet B+ and BB rams have been sold to commercial producers from the flock at the University of Wisconsin-Madison. To our knowledge there is only one flock in Wisconsin that is being specifically managed to retain the FecB allele.

Global

In general, the gene flow of the Improved Awassi and Assaf breed of sheep (between 1965 to the mid 1980's) was characterized by free animal movements, based on commercial interests, with a minimum of government involvement. Improved Awassi and Assaf were transferred to 15 different countries, mostly to Eastern Europe, Central Asia and the Iberian Peninsula. With a few exceptions, where the transfers were part of a bilateral co-operation program, the movements of these breeds were commercial transfers with freely agreed benefits by stakeholders, exporters and importers alike. In all cases animals were purchased.[4]

By the time the Afec strains were developed, European regulations disallow transfer of live sheep and semen from Israel. As such, the benefits of the Afec-Assaf and Afec-Awassi are limited primarily to Israel, with some overflow of effects to the Palestinian Authorities.

E. Gootwine visited India twice and based on these visits, Indian growers changed the breed for the gene introgression, in a way that the final output will be more desired by the farmers. We have no estimates for an economic evaluation, however it seems to be marginal as the value of sheep in India is low.

7 Social Impact

Almost all Awassi sheep kept by Bedouin farmers in the Negev were managed in the past under traditional semi-extensive management. Decreases in recent years in the availability of grazing land in the Negev area have forced Bedouin growers to spend more on feeding their animals by purchasing costly grains and fodder, making sheep production nearly

[4] Rummel, T., Valle Zárate, A. and Gootwine, E. (2005). The worldwide gene flow of the Improved Awassi and Assaf Breeds of Sheep from Israel. In: "Gene Flow in Animal Genetic Resources. A study on Status, Impact and Trends" of the Institute of Animal Production in the Tropics and Subtropics of the University of Hohenheim, Germany. Cuvillier Verlag, Göttingen.

unprofitable. Beginning in 2005, E. Gootwine worked together with the Bedouin communities to overcome the new economic constraints by improving their flocks' productivity by introducing new genotypes such as the Afec Awassi that carry the FecB (Booroola) mutation. The successful integration of the Afec Awassi in the Bedouin sector under intensive management has led to improvements in flock productivity, economic gains and additional social benefits to the community (e.g. increases in literacy through documentation and tighter collaboration with veterinary services).[5] The German Research Council DFG and the Middle East regional DANIDA funded the project which was based on the outcomes of the BARD funded research.

8 Economic Impact

8.1 Investment Cost

BARD contributed $692,000 in research funds between 1985-1993. External Funding for integration of the Afec-Awassi in the Bedouin livestock totaled $160,000.

8.2 The Benefits

The benefit calculations are based on the increased live births per ewe per year which is 0.6[6]. The benefit is only for the marginal costs, meaning that the sheep and all associated costs are already paid.

Lambs for meat sell at an average price of $445/head in recent years. The marginal cost of raising a lamb is $140/head, consisting of: $71 for feed, $49 for milk powder, $20 for labor and other variable costs[7,8].

The farmer has to pay $40 for genotyping tests for the ewe. A sheep has first offspring at an age of 1 and a half years and continues parturition until age 5-6, giving birth in this period to an average extra 2.4 lambs. Genotyping cost of the mother ewe is thus equivalent to $17/lamb.

Generally, Afec ewes do not produce more milk. The main target was the meat sector. There is some extra feeding that should be given to prolific ewe which may be considered as addition cost of around $20/head. On the other hand, Afec breeders sell ram and ewe

[5] Gootwine, E. (2011). Mini review: Breeding Awassi and Assaf sheep for diverse management. Trop. Anim. Health Prod. 43: 1289-1296.
[6] Israeli ministry of agriculture, in Hebrew: http://www.isb.org.il/news/files/%D7%93%D7%A4%D7%95%D7%9F%20%D7%9B%D7%91%D7%A9%D7%AA%20%D7%94%D7%90%D7%A4%D7%A7%202014.pdf
[7] Israeli ministry of agriculture, in Hebrew: https://www.moag.gov.il/shaham/ProfessionalInformation/Documents/presentation_yomiyun_zon_july_2018_1.pdf
[8] Israeli ministry of agriculture, cost calculation, in Hebrew https://www.moag.gov.il/shaham/professionalinformation/documents/tachshiv_sheep_meat.pdf

lambs as breeding material for a high price. We assume that the latter compensates for the extra feeding costs.

The annual extra profit per *B*+ ewe is $188 [($455 - $140 - $17) × 0.63 = $188]. The number of *B*+ carriers in Israel is estimated by summing the numbers from 4 different data groups.

Group A - Auction Sales: The auctions of BB males conducted by ARO to farmers started in 2002. In 2002, 7 males were sold, in 2003 10 males and in 2004, 42 males were sold. On average 35 males were sold every year between 2002 to 2018, which is a total of 535 BB males. Each of them produced about 50 *B*+ daughters. We assume that each daughter is responsible for at least one *B*+ daughter. This source yields 26,000 *B*+ carriers currently in Israel.

Group B - Genotyping 11,000 Bactochem genotyping tests were conducted in Israel in 2017 – 2018. Based on these tests, the number of heads per herd can be estimated, leading to an approximation of 30,000 *B*+ females in this group. Part of these farmers are Bedouins, and were included in group A.

Group C: There are at least 10,000 *B*+ carriers dispersed in herds that no longer follow up with the genotyping required for the Afec breed.[9]

Group D: We estimate 7,000 *B*+ carriers in farms in the Palestinian Authority.

Assuming there is some overlap between these groups we estimate that currently in Israel and in the Palestinian Authority there are 55,000 *B*+ carriers. The starting point of large-scale implementation was 2004 with 2,000 *B*+ carriers and we assume a linear increase in their number until today. The lamb meat sector is in stagnation in Israel, and we therefore assume no further growth between 2019 - 2028.

The wholesale and retail income for sheep originated products, is 35% of the end-consumer price. Therefore, we added 35% to the benefit calculated.

8.3 Economic Results

The outcome of the breeding program for the prolific Afec strain was a direct result of BARD's financial support. The Afec *B*+ carrier ewes in the Bedouin communities' integration was supported by other funds but relied on the research outcome supported by BARD. According to the calculation described in the methodology section we attribute 90% of the benefit to BARD.

- Net present value of the BARD's investment is $204 million, thereof already attained $76 million
- The Internal rate of return is 18%

[9] Source: Elisha Gootwine – from acquaintance with all those that have adopted the Afec in the past

- Benefit cost ratio is 65, thereof already attained 25

The Israel economy benefit is calculated according to its production

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

- The Social contribution, as detailed above, is not included.

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	90%					
Share in the Benefit		90%				
Cost	4	3	3	1.6	1.6	
Benefit	231	207	79			
Net Present Value	227	204	76	-2	206	0
Internal Rate of Return	18%	18%	16%			
Benefit Cost Ratio	65	65	25	-1	129	

8.4 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 $89 million to a high result of $343 million (see Table 3).

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

			BARD's Share in the Benefit		
			Low	Central	High
			80%	90%	100%
Change in Benefit	Low	50%	89	101	112
	Central	100%	181	204	227
	High	150%	273	308	343

9 Appendix A: BARD Awards

Table 1: Details of the 3 BARD awards

Project No	Full Title				
	Investigators	Institutes	Budget	Duration	Start Year
IS-797 -**85**	Genetic Improvement of Sheep by Introduction of Foreign Genetic Information into Prolific Breeds				
	Gootwine, E. Foote, W.C Shani, M. Goot, H	ARO, Min. Ag Utah St. U ARO, Min. Ag ARO, Min. Ag	$230.000	3 year	1985
US-1153-**86**	Improvement of prolificacy of US and Israeli sheep populations through inclusion of the F gene of the Booroola Merino.				
	Thomas, D. L Gootwine, E. Braw-Tal, R. Bor, A Lewin, H.A. P.J. Dziuk,	U Wisconsin ARO, Min. Ag ARO, Min. Ag ARO, Min. Ag UC Davis U Illinois	$192.000	3 year	1986
IS-1817-**90C**	Improvement of prolificacy of US and Israeli sheep populations through inclusion of the F gene of the Booroola Merino - -Stage II				
	Gootwine, E. Thomas, D. L Braw-Tal, R. Bor, A Dziuk, P.J.	ARO, Min. Ag U Wisconsin ARO, Min. Ag ARO, Min. Ag U Illinois	$270.000	3 year	1990

10 Appendix B: Information providers: Personal communication

E. Gootwine - PI for BARD grants, Department of Ruminant Science, ARO

D. Thomas – PI for BARD grants, Sheep Management and Genetics, University of Wisconsin-Madison

Farmers and extension experts: Gadi Navat, Haim Mor-Yosef. Yizak Shefer