The Food Security Implications from GM Maize Adoption in South Africa

Kristiina Ala-Kokko, University of Arkansas, kmalakok@uark.edu
L. Lanier Nalley, University of Arkansas, llnalley@uark.edu
Petronella Chaminuka, South African Agricultural Research Council, chaminukap@arc.agric.za
Aaron Shew, Arkansas State University, ashew@astate.edu
Jesse Tack, Kansas State University, jtack@ksu.edu
Marty Matlock, University of Arkansas, mmatlock@uark.edu

Motivation

- White maize in South Africa is the only staple crop produced on a widespread commercial basis for direct human consumption using GM varieties.
- White maize is an important field crop in South Africa, serving as the staple food crop for much of the population, particularly for low-income households.
- Although South Africa is classified as an upper-middle-income country, food insecurity is an ongoing concern for a large segment of its population, as evident from 2014-2015 when 22% of households experienced food insecurity due to severe drought and subsequent food price shocks.
- Critics of biotechnology often suggest GM crops have not contributed to increases in yields, reductions in pesticide usage, or benefits to the consumer.
- No studies, to our knowledge, have quantified the potential gains derived from GM crop adoption for direct human consumption.

Research Questions

1. Does the introduction of GM maize improve food security in South Africa through the availability of additional maize rations?
2. How has the producer and consumer surplus changed with the adoption of GM maize in South Africa?
3. Is GM maize more profitable for producers?

Data

The South African National Maize Cultivar Trails yield (tons/hectare) data for white maize genotypes was used in this analysis. This dataset included observations for both white and yellow maize, for a total of 58,952 observations across 106 locations and 491 cultivars across 28 years. While the National Maize Cultivar Trials test both white and yellow maize, we focus on only white maize, as it is for direct human consumption. Of the total observations, 83 percent were dryland trials compared to 17 percent of trails under irrigation. The maize cultivar trails began in 1980, with the first GM maize trails starting in 1999 with the introduction of *Bt* yellow maize. Herbicide tolerant maize was introduced shortly thereafter in 2005. Table 1 provides an overview of GM white maize area in South Africa by province as well as the adoption rates for GM white maize in South Africa from 2001-2018.

Table 1. GM white maize area harvested in South Africa by year by province in thousands of hectares: 2001-2018.

Year	Eastern Cape	Free State	Gauteng	Kwazulu-Natal	Limpopo	Mpumalanga	North West	Northern Cape	Western Cape	South Africa	% White Maize that is GM
2001	0.0	2.4	0.2	0.1	0.1	0.7	2.6	0.0	0.0	6.2	0%
2002	0.1	20.6	1.8	1.0	1.1	7.0	23.6	0.1	0.0	55.3	3%
2003	0.3	64.4	6.0	3.6	4.1	22.4	76.8	1.0	0.0	178.6	8%
2004	0.4	52.8	6.4	2.9	2.6	21.0	60.8	0.5	0.0	147.4	8%
2005	1.2	191.4	17.4	10.2	9.9	65.0	197.2	0.9	0.0	493.0	29%
2006	1.3	151.8	22.0	14.1	5.3	68.6	184.8	6.6	0.0	454.5	44%
2007	1.9	396.8	37.2	23.6	24.8	136.4	384.4	2.3	0.0	1007.4	62%
2008	1.7	386.4	44.8	23.0	23.0	150.1	341.6	1.7	0.6	972.7	56%
2009	2.4	446.4	54.5	31.6	26.1	169.9	442.4	2.0	1.2	1176.3	79%
2010	2.4	517.5	63.8	34.5	19.5	174.0	476.3	1.5	0.4	1289.8	75%
2011	2.2	428.3	53.3	28.1	18.0	129.6	360.0	1.4	0.2	1021.0	72%
2012	2.8	575.1	59.9	35.6	25.9	129.6	494.1	1.8	0.4	1325.3	81%
2013	3.1	609.0	62.2	39.5	25.2	142.8	474.6	1.8	0.3	1358.4	84%
2014	2.1	613.2	54.6	36.1	25.2	141.1	428.4	1.8	0.4	1303.0	84%
2015	2.3	639.0	39.6	36.0	25.7	138.6	418.5	3.2	0.4	1303.2	90%
2016	1.8	351.0	44.1	34.2	28.4	144.0	306.0	3.4	0.5	913.3	90%
2017	3.7	684.3	51.0	42.5	34.0	136.0	442.0	3.0	0.2	1396.6	85%
2018	3.0	560.3	43.5	39.2	10.4	121.8	321.9	3.1	0.0	1103.2	87%

Methodology

Estimation of additional rations

- We first estimate the additional tons of white maize produced by each province for each year attributable to GM adoption by calculating the product of the area (hectares) of white maize production, GM adoption rate, and yield gain coefficient (tons/hectare) associated with GM white maize production. Province specific genetic gain coefficients were derived from Shew et al. 2020.
- The number of additional rations attributable to GM maize adoption each year is estimated as the summation of additional tons of white maize produced in each province attributable to GM maize adoption divided by the maize consumption (kilograms) per capita per year in South Africa (Table 2).

Estimation of welfare gains

- An equilibrium displacement model was developed to quantify changes in producer and consumer surplus attributable to the adoption of GM technology in white maize production in South Africa (Table 2).

Profitability and profit margin differentials between GM and non-GM white maize

- Using the top-yielding dryland conventional and *Bt* maize varieties from 18 locations in Free State and North West provinces from the National Maize Cultivar trials, the mean yield and yield variance for both the conventional and *Bt* varieties were estimated for each location.
- We compare the highest yielding GM and non-GM varieties in a head-to-head profitability comparison using cost of production, mean yield and estimated yield variance (Table 3).

Main Findings

Table 2. Changes in producer and consumer surplus (2018 USD) and additional maize rations attributable to the adoption of GM maize in South Africa: 2001-2018.

Year	Price/ton (2018 USD)	Additional tons of maize	Consumption of maize (kg/capita/yr)	Additional rations	Consumer surplus (2018 USD)	Producer surplus (2018 USD)	Net surplus (2018 USD)
2001	307.26	3,271	111.96	29,215	82,180,175	-33,908,344	48,271,831
2002	154.86	28,834	112.64	255,982	46,112,148	-19,026,323	27,085,825
2003	161.85	93,426	113.48	823,280	55,302,640	-22,818,410	32,484,229
2004	107.04	78,059	110.71	705,077	37,057,731	-15,290,382	21,767,349
2005	182.16	260,596	108.03	2,412,253	69,101,679	-28,512,029	40,589,650
2006	236.20	244,723	101.17	2,418,930	70,667,153	-29,157,959	41,509,194
2007	224.15	538,825	100.05	5,385,559	60,422,812	-24,931,043	35,491,769
2008	180.29	531,307	96.67	5,496,093	62,922,961	-25,962,629	36,960,332
2009	132.96	635,555	94.15	6,750,447	44,707,871	-18,446,905	26,260,966
2010	200.69	698,350	101.19	6,901,375	79,807,036	-32,929,164	46,877,872
2011	240.68	557,516	100.43	5,551,288	85,766,089	-35,387,927	50,378,161
2012	217.63	711,845	99.4	7,161,419	72,160,333	-29,774,059	42,386,274
2013	200.87	737,642	100.1	7,369,046	55,213,235	-22,781,521	32,431,714
2014	248.53	712,222	101.31	7,030,123	87,212,112	-35,984,571	51,227,542
2015	350.62	708,864	101.95	6,953,051	98,573,343	-40,672,326	57,901,017
2016	159.06	505,862	102.46	4,937,167	43,798,015	-18,071,490	25,726,526
2017	154.80	763,949	103.4	7,388,287	68,200,467	-28,140,180	40,060,287
2018	163.07	610,744	103.4	5,906,617	63,494,050	-26,198,266	37,295,784
			Average	**4,637,512**	**65,705,547**	**-27,110,752**	**38,594,796**
			Total	**83,475,209**	**1,182,699,850**	**-487,993,530**	**694,706,321**

Table 3. Break even and relative profit margins for conventional and Bt maize varieties in Free State and North West provinces: 2000-2017.

		Break Even (%)†		Relative Profit Margin (%)	
	Location	Conventional	Bt	Conventional	Bt
Free State	Bethlehem	92.04%[a]	93.88%[b]	36.27%[x]	42.95%[y]
	Blesbokfontein	29.97%[a]	52.13%[b]	-6.60%[x]	0.88%[y]
	Bothaville	84.36%[a]	88.61%[b]	24.73%[x]	31.30%[y]
	Bultfontein	78.23%[a]	85.57%[b]	10.56%[x]	17.54%[y]
	Clocolan	23.15%[a]	49.84%[b]	-7.54%[x]	-0.03%[y]
	Frankfort	39.15%[a]	52.10%[b]	-6.14%[x]	1.32%[y]
	Kroonstad	99.81%[a]	99.80%[a]	34.75%[x]	41.04%[y]
	Leribe	19.54%[a]	49.56%[b]	-7.62%[x]	-0.12%[y]
	Marquard	91.35%[a]	93.86%[b]	20.85%[x]	27.53%[y]
	Maseru	60.47%[a]	71.30%[b]	5.32%[x]	12.44%[y]
	Memel	100.00%[a]	100.00%[a]	43.63%[x]	49.67%[y]
	Nampo	94.41%[a]	95.83%[b]	22.09%[x]	28.73%[y]
	Reitz	99.65%[a]	99.54%[a]	34.97%[x]	41.25%[y]
	Tweeling	99.43%[a]	99.48%[a]	39.80%[x]	45.95%[y]
	Viljoenskroon	89.67%[a]	92.30%[b]	36.30%[x]	42.54%[y]
	Vrede	93.34%[a]	94.88%[b]	17.83%[x]	24.59%[y]
	Wesselsbron	86.26%[a]	89.89%[b]	27.39%[x]	33.88%[y]
	Windfield	99.86%[a]	99.88%[a]	56.18%[x]	61.87%[y]
	Average	**76.70%[a]**	**83.80%[b]**	**21.27%[x]**	**27.96%[y]**
North West	Athole	97.84%[a]	97.87%[a]	71.31%[x]	69.17%[x]
	Coligny	98.57%[a]	98.46%[a]	41.43%[x]	40.75%[x]
	Delareyville	85.14%[a]	85.97%[b]	25.18%[x]	25.43%[x]
	Gerdau	93.23%[a]	93.53%[a]	43.03%[x]	42.26%[x]
	Glaudina	75.12%[a]	76.67%[b]	16.69%[x]	17.49%[x]
	Grootpan	96.05%[a]	96.28%[a]	66.88%[x]	64.94%[x]
	Hartbeesfontien	84.52%[a]	85.24%[b]	20.84%[x]	21.36%[x]
	Kameel	67.99%[a]	70.29%[b]	4.32%[x]	5.92%[x]
	Koster	86.93%[a]	87.45%[a]	23.21%[x]	23.59%[x]
	Leeudoringstad	98.63%[a]	98.57%[a]	51.92%[x]	50.70%[x]
	Lichtenburg	87.72%[a]	88.21%[a]	52.30%[x]	51.05%[x]
	Ottosdal	98.13%[a]	98.12%[a]	44.76%[x]	43.90%[x]
	Potchefstroom	87.36%[a]	87.82%[a]	21.72%[x]	22.19%[x]
	Schweizerreineke	92.57%[a]	92.77%[a]	31.00%[x]	30.91%[x]
	Setlagole	63.19%[a]	65.69%[b]	7.62%[x]	9.00%[x]
	Tweebuffels	85.71%[a]	86.45%[b]	25.68%[x]	25.90%[x]
	Ventersdorp	99.80%[a]	99.73%[a]	47.47%[x]	46.47%[x]
	Wolmaranstad	98.83%[a]	98.78%[a]	51.57%[x]	50.36%[x]
	Average	**88.74%[a]**	**89.33%[b]**	**35.94%[x]**	**35.63%[x]**

†Based off of the mean yield and yield variance in Table 5 assuming an average price of 147.12 (2019 USD) and average total cost of 17.06 (2019 USD) for Free State and 14.17 (2019 USD) for North West simulated 1000 times using @Risk.
[b]Break even percentage for Bt maize varieties in location l was statistically different (p-value < 0.05) from conventional maize varieties.
[y]The relative profit margin for Bt maize varieties in location l was statistically different (p-value < 0.05) from conventional maize varieties.

Conclusions

1. We estimate that the total benefits attributable to GM white maize adoption in South Africa from 2001 to 2018 amount to $695 million (2018 USD).
2. Benefits attributable to the adoption of GM white maize in South Africa also manifest through 83,475,209 additional white maize rations from 2001 to 2018.
3. On average, more GM adopters break-even compared to their conventional counterparts in Free State and North West provinces.
4. GM producers in Free State, but not in North West, also benefit from higher relative profit margins.
5. The findings from this study suggest that GM white maize adoption in South Africa has contributed to improved food security and producer profitability across the region.