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BIOFORTIFICATION, AN ALTERNATIVE TO REDUCE FOOD INSECURITY AND ITS ADVERSE EFFECTS IN DEVELOPING COUNTRIES: A HONDURAS CASE STUDY

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2. Abstract

Food insecurity can generate nutritional problems such as iron deficiency anemia, which in countries like Honduras is a moderate public health problem. The AgroSalud project is enhancing the iron content of beans and rice in order to improve the iron intake of vulnerable groups, especially children under five years and pregnant women. Iron- biofortified rice and beans together can reduce the deficit in iron intake by more than a 100% depending on the age group, farmer adoption and other variables. This, in turn, would increase the number of healthy (disability-adjusted life years, DALYs) years that the Honduran population could live.

3. Keywords: Food security, biofortification, iron, rice, beans, Honduras.

4. JEL codes: Z00

5. Main text

5.1 Introduction

“Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life” (FAO, 2002). Under this definition, biofortified crops, those developed through traditional plant-breeding to have naturally higher levels of nutrients and to retain positive agronomic qualities such as high yields and disease resistance (AgroSalud, 2010), are an alternative to reduce food insecurity in the world. Through their nutritional and agronomic improvements, biofortified crops could provide enough food in quantity (energy) and quality (nutritionally) to meet people’s dietary needs and food preferences. Beans and rice are important in Central Americans’ diet. Beans, with a daily per capita intake in Honduras of 29.6 grams (FAOSTAT, 2005), is one of the highest in world, meanwhile rice, with a daily per capita intake of 45.7 grams is consumed in most of the Honduran’s dishes.

The AgroSalud project is working on the development of rice and bean varieties with a higher iron content. In the case of rice, an improvement of 3 µg/g and 6 µg/g is expected under a pessimistic and optimist scenario, respectively. For beans, these improvements are 30 µg/g and 50 µg/g depending on the scenario. With these biofortified crops, AgroSalud aims to address one of the most important nutritional problems facing Latin America and the Caribbean (AgroSalud, 2010): high levels of anemia mainly due to iron deficiency (McClean et al., 2007). Anemia is a global public health problem affecting both developing and developed countries with major consequences for human health as well as social and economic development. (WHO, 2008). The consequences of anemia include temporary and permanent incapacities and the death of those who are afflicted by severe anemia (Stein *et al*, 2005). Therefore, the future development of some developing countries is at risk because the potential productivity of their populations is compromised by anemia (PSI. Nutrition, 2008). In Honduras, anemia is a moderate public health problem affecting 29.9% of the population in 2001 (WHO, 2008)

The purpose of this analysis is to assess the economic impact that the introduction of iron-biofortifed rice and beans could have in Honduras through the improvements they could produce in food security.

5.2 Methods

The Model for Assessing the Impact of Nutritional interventions (MAIN) was used (García et al, 2008) to estimate the Disability-Adjust Life Years or DALYs that could be saved through the introduction of biofortifed rice and beans in Hondurans diets. The DALYs methodology estimates the health benefits, expressing them in just one index, DALYs lost (Zimmerman and Qaim, 2004), which can be compared with those of other alternatives as well as monetized, facilitating their analysis and economic interpretation. DALYs lost is the sum of the healthy life years lost by mortality and the healthy life years lost due to incapacity.

$$\text{DALYs lost} = \begin{array}{c}\text{Years of healthy life}\\ \text{lost by death}\end{array} + \begin{array}{c}\text{Years of healthy life}\\ \text{lost due to incapacity}\end{array}$$

The impact of biofortification can be determined by the difference between the DALYs lost due to iron deficiency with and without biofortification (Zimmerman and Qaim, 2004).

If, upon consuming the iron-biofortified crop, iron intake is increased, the iron deficit is decreased, and the incidence of illnesses caused by this micronutrient deficiency is decreased, the number of DALYs lost in the scenario with biofortification would be lower than that lost in the baseline scenario or without biofortification, resulting in a positive impact:

Impact of biofortification = DALYs lost with biofortification – DALYs lost without biofortification.

The methodology makes it possible to estimate the impact that the greater intake of iron would have on health by reducing the incidence of the diseases related to iron deficiency, as can be seen in the next equation (Zimmerman and Qaim, 2004):

$$DALYslost = \sum_j T_j M_j \left(\frac{1 - e^{-rL_j}}{r} \right) + \sum_i \sum_j T_j I_{ij} D_{ij} \left(\frac{1 - e^{-rd_{ij}}}{r} \right)$$

Tj = Total number of people in target group j

Mj = Rate of mortality associated with the deficiency in target group j

Lj = Average life expectancy remaining in target group j

Iij = Rate of incidence of illness i in target group j

Dij = Weight of the incapacity due to illness i in target group j

dij = Duration of illness i in target group j (for permanent disability dij is equal to the average of the remaining life expectancy Lj)

r = Rate of discount for years of future life.

For the DALYs calculations, the first step was to identify the conditions related to iron deficiency, which cause incapacity and loss in productivity (Stein *et al*. 2005). Consequences of iron deficiency may include anemia which can cause damage in motor functions and in psychological development and maternal mortality and increases in stillbirths and infant mortality (Hotz, 2004).

The second step was to identify the population groups affected and to estimate its size according to the different age ranges based on national population censuses. Since iron deficiency does not affect all population groups in the same way, a distinction was made among children less than 5 years of age, children 6-14 years, women over 15 years and men older than 15 years. For example, damage in psychological development can affect boys and girls 5 years or younger, while maternal mortality can affect women of reproductive age (15-49 years).(The World Bank Group, 2008).

The number of potential cases that could develop each illness was estimated by multiplying the population by the incidence within each age group. For the incidence rate, information from World Health Organization was used (WHO, 2008). After that, to estimate the years during which those affected would live with illnesses or the incapacities stemming from such illnesses, the average age at which these conditions or illnesses commonly occur (Stein *et al*, 2005) (ref), the life expectancy of the Honduran population at birth (The World Bank Group, 2008), and the duration of illness (Stein *et al*, 2005) (ref) were used. Then, multiplying these years by the weight of the incapacity due to each illness (Stein *et al*, 2005) the number of healthy years that would be lost as a result of such an ailment (*DALYs lost*) was calculated for each population group.

To determine the magnitude of dietary iron deficiency based on average intakes in Honduras, a food composition table was used to estimate the level of individual consumption for iron, thereby characterizing the overall diet of the groups under analysis (Stein *et al*, 2005). Some data from National Survey of Honduras (Secretaria de Salud de Honduras, 2005) was used for this purpose.

The amount of iron that the target group would ingest from the biofortified beans and rice was estimated using the additional amount of iron that the crops would have once they are biofortified and the farmers' level of adoption, given that not all farmers will adopt the variety or dedicate the entire area planted to the biofortified variety. Therefore, the total crop amount consumed by the target population will not be biofortified, given that non-biofortified varieties will also be available in the market. Information about the amount of iron lost due to post-harvest activities such as handling, cooking, etc. (personal communication Steve Bebbe y Cesar Martinez), were taken into account. The next step was to simulate the scenario once the biofortified varieties have been released and adopted by producers and consumers. Given that the majority of these varieties being developed have not been disseminated, much less adopted or consumed by the target population, a series of assumptions were made to simulate a scenario with biofortification, one optimistic and another pessimistic (Tables 1 and 2).

Table 1. Assumptions for iron-biofortified beans in pessimistic and optimistic scenarios

Assumption	Pessimistic scenario	Optimistic scenario
Additional iron content (µg/gr.)	30	50
Post-harvest losses (cooking, handling, etc.) (%)	10	0
Crop adoption rate (%)	20	50

Personal communication, Steve Beebe, Head Bean Programme at CIAT.2007

Table 2. Assumptions for iron-biofortified rice in pessimistic and optimistic scenarios

Assumption	Pessimistic scenario	Optimistic scenario
Additional iron content (µg/ gr.)	3	6
Post-harvest losses (cooking, handling, etc.) (%)	10	0
Crop coverage rate (%)	20	50

Personal communication, César Martinez, Head Rice Programme at CIAT.2007

To estimate the amount of additional iron that Hondurans would ingest once they consume the biofortified rice and bean, iron coming from the diet without the biofortified products (Secretaria de Salud de Honduras, 2005) were added to that supplied by the biofortified crops. After that, the iron deficit in the diet was estimated comparing iron intake levels with the Recommended Dietary Allowance (RDA) for the United States and Canada (Institute of Medicine , 2001).

Once the scenario with biofortified beans and rice consumption was simulated, and the new iron intake estimated, the new incidence for the illnesses related to iron deficiency was estimated (Stein *et al*, 2005). With the new incidence, the number of new cases of ailments stemming from iron deficiency was estimated for both pessimistic and optimistic scenarios (Tables 3 and 4).

Table 3. Incidence and number of those affected by illnesses stemming from iron deficiency in Honduras. Pessimistic scenario.

Functional outcomes related to Iron Deficiency Anemia	Iron Deficiency Anemia nivel	Children (<=5 years)		Children (6-14 years)	
		New Incidence Rate (%)	New Number of Affected (Thousand)	New Incidence Rate (%)	New Number of Affected (Thousand)
Impaired physical activity	Moderate	6.66	7,755.89	1.56	2588.35
	Severe	0.01	8.56	0.00	3.59
Impaired mental development	Moderate	5.82	6,779.98	0.00	0.00
	Severe	0.00	0.77	0.00	0.00
Stunting		0.00	0.00	0.00	0.00
		Women (>= 15 years)		**Men (>= 15 years)**	
Impaired physical activity	Moderate	0.49	1066.31	0.21	466.31
	Severe	0.00	9.19	0.00	0.46

Table 4. Incidence and number of those affected by illnesses stemming from iron deficiency in Honduras. Optimistic scenario.

Functional outcomes related to Iron Deficiency Anemia	Iron Deficiency Anemia Nivel	Children (<=5 years)		Children (6-14 years)	
		New Incidence Rate (%)	New Number of Affected (Thousand)	New Incideence rate (%)	New Number of Affected (Thousand)
Impaired physical activity	Moderate	4.12	4,793.74	0.94	1568.619
	Severe	0.00	5.29	0.00	2.179
Impaired mental development	Moderate	3.60	4,190.55	0.00	0.000
	Severe	0.00	0.48	0.00	0.000
Stunting		0.00	0.00	0.00	0.000
		Women (>= 15 years)		**Men (>= 15 years)**	
Impaired physical activity	Moderate	0.33	729.12	0.13	291.45
	Severe	0.00	6.29	0.00	0.29

The number of healthy years that would be lost were estimated in the pessimistic and optimistic biofortification scenarios using the number of new cases of the resulting ailments that would occur, as well as data on the severity of the incapacity, its duration and average age of occurrence.

The DALYs that would be lost in the biofortification models were compared with those obtained in the model without biofortification in order to estimate the number of healthy years that society would lose due to the iron deficiency studied. This is the amount of time expressed in additional healthy years that Hondurans would be able to contribute to their economy if they did not lose their physical and intellectual capacities, partially or totally, due to the iron deficiency. Multiplying this DALYs by the national per capita income (The World Bank Group, 2008), the contribution of biofortification to the country's Gross National Product (GNP) was estimated.

5.3 Results

Under current conditions, without biofortification and with an average deficit in iron intake of 4,277 µg/day, Honduras' society is losing 2.6 million DALYs or healthy years annually. In monetary terms using national per capita income, this implies that Honduras is losing 3,000 million dollars annually (Table 5).

Table 5. DALYs lost annually due to iron deficiency without biofortification

Loss	**Lost**	**Children <= 5**	**Children 6-14**	**Women >= 15**	**Men >= 15**	**Total**
due to mortality	YLL	119	0	341	0	460
due to temporal disability	YLD temp	539,383	236,481	335,931	146,550	1,258,345
due to permanent disability	YLD perm	1,407,973	0	0	0	1,407,973
Total due to disability	YLD Total	1,947,356	236,481	335,931	146,550	2,666,318
Total	DALY Lost	1,947,476	236,481	336,272	146,550	2,666,779
In monetary terms (million US$)		2,218.2	269.4	383.0	166.9	3,037.5

Introducing AgroSalud’s iron-biofortifed rice and beans in Honduras, in a pessimistic scenario the iron supplied in the daily diet would be improved by 10,456 µg/day for children under 5 years, 11,049 in children between 6 and 14 years, 11,826 in women 15 years and older and 12,456 in men 15 years and older (Table 6). As such, iron-biofortifed rice and beans could contribute to reducing iron deficiency by 24.15% to 126.68%, depending on the demographic group. Consequently, the health burden could be reduced on average 17.5% and a total of 465,826 DALYs or healthy years could be gained (table 7), representing US$530.6 millions dollars saved annually.

Table 6. MAIN results for impact estimation of iron-biofortifed rice and beans in Honduras (pessimistic scenario).

	Children <= 5 years old	**Children 6-14 years old**	**Women >= 15 years old**	**Men >= 15 years old**
Current iron supply from all food sources (µg/day)	8,590	9,150	9,860	10,290
Current iron deficit (µg/day)	2,410	4,850	8,140	1,710
Improved iron supply (µg/day) with biofortified drice and beans.	10,456	11,049	11,826	12,456
Contribution of iron-biofortifed rice and beans to reduce iron deficit (%)	77.4	39.17	24.15	126.68
Gained with biofortification (DALYs)	372,044	31,753	32,720	29,310
Gained with biofortification (million US$)	423,758	36,167	37,268	33,384

In the optimistic scenario, the health burden is reduced by an average of 48.3% and 1.4 million DALYs could be gained annually, representing US$1,467 millions dollars saved (Table 7), through a 46.43% improvement in iron intake in women 15 years and older, 243.5% in men 15 years and older and 148.85% in children less than 5 years due to the consumption of biofortified rice and beans.

Table 7. MAIN results for impact estimation of iron-biofortifed rice and beans in Honduras (optimistic scenario).

	Children <= 5 years old	Children 6-14 years old	Women >= 15 years old	Men >= 15 years old
Current iron supply from all food sources (µg/day)	8,590	9,150	9,860	10,290
Current iron deficit (µg/day)	2,410	4,850	8,140	1,710
Improved iron supply (µg/day) with biofortifed-rice and beans.	12,177.2	12,801.2	13,639.3	14,453.7
Contribution of iron biofortifed rice and beans to reduce iron deficit (%)	148.85	75.28	46.43	243.49
DALYs gained with biofortification	973,752	112,409	128,708	73,275
In monetary terms (millions US$)	1,109,104	128,034	146,598	83,460

5.4 Discussion and conclusions

Previous analysis has been done for the impact estimation of single biofortified crops, e.g. iron-biofortified bean, zinc-biofortified rice, etc. for Honduras and other Latin American countries (Johnson, 2004) (Meenakshi, 2006), but impact estimation of two or more biofortified crops under a diet scenario has not been carried out before. The singles analyses showed that iron-biofortified beans could reduce by 4% and 22% the number of DALYs lost by iron deficiency anemia in a pessimistic and optimistic scenario respectively (Meenakshi, 2006). In the case of iron biofortified rice, the number of DALYs gained could be 5.2% and 25,81% for each scenario (Salomón Pérez, unpublished data). Meanwhile, the number of DALYs gained by the combination of iron-biofortified rice and beans in the current study in Honduras are 17.47% and 483% in a pessimistic and optimistic scenario respectively. The highest results for iron biofortified rice and beans is based in that both crops are consumed every day in most of the Hondurans dishes, being complementary crops into their diets.

The consumption of iron-biofortifed rice and beans are a good alternative to reduce iron-deficiency anemia—in Honduras. Introducing these biofortifed crops could substantially reduce the deficit in iron intake; for some population groups (list which ones), these crops could meet 100% of the iron deficit. In turn, this dietary improvement reduces DALYs by approximately

18% and 49% for a pessimistic and optimistic scenario respectively. In this way, DALYs saved can be seen as an indicator of food security improvements.

If comparable results are obtained in other countries, biofortification could be an alternative to improve food security in many regions through the supply of traditional crops with higher contents of essential nutrients, which can reduce these nutrient deficiencies and the health outcomes related to them, without additional costs or diet changes. For that, more investment in biofortification research, development and dissemination must be done in order to bring to farmers new varieties with better nutritional levels that retain the agronomic and quality aspects required by consumers and producers. The latter form the base for the adoption process and the sustainability of this process.

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8. Appendix

Appendix 1. Population by group age in Honduras.

Group	Population
Total	7,206,780
Children <=5 years	1,164,042
Children 6-14 years	1,660,998
Women >=15 years	2,188,685

Men >=15 years	2,193,055

Source: World Bank statistics (The World Bank Group, 2008)

Appendix 2. Diseases related to iron deficiency, degree of incapacity generated, average age at which the illness appears, life expectancy at birth, rate of incidence and number of people affected by iron deficiency in Honduras according to age ranges. Scenario without biofortification.

Functional outcomes related to Iron Deficiency Anemia	IDA nivel	Children			Children (<=5 years)			Children (6-14 years)		
		Disability weights	Average age of onset (years)	Rest of Life	Incidence rate %	Number of affected (thousand)	Duration of the disease (years)	Incidence rate (%)	Number of affected (thousand)*	Duration of the disease (years)
Impaired physical activity	Moderate	1.1%	0.5		8.236	9,587.5	5.5	1.800	2,989.8	8.0
	Severe	8.7%	6.0		0.009	10.6	5.5	0.003	4.2	8.0
Impaired mental development	Moderate	0.6%	5.0	66.0	7.200	8,381.1	61.0			
	Severe	2.4%			0.001	1.0	61.0			
Stunting		0.0%	0.0	0.0	0.000%	0.0	0.0			
		Adults			**Women (>= 15 years)**			**Men (>= 15 years)**		
Impaired physical activity	Moderate	1.1%	15.0	58.0	0.540	1,180.9	43.0	0.266	582.9	38.0
	Severe	9.0%	15.0	53.0	0.005	10.2	43.0	0.000	0.6	38.0

*Result of multiplying the population of said target group by the incidence.

N/A: Not Applicable

Appendix 3. Incidence rates and number of people affected by iron deficiency anemia after iron biofortification of rice and beans (pessimistic scenario)

Functional outcomes related to Iron Deficiency Anemia	IDA nivel	Children (<=5 years)		Children (6-14 years)	
		New Incidence rate (%)	**New Number of affected (thousand)**	**New Incidence rate (%)**	**New Number of affected (thousand)**
Impaired physical activity	Moderate	6.66	7,755.89	1.56	2588.35
	Severe	0.01	8.56	0.00	3.59
Impaired mental development	Moderate	5.82	6,779.98	0.00	0.00
	Severe	0.00	0.77	0.00	0.00
Stunting		0.00	0.00	0.00	0.00
		Women (>= 15 years)		**Men (>= 15 years)**	
Impaired physical activity	Moderate	0.49	1066.31	0.21	466.31
	Severe	0.00	9.19	0.00	0.46

Appendix 4. Incidence rates and number of people affected by iron deficiency anemia after biofortification (optimistic scenario)

Functional outcomes related to IDA	IDA nivel	Children (<=5 years)		Children (6-14 years)	
		New Incidence rate (%)	**New Number of affected (thousand)**	**New Incideence rate (%)**	**New Number of affected (thousand)**
Impaired physical activity	Moderate	4.12	4,793.74	0.94	1568.619
	Severe	0.00	5.29	0.00	2.179
Impaired mental development	Moderate	3.60	4,190.55	0.00	0.000
	Severe	0.00	0.48	0.00	0.000
Stunting		0.00	0.00	0.00	0.000
		Women (>= 15 years)		**Men (>= 15 years)**	
Impaired physical activity	Moderate	0.33	729.12	0.13	291.45

Severe	0.00	6.29	0.00	0.29

Appendix 5. DALYs lost with iron-biofortified rice and beans in Honduras (pessimistic scenario)

Loss	Lost	Children <= 5	Children 6-14	Women >= 15	Men >= 15	Total
due to mortality	YLL	97	0	212	0	309
due to temporal disability	YLD temp	436,340	204,728	303,341	117,240	1,061,649
due to permanent disability	YLD perm	1,138,994	0	0	0	1,138,994
Total due to disability	YLD Total	1,575,334	204,728	303,341	117,240	2,200,643
Total	DALY Lost	1,575,432	204,728	303,552	117,240	2,200,952
In monetary terms (million US$)		1,794.4	233.2	345.7	133.5	2,506.9

Appendix 6. DALYs lost with iron-biofortified rice and beans in Honduras (optimistic scenario)

Loss	Lost	Children <= 5	Children 6-14	Women >= 15	Men >= 15	Total
due to mortality	YLL	46	0	145	0	190
due to temporal disability	YLD temp	269,692	124,071	207,419	73,275	674,457
due to permanent disability	YLD perm	703,986	0	0	0	703,986
Total due to disability	YLD Total	973,678	124,071	207,419	73,275	1,378,444
Total	DALY Lost	973,724	124,071	207,564	73,275	1,378,634
In monetary terms (million US$)		1,109.1	141.3	236.4	83.5	1,570.3