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Agronomic Biofortification from a Stakeholder's Viewpoint

Evidence from Studies on Iodine-Enriched Foods in Uganda

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List of Abbreviations

AHP	Analytical Hierarchy Process
IDDs	Iodine Deficiency Disorders
PMT	Protection Motivation Theory
SWOT	Strengths, Weaknesses, Opportunities, and Threats
USI	Universal Salt Iodization

8.1 Introduction

In the last decades, considerable progress has been made in global nutrition and health, but the Sustainable Development Goals (SDGs) that aim to tackle nutritional deficiencies are far from being met (Fullman et al. 2017; Hay et al. 2017; Sachs 2012). Agriculture, through nutrition-sensitive interventions, will inevitably play a crucial role in helping to meet global targets on nutrition and health (Fiorella et al. 2016; Jaenicke and Virchow 2013; Pandey et al. 2016; Ruel and Alderman 2013). Nevertheless, technologies and innovations in the history of agriculture were mainly targeted at increasing production and productivity to tackle food insecurity and end hunger, rather than improving nutrient and other quality traits in food crops (Zhao and Shewry 2011). As a consequence, many agricultural systems currently fail to sustainably deliver micronutrients (Burchi et al. 2011; Pandey et al. 2016; Welch and Graham 2005). Consequently, people's diets in poor, developing regions are

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dominated by staples low in vitamins and minerals (Cakmak et al. 2017; Carvalho and Vasconcelos 2013). As of today, micronutrient malnutrition, known as *hidden hunger,* affects nearly half of the world's population (Carvalho and Vasconcelos 2013; Govindaraj 2015; Kennedy et al. 2003; Muthayya et al. 2013; Saltzman et al. 2017; Stein 2010).

Iodine deficiency, a well-known cause of preventable mental retardation, is still a major public health problem, with a third of the total population not meeting the recommended iodine levels (Smoleń and Sady 2012), including about 241 million school-aged children (Andersson et al. 2012). Worldwide, about 2 billion people are estimated to be at risk of iodine deficiency (Gonzali et al. 2017; Li and Eastman 2012), especially those resource-poor households from landlocked regions that have a lack of access to iodine-rich seafoods or from frequently flooded areas, where mineral plant uptake from the soil is hampered (Fuge and Johnson 2015; Miller and Welch 2013).

Iodine is an essential trace element needed in the production of thyroid hormones, and its deficiency has been associated with a number of adverse health outcomes, collectively coined as iodine deficiency disorders (IDDs), such as goiter, preventable mental retardation, and cretinism (Fuge and Johnson 2015; Li and Eastman 2012). Universal salt iodization (USI) is generally considered to be a successful strategy to enhance iodine intake levels, but alone they are not sufficient to tackle IDDs in endemic areas, especially in rural landlocked regions of the developing world (Pearce et al. 2013; Zimmermann and Andersson 2012). Moreover, in view of the impacts of salt consumption on cardiovascular diseases such as hypertension (Cerretani et al. 2014), the need for novel, complementary strategies to improve iodine intake levels has been highly recommended by the World Health Organization (Smoleń and Sady 2012).

Biofortification, the process of enriching staple foods with essential micronutrients, is one such strategy that has shown to be an effective way to increase vitamin and mineral levels in various staple crops (Bouis and Saltzman 2017; De Steur et al. 2015a) and humans (De Moura et al. 2014; De Steur et al. 2017a). There are three types of biofortification, depending on the technology behind the micronutrient enhancement: conventional biofortification (crossbreeding), GM biofortification (biotechnology), and, only in the case of minerals, agronomic biofortification (mineral fertilization) (Carvalho and Vasconcelos 2013; Codex Alimentarius Commission 2015). For iodine, biofortification can be achieved using these three techniques: conventional plant breeding, genetic modification, or applying nutrient-rich fertilizers to soils or by foliar spraying of crops (Gonzali et al. 2017; Perez-Massot et al. 2013; Zhu et al. 2007).

Despite the potential of iodine and other biofortified crops to fight the hidden hunger and contribute to nutrition-related SDGs (Adenle et al. 2019; Bouis and Saltzman 2017; Mayer et al. 2008; Thompson and Amoroso 2010), its success will ultimately depend on whether stakeholders, including farmers, consumers, regulators, and health planners, accept and adopt it. Previous biofortification studies have mainly targeted consumers and evaluate their acceptance and willingness-to-pay (Birol et al. 2015a; De Steur et al. 2017b; Talsma et al. 2017). Aside from a small number of farmer studies (Birol et al. 2009, 2015b), other stakeholders are hardly considered as a targeted group to evaluate their reactions to biofortification.

This chapter provides an overview of two case studies that examine stakeholder reactions toward iodine biofortification in Uganda. In this area, many children live in iodine-poor regions with limited access to fish, seafood, or iodized salt (Acham et al. 2012; Bimenya et al. 2002; Ehrenkranz et al. 2011; FAO 2010a; WHO 2010), which accounts for substantial prevalence rates of iodine deficiency (ICCIDD 2013, Uganda Bureau of Statistics (UBOS) and ICF 2017).

The first case study (De Steur et al. 2015b) applies the protection motivation theory (PMT) to determine preferences of 360 parents of primary school children and 40 school heads toward the potential use of iodine-biofortified legumes in school meals in Uganda. PMT aims to evaluate the decision-making process of an individual with respect to both a trait and coping strategy, respectively maladaptive and adaptive behavior (Maddux and Rogers 1983; Rogers 1975). Thereby, the threat appraisal consists of the perceived fear, severity, and vulnerability of the threat, while the coping appraisal deals with self-efficacy, response efficacy, and response costs, with higher threat/coping appraisal leading to a higher intention to adopt a strategy (e.g. biofortified food consumption). The PMT model has been used in various settings and sectors (Floyd et al. 2000; Milne et al. 2000), including in the field of functional foods (Cox and Bastiaans 2007; Henson et al. 2008; Mabaya et al. 2010). Here, the focus is on iodine biofortification for children, through surveying their parents and school heads, as there is a clear association between iodine deficiency and school performance (Bougma et al. 2013; Pineda-Lucatero et al. 2008; Qian et al. 2005). Moreover, there is a lack of iodine-rich foods in East-African school feeding programs (Murphy et al. 2007).

The second case study (Olum et al. 2018) has a broader scope as it uses a multi-stakeholder SWOT-AHP (Strengths, Weaknesses, Opportunities, and Threats; Analytical Hierarchy Process) analysis to identify the most important factors that can inform the development of agronomic iodine biofortification in Uganda. In total, representatives from seven stakeholder groups participated in this study. Notwithstanding the various stakeholder analysis tools that are applicable to food, such as SWOT analysis, AHP analysis, Stochastic Multicriteria Acceptability Analysis (SMAA), Stochastic Multicriteria Acceptability Analysis with Ordinal criteria (SMAA-O), Simple Multi-Attribute Rating Technique (SMART), S-O-S (SMAA-O in SWOT), Strategic Orientation Rounds (SOR), and Delphi Rounds (Kajanus et al. 2012; Rutsaert et al. 2014; Wentholt et al. 2009), the combination SWOT-AHP was selected for several reasons. Through its quantitative approach, AHP allows for prioritization and stakeholder comparison, and hence addresses criticisms of SWOT analysis (Shinno et al. 2006). Another contribution is the pairwise comparison of preferences (Kauko 2004; Reed et al. 2014), by which each factor is weighted against all other factors, each one at a time, aside from assessment of an overall influence according to the eigenvalue method (priority scoring approach) (Saaty 2008). This method has been recently applied in different agricultural interventions, though often only for a small number of stakeholder groups, such as farmers (Bhatta and Doppler 2010; Reed et al. 2014; Shrestha et al. 2004; Stainback et al. 2012).

In the next sections, a brief overview of the methods and the most important findings of each of the studies will be given, followed by a general discussion.

8.2 Study Design

8.2.1 Protection Motivation Behavior of Households and School Heads

A multi-stakeholder's consultative workshop was conducted in Northern Uganda (this study was based in Kisoro District of Uganda, which is historically a region with the highest prevalence of endemic iodine deficiency (WHO 2006), mainly due to its mountainous landscape, liable to longstanding iodine leaching from soil, and its limited accessibility, which impedes coverage of iodized salt intervention. As we aimed to evaluate the potential of implementing iodine-biofortified legumes at schools and school feeding programs, in order to reach school-aged children, our first survey on stakeholder reactions was conducted at school and household levels. Thereby, we have used a cross-sectional study design among school heads and parents. First, 40 out of 136 eligible schools were systematically selected. From each school, nine households were randomly selected, bringing the total sample size to 360 households.

Structured questionnaires were used for each group of respondents (households versus school heads) and consisted of the socio-demographic profile, knowledge about micronutrients, iodine, IDDs, and possible interventions (salt iodization and biofortification). Knowledge was assessed using a five-point scale of familiarity (1 "not at all familiar" to 5 "extremely familiar") in line with previous literature (Jooste et al. 2005; Mohapatra et al. 2001; Otieno et al. 2013). A couple of awareness questions were added to assess the awareness about the link between iodine intake and mental development or school performance (1 "not at all aware" to 5 "extremely aware"). School heads and parents were also required to give their opinion about the risk of IDDs and living in hilly areas in addition to the adequacy of children's diet with regard to adequate iodine intake (1 "yes" to 3 "don't know"). Reliability analysis was used to develop an overall knowledge construct for school heads (Cronbach's $\alpha = 0.78$) and parents (Cronbach's $\alpha = 0.84$).

In addition, PMT constructs, measured at a five-point Likert scale ("strongly disagree" = 1 to "strongly agree" = 5 or "extremely unlikely" = 1 to "extremely likely" = 5), were also developed, in line with previous studies (Cox et al. 2004, 2008; Henson et al. 2010a, b; Hodgkins and Orbell 1998; Talsma et al. 2013) (see Table 8.1).

Perceived severity, perceived vulnerability, and perceived fear belong to the composite factor threat appraisal, which generated a Cronbach's alpha value of 0.71 for school heads and 0.78 for parents. Coping appraisal, which consists of self-efficacy, response efficacy, and response cost, had a Cronbach's alpha of 0.74 school heads and 0.62 for parents, respectively. For the protection motivation construct itself, school head had a Cronbach's alpha of 0.68, whereas parents had 0.69.

8.2.2 SWOT-AHP Analysis by Key Stakeholder Groups

A multi-stakeholder's consultative workshop was conducted in Northern Uganda (for an in-depth overview of the design and methods, see Olum et al. (2018)). This workshop involved 56 participants from seven stakeholders' groups. The participants represented stakeholders who could influence the production, marketing, policy, and regulatory environment of iodine biofortification once it would be implemented. The stakeholder groups include representatives from academia, district counselors, community development officers (CDO), elite farmers, agro-input companies, government extension officers, and nongovernmental organizations (NGOs) extension officers. The workshop employed a hybrid SWOT-AHP tool to explore perceptions of stakeholders on factors that could affect the implementation of agronomic iodine biofortification from a developing country context. The SWOT analysis is the most commonly used tool for evaluating internal (strengths and weaknesses) and external (opportunities and threats) factors when formulating implementation strategies of a project or intervention

Table 8.1 Constructs and items of the protection motivation theory, as applied to the case of biofortification to tackle iodine deficiency in Uganda.

Construct	Item
Perceived severity	IDDs frighten you as a very serious health problem.
	You know children who have suffered from IDDs.
	It is possible that children and/or schools perform poorly because of iodine deficiency.
Perceived vulnerability	You feel children are vulnerable to suffer from IDD if they do not eat iodine-rich foods.
	Children are likely to perform poorly at school due to iodine deficiency.
	In your opinion, is protecting children from the risk of IDDs by opting for foods rich in iodine important?
Perceived fear	Thoughts about IDDs affect your mood.
	The school performance of children affects your mood.
Self-efficacy	It is possible for your children to eat iodine-biofortified legumes at school.
	I would agree to include iodine-biofortified legumes in school meals.
Response efficacy	Consuming iodine-rich foods will reduce the risk of IDDs.
	Iodine-biofortified legumes will help improve school performance of children.
Response cost	I doubt the cost effectiveness of biofortified foods.
Protection motivation	How likely are you to accept iodine-biofortified legumes as a source of iodine for your children?
	How likely is it that you will include iodine-biofortified legumes in the household/school menu for the children?
	Are you likely to buy iodine-biofortified legumes for the household/school?
	I will consider advocating for inclusion of iodine-biofortified legumes in school meals.

(Shafieyan et al. 2017; Zarafshani et al. 2015), but its qualitative information makes it often hard to use it (solely) as a tool for decision making (Shinno et al. 2006). To overcome this drawback, the tool was applied in combination with AHP, a multi-criteria decision analysis (MCDA) method based on pairwise comparison and weighing of factors using priority scoring (eigenvalue) techniques (Saaty 2008).

Based on this SWOT-AHP method, data was collected in the following phases: First, participants worked in small groups (three to five) to brainstorm on the identification of SWOT aspects related to agronomic iodine biofortification. Thereby, a short presentation was given on how to participate in SWOT analysis. The groups' SWOT factors were then presented and related factors were combined to produce final list agreeable to everyone. In the second phase, each stakeholder group (e.g. representatives of agro-input companies in one group) carried out pairwise comparison among the SWOT factors generated: first between selected top five factors in each SWOT category (e.g. all strength factors) and second, between the SWOT categories (e.g. all strengths vs all weaknesses). All pairwise comparisons were made on an importance scale of 1–9, as proposed by Saaty (2002), where '1' means that the two factors are equally important and '9' means that one factor is by far more important than the other). During the exercise, the stakeholders were asked to critically assess each pair of factors one at a time and honestly quantify their relative importance, given that guessing would lead to inconsistent results.

8.3 Data Analysis

8.3.1 Protection Motivation Behavior of Households/School Heads

Data were analyzed using StataIC v.12, Chi-square test for proportions and Mann–Whitney U tests to compare means. For the knowledge and PMT constructs, factor scores were extracted using factor analysis and they were justified based on reliability assessment of Cronbach's alpha (Rowe 2006). The relationships between variable in the PMT model and others were determined using multiple linear regression.

8.3.2 SWOT-AHP Analysis by Key Stakeholder Groups

Data from pairwise comparisons were analyzed using eigenvalue method to generate priority scores for the SWOT factors (Olum et al. 2018). First, data from pairwise comparison is entered into a reciprocal judgment matrix A where relative weights w are represented by a_{ij} = the element of row i and column j and its reciprocal $1/a_{ij}$ on the opposite side of the diagonal. All elements along the diagonal take a value of 1 as they are being compared to themselves.

$$A = a_{ij} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & w_1/w_3 .. w_1/w_n \\ w_2/w_1 & w_2/w_2 & w_2/w_3 .. w_2/w_n \\ w_3/w_1 & w_3/w_2 & w_3/w_3 .. w_3/w_n \\ \vdots & \vdots & \vdots \; \dots \; \vdots \\ w_n/w_1 & w_n/w_2 & w_n/w_3 \dots w_n/w_n \end{bmatrix}$$

Second, each element of the matrix is divided by the total of its column. To normalize the eigenvector, the elements of each row is then summed and divided by the number of elements in the same row. Two kinds of priority scores are generated, i.e. local priority scores, which reflects priorities (importance) of factors within SWOT categories, and the global priority scores, which prioritizes factors across categories. The priority scores of SWOT categories (e.g. Strength category) are referred to as *scaling factors*.

The eigen vector was examined for consistency of answering, using the following equations:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

$$CR = CI / RI$$

CI = Consistency ratio; CI = Consistency index; RI = Random index produced by a random matrix of order n (for the Random index table, see Saaty (2002)); n = number of pairwise comparisons; and λ_{max} = the biggest eigenvalue of the matrix.

As a general rule, the pairwise comparison matrix were accepted if it produced a CR equal or below 0.1 (Saaty 2008). If this was not the case, elements forming the matrix were reexamined.

8.4 Results of the Case Study

8.4.1 Protection Motivation Behavior of Stakeholders (Households/School Heads) (Case 1)

8.4.1.1 Characteristics of Respondents

In both the sample of school heads and parents, there were more male than female respondents, with a similar mean of age around 35–37 years (see Table 8.2). As expected, school heads were on average more educated than parents. The formers were mostly employed by the government or privately unlike the latter. Parents had a lower income (70 US$ per month), hence highlighting the socioeconomic challenges they face. School heads were also more optimistic about children's academic performance compared to parents which is reflected in the significantly higher degree of perceived academic satisfaction of children. With regard to school feeding programs, only three in five schools were already implementing such programs with mostly parents contributing to sustain them. The primary source of food different between schools (own farm) and parents (markets). Results further indicated

Table 8.2 Sample descriptives of school heads and parents in Kisoro, Uganda.

	Respondents				
Characteristic	**School heads (*n* = 40)**		**Parents (*n* = 360)**		***p*-value**
	n	**%**	***n***	**%**	
Gender					
Male	30	75	190	52.8	0.007**
Female	10	25	170	47.2	
Age (mean ± SD)	36.9[a]	±10.35[a]	34.9[a]	±8.48[a]	0.347
Education level					
No formal education	0	0	73	20.3	
Primary education	0	0	114	31.7	
Secondary education	0	0	83	23.1	0.001***
Tertiary	40	100	82	22.8	
University	0	0	8	2.2	
Occupation					
Unemployed	0	0	84	23.3	
Casual worker	0	0	11	3.1	0.001***
Self-employed	0	0	190	52.8	

(*Continued*)

Table 8.2 (Continued)

	Respondents				
Characteristic	**School heads (*n* = 40)**		**Parents (*n* = 360)**		***p*-value**
Government/private worker	40	100	75	20.8	
Income (mean ± SD) (in UGX)	—	—	174 400[a]	±148 850[a]	
Size (mean ± SD)	644.43[a]	±323.29[a]	2.37[a]	±0.998[a]	
Children's academic performance					
Poor	0	0	151	41.9	
Fair	7	17.5	52	14.4	
Good	25	62.5	75	20.8	0.001***
Very good	6	15.0	41	11.4	
Excellent	2	5.0	41	11.4	
Academic performance satisfaction					
Not at all satisfied	6	15.0	123	34.2	
Slightly satisfied	9	22.0	61	16.9	0.001***
Moderately satisfied	22	55.0	32	8.9	
Very satisfied	3	7.5	109	30.3	
Extremely satisfied	0	0.0	35	9.7	
School feeding program					
Yes	60	60.0	—	—	
No	40	40.0	—	—	
Support source ($n = 24$)[a]					
Parents	23	95.8	—	—	
Government	1	4.2	—	—	
Source of food					
Own farm	2	8.3	215	59.7	
Market	21	87.5	134	37.2	0.001***
Donation	1	4.2	11	3.1	
Type of salt used					
Traditional	2	5.0	53	14.7	
Industrial iodized	38	95.0	243	67.5	0.001***
Both	0	0.0	64	17.8	
Frequency of iodized salt intake	5.79	±1.64	5.66	±2.22	0.494

UGX, Ugandan shillings; SD, standard deviation.
Note: Based on De Steur et al. (2015b). Proportions and means were compared using Chi-square tests and Mann–Whitney U test, respectively.
, * denote significance at 0.01 and 0.001, respectively.
[a] Values refer to means and standard deviations.

that iodized salt was commonly used at school but not at home, where most parents still used traditional, noniodized salt. Nevertheless, the mean consumption of iodized salt was the same in both samples.

Knowledge about salt iodization and iodine was high among school heads and parents, but they were less familiar with IDDs, vitamins, and minerals applies (see De Steur et al. 2015b). Lack of knowledge about micronutrients is worse, especially among school heads, of which 60% had even reported to run a school feeding program (De Steur et al. 2015b). As expected, knowledge about biofortification was low for both groups.

8.4.1.2 Effect of Protection Motivation Constructs on the Intention to Adopt Biofortified Legumes

When looking at the scores on the protection motivation constructs, threat appraisal was generally high for both samples. This was mainly attributable to the high values of perceived fear and vulnerability. However, it was only perceived vulnerability that differed significantly between school heads and parents. Coping appraisal was also high, contrary to the low response cost in both samples. Protection motivation was also significantly higher among parents as compared to school heads (Table 8.3).

Tables 8.4 and 8.5 present the results of the multiple regression analysis which assess how variables external to the PMT model influenced each of the composite constructs of the PMT. Findings show that age, occupation, household size, and income significantly affected parents' threat appraisal. Male school heads had a higher level of coping appraisal, while only occupation, education, and age negatively affected coping appraisal among parents. However, knowledge about iodine and IDDs as well as household size were positive determinants of coping appraisal among parents. Occupation and knowledge showed significant effects on protection motivation to adopt biofortified foods only for parents.

Table 8.3 Variation in the protection motivation constructs between the school heads and parents of school children, depicting intention to adopt iodine-biofortified legumes.

	School heads (*n* = 40)		**Parents (*n* = 360)**		
Constructs of the PMT	**Mean**	**SD**	**Mean**	**SD**	***p*-value**
Threat appraisal	4.37	0.46	4.35	0.46	0.61
Perceived severity	4.12	0.68	4.08	0.62	0.57
Perceived vulnerability	4.53	0.46	4.37	0.57	0.05*
Perceived fear	4.63	0.49	4.74	0.54	0.08
Coping appraisal	4.36	0.44	4.50	0.47	0.03*
Response efficacy	4.31	0.55	4.30	0.54	0.86
Self-efficacy	4.40	0.47	4.70	0.55	0.00***
Response cost	2.48	1.26	2.18	0.92	0.25
Protection motivation	4.24	0.48	4.41	0.49	0.01**

Note: Based on De Steur et al. (2015b). Means were compared using Mann–Whitney U test.
*, **, *** denote significance at 0.05, 0.01, and 0.001, respectively.

Table 8.4 Predictors of the composite constructs of the PMT for use of iodine-biofortified legumes, for school heads in Kisoro, Uganda.

	Threat appraisal R^2 = 0.140		**Coping appraisal R^2 = 0.087**		**Protection motivation R^2 = 0.132**	
Predictor variables	**β**	***p*-value**	**β**	***p*-value**	**β**	***p*-value**
Gender	0.131	0.660	0.491	0.045*	0.268	0.431
Age	−0.006	0.637	0.008	0.674	−0.016	0.148
Education						
Occupation						
Income						
School size	0.001	0.128	0.0001	0.903	0.0003	0.460
Knowledge of IDDs	0.277	0.063	0.086	0.607	0.255	0.107
Satisfaction with academic performance	−0.040	0.766	−0.007	0.966	0.086	0.569

Note: Based on De Steur et al. (2015b).
*, **, *** denote significance at 0.05, 0.01, and 0.001, respectively.

Table 8.5 Predictors of the constructs of PMT for use of iodine-biofortified legumes, for parents of schoolchildren in Kisoro, Uganda.

	Threat appraisal R^2 = 0.104		**Coping appraisal R^2 = 0.133**		**Protection Motivation R^2 = 0.090**	
Predictor variables	**β**	***p*-value**	**β**	***p*-value**	**β**	***p*-value**
Gender	−0.073	0.493	−0.004	0.961	0.026	0.762
Age	−0.016	0.047*	−0.023	0.006**	−0.004	0.574
Education	−0.127	0.315	−0.291	0.019*	−0.254	0.126
Occupation	−0.628	0.001***	−0.611	0.002**	−0.571	0.006**
Income	0.004	0.002**	0.003	0.072	0.001	0.204
Household size	0.084	0.028*	0.098	0.005**	−0.007	0.865
Knowledge of IDDs	0.096	0.148	0.193	0.016*	0.160	0.017*
Satisfaction with performance at school	0.001	0.987	−0.012	0.808	0.062	0.225

Note: Based on De Steur et al. (2015b).
*, **, *** denote significance at 0.05, 0.01, and 0.001, respectively.

Combining independent PMT constructs with external determinants in Table 8.6 show that two variables had an effect on the intention to adopt biofortified legumes. Among school heads, it was only response cost that exhibited a significant negative effect on intention to adopt. Self-efficacy was relevant for the parents with a positive effect on intention to adopt iodine-biofortified legumes. Other constructs of the PMT model as well as socio-demographic

Table 8.6 Predictors of intention to adopt biofortified legumes among school heads and parents in Kisoro, Uganda, by multiple linear regression (Robust).

	School heads (R^2 = 0.424)		Parents[a] (R^2 = 0.457)	
Predictors	**β**	***p*-value**	**β**	***p*-value**
Gender	0.068	0.828	0.046	0.513
Age	−0.016	0.168	0.007	0.283
Education			−0.083	0.563
Occupation			−0.184	0.144
Income			−0.001	0.435
School/household size	0.0002	0.639	−0.061	0.069
Knowledge of iodine and IDD	0.265	0.113	0.056	0.167
Academic performance satisfaction	0.116	0.462	0.063	0.181
Perceived severity	0.162	0.517	0.206	0.089
Perceived vulnerability	0.049	0.842	0.007	0.910
Perceived fear	−0.077	0.638	0.025	0.575
Response efficacy	0.137	0.532	0.141	0.120
Self-efficacy	0.172	0.416	0.475	0.001***
Response cost	−0.217	0.041*	0.022	0.548

Note: Based on De Steur et al. (2015b).
*, *** denote significance at 0.05 and 0.001, respectively.
[a] Taking into account within and between cluster variances.

and other variables were not significant determinants of intention to adopt. As a whole, the significant variable accounted for a large variation of protection motivation (i.e. 42% for school heads and 45% for parents).

8.4.2 SWOT-AHP Analysis by Key Stakeholder Groups (Case 2)

Table 8.7 presents the priority scores of the internal (strengths and weaknesses) and external (opportunities and threats) factors that were generally agreed upon as being important for the implementation of agronomic iodine biofortification in a developing country context (Northern Uganda). The priority scores are the weights of each factors on the perceptions of the stakeholders on the development of agronomic iodine biofortification. As the priority scores are relative values generated from pairwise comparison of factors, those factors with low priorities should not be interpreted as unimportant for the development of agronomic iodine biofortification. Rather, they are important as compared to other factors.

The results show that the opportunities (priority score 0.499) and strengths (0.317) (positive factors) play the most important role in determining the overall perceptions of the consulted stakeholders. In other words, 81.6% (aggregated scores of strengths and opportunities) of the overall perception of agronomic iodine biofortification is dominated by positive factors, both internal and external. Nevertheless, the level of optimism varies according

Table 8.7 SWOT factors and their priority Scores (AHP) for the development of agronomic iodine biofortification.

SWOT Categories and factors	Local priority scores (within SWOT groups)						Global priority scores (across groups)						
	ACAD	NGO	GOV. ExT	CDO	AGRO. INPUT	FARM	ACAD	NGO	GOV. ExT	CDO	AGRO. INPUT	FARM	Overall
Strengths							**0.341**	**0.546**	**0.308**	**0.241**	**0.323**	**0.143**	**0.317**
S1: Less expensive way for fighting IDDs	0.123	0.219	0.134	0.093	0.077	0.059	0.042	0.120	0.041	0.022	0.025	0.008	0.043
S2: Simple, easily to implement	0.194	0.045	0.041	0.062	0.291	0.339	0.066	0.025	0.013	0.015	0.094	0.048	0.044
S3: Culturally acceptable in Uganda	0.304	0.042	0.140	0.372	0.429	0.060	0.104	0.023	0.043	0.090	0.139	0.009	0.068
S4: Reduce risks for chronic diseases	0.317	0.231	0.485	0.340	0.062	0.212	0.108	0.126	0.149	0.082	0.020	0.030	0.086
S5: Can be blended with other nutrients	0.062	0.464	0.200	0.133	0.142	0.330	0.021	0.253	0.062	0.032	0.046	0.047	0.077
Weaknesses							**0.074**	**0.059**	**0.051**	**0.058**	**0.052**	**0.076**	**0.062**
W1: Iodine fertilizers not readily available	0.327	0.038	0.069	0.065	0.283	0.051	0.024	0.002	0.004	0.004	0.015	0.004	0.009
W2: Fertilizers are expensive	0.231	0.056	0.131	0.100	0.103	0.052	0.017	0.003	0.007	0.006	0.005	0.004	0.007
W3: Overuse of I fertilizers cause toxicity	0.069	0.128	0.279	0.429	0.401	0.426	0.005	0.008	0.014	0.025	0.021	0.032	0.018
W4: Takes long to supply iodine	0.313	0.471	0.448	0.169	0.107	0.259	0.023	0.028	0.023	0.010	0.006	0.020	0.018
W5: Iodine volatile and can be lost	0.059	0.306	0.073	0.237	0.107	0.213	0.004	0.018	0.004	0.014	0.006	0.016	0.010
Opportunities							**0.408**	**0.329**	**0.546**	**0.552**	**0.574**	**0.584**	**0.499**
O1: Government support and extension	0.262	0.244	0.082	0.305	0.077	0.104	0.107	0.080	0.045	0.168	0.044	0.061	0.084
O2: Existence of fertile soils, deficient in I	0.156	0.075	0.390	0.033	0.185	0.370	0.064	0.025	0.213	0.018	0.106	0.216	0.107
O3: Emerging fertilizer companies	0.098	0.047	0.069	0.290	0.241	0.070	0.040	0.015	0.038	0.160	0.138	0.041	0.072
O4: High prevalence of IDDs	0.342	0.529	0.388	0.067	0.436	0.397	0.140	0.174	0.212	0.037	0.250	0.232	0.174
O5: Fertilizer policy in Uganda	0.141	0.104	0.072	0.305	0.060	0.059	0.058	0.034	0.039	0.168	0.034	0.034	0.061

Threats							**0.176**	**0.067**	**0.095**	**0.149**	**0.052**	**0.198**	**0.123**
T1: Low knowledge & awareness of farmers	0.187	0.247	0.140	0.405	0.234	0.571	0.033	0.017	0.013	0.060	0.012	0.113	0.041
T2: Fertilization affected by environment	0.053	0.064	0.071	0.062	0.124	0.062	0.009	0.004	0.007	0.009	0.006	0.012	0.008
T3: Low fertilizer use in Uganda	0.311	0.286	0.457	0.299	0.124	0.130	0.055	0.019	0.043	0.045	0.006	0.026	0.032
T4: Likely misconception of technology	0.147	0.106	0.079	0.054	0.049	0.095	0.026	0.007	0.008	0.008	0.003	0.019	0.012
T5: Competing needs for yield	0.301	0.297	0.253	0.180	0.471	0.142	0.053	0.020	0.024	0.027	0.024	0.028	0.029

ACAD: Academic group; GOV.EXT: Government extension group; CDO: Community development officers; AGRO.INPUT: Agro-input company sample; FARM: Elite farmers group.
Note: Based on Olum et al. (2018). Bold values indicate SWOT group (e.g. strengths combined) priority scores.

to the stakeholder group that is consulted. Within the negative factors, the threats contributed 12.3%, while all weaknesses together only contributed 6.2% to the overall perception of the stakeholders.

The variation in stakeholders' perceptions of the relative importance of the individual SWOT factors is shown in Figure 8.1. Within strength category, analysis reveals that its perceived effectiveness (S4: *effective in reducing chronic disease risk*) and its potential to offer multiple nutrients (S5*: iodine fertilizers can be blended with other plant nutrients*) are overall considered as the most important strengths of agronomic iodine biofortification (Figure 8.1a). The elite farmers and the agro-input company representatives, however, assigned relatively higher priorities to S2 (*simple and easy to implement*), while the agro-input and the CDO groups agreed that being *culturally acceptable* in Uganda (S3) is the most important strength of agronomic iodine biofortification. Stakeholders also generally considered the intervention to be a relatively inexpensive means of providing iodine and reducing IDDs (S1).

Analysis of opportunities demonstrates that the stakeholders consulted hold a general view that the *high prevalence of IDDs in Uganda* (O4) is the most important opportunity for the promotion of agronomic iodine biofortification, as it scored the highest priority loading. This is with exception of the CDO group, whose beliefs that O1 (*existence of government support and extension services*) and O5 (*existence of favorable fertilizer policy in Uganda*) are relatively more crucial (Figure 8.1c).

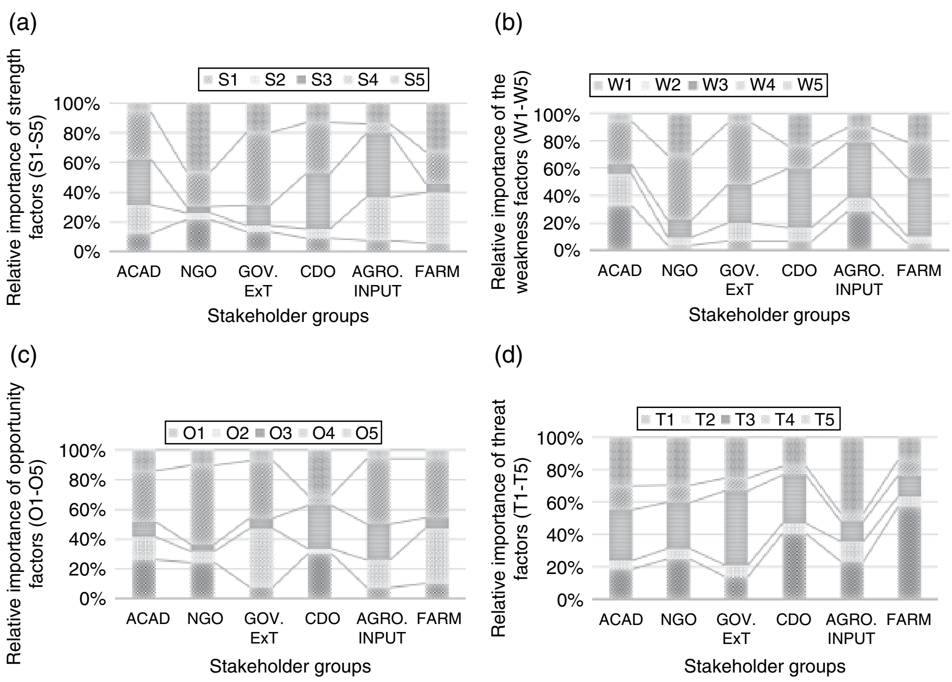

Figure 8.1 Relative importance of (a) strengths, (b) weaknesses, (c) opportunities and (d) threats of agronomic iodine biofortification according to stakeholder categories consulted. Note: Based on Olum et al. (2018). For descriptions of each factor and stakeholder group, see Table 8.7.

The most crucial weaknesses of the intervention are W3 (*overuse of fertilizers causes toxicity*) and W4 (*agronomic biofortification takes a longer time to supply iodine*) (Figure 8.1b), although the academic group puts most emphasis on W1 (*iodine fertilizers are not readily available*). According to the NGO representative, W5 (*iodine is volatile and can easily be lost upon application*) is the second most important weakness of the intervention. Within the threat category, with respect to the threat analysis, the *low knowledge and awareness* of the majority of Ugandan farmers about fertilizer application (T1) and the *general low number of fertilizer use in Uganda* (T3) are the most worrying threats to the implementation of agronomic iodine biofortification. Furthermore, also T5 (*farmers have competing needs for yields other than quality/nutrient*) received a high priority value for most stakeholder groups (Figure 8.1d).

8.5 Discussion

This chapter described two case studies on stakeholder reactions toward iodine-biofortified foods. The first case evaluates the intention of school heads and parents of school-aged children to include iodine-biofortified legumes in school feeding programs. The second case study takes a broader scope of stakeholder groups and applies the AHP, a multicriteria decision-making tool, to understand the stakeholders' evaluation of the relative importance of SWOT factors in implementing agronomic iodine biofortification in Uganda. Both cases provide insights into key factors that need to be considered in implementing iodine biofortification technology in a developing country.

8.5.1 Protection Motivation Behavior of Households/School Heads

The first case study applied a PMT-based framework to iodine biofortification in order to evaluate their potential adoption by school heads and parents. As such, this model analyzes the effect of both internal (coping, threat) PMT components and external factors on protection *motivation intention* (i.e. *iodine-rich legumes*) *in a risk region of Uganda. The positive reactions* correspond with previous research on nutritious (Dannenberg 2009; de Beer 2012; Lusk et al. 2005; Mogendi et al. 2016) and biofortified foods (De Steur et al. 2017c).

Furthermore, there is considerable knowledge about salt iodization and iodine among school heads and parents, which could potentially lead to satisfactory intake levels of iodized salt (Buxton and Baguune 2012; Mohapatra et al. 2001). However, parents largely did not associate iodine deficiency with its disorders, though they were informed that some children are affected by goiter and also perform poorly at school. The lack of knowledge about the causes of IDDs has also been reported in previous studies (Abuye and Berhane 2007; Charlton et al. 2012; Jooste et al. 2005; Mallik et al. 1998). The effect of knowledge on protection motivation is unexpected and different from previous studies (Henson et al. 2010b). However, this can be explained by the focus of this study (i.e. high-risk region of iodine deficiency), and the observed high awareness of iodine but inadequate options of coping strategies. In addition, Talsma et al. (2013), found that vitamin A (deficiencies) knowledge among caretakers of children significantly increases the intention to adopt provitamin A biofortified cassava in Kenya. The negative effect of education on protection motivation was unexpected given the earlier observations showing that knowledge about iodine is enhanced by education (Bornkessel et al. 2014; Molster et al. 2009). This may be due the history of iodized salt usage among parents rather than their education levels.

Given that knowledge of the health problem is still crucial for enabling protection motivation, better awareness campaigns among vulnerable communities are warranted. This is also relevant to biofortification, given that findings indicate that few people reported to have heard about this intervention. Those few could be the ones who were already exposed to orange sweet potatoes biofortification intervention in 2007 (Hotz et al. 2012). This may have a positive effect on consumers' intention to adopt, as reported in previous research on folate and vitamin A biofortified foods (De Steur et al. 2013; Depositario et al. 2009).

Comparison of school heads and parents revealed differences in perceived vulnerability. This could be explained by varying perception of children's academic performance between both stakeholder groups. Similarly, the significantly higher parental self-efficacy confirms previous findings of the beliefs that control parents have over children with regard to healthy eating, given that unhealthy choices are normally considered as short-term and modifiable (Russell and Worsley 2013). There is also a general optimism (protection motivation) for using iodine-biofortified foods in school feeding programs, which is positive from a nutritional intervention point of view, although such programs require large external support (Bundy et al. 2011).

In addition, socio-demographics such as gender and age significantly affect the likelihood of adopting a behavioral change toward biofortified foods. Males were reported to have a higher coping appraisal than women, contrary to what previous studies have indicated (Cox and Bastiaans 2007; Lowenstein et al. 2013; Renner et al. 2008). Similarly, being employed and older is not supported by previous studies that explore similar relationships on PMT components, which provide evidence of a positive link between severity of health problems with being employed and younger (Avila-Burgos et al. 2005). Nonetheless, our findings also show that parents who are aged and employed did not perceived iodine deficiency as a serious problem, which can also be explained by their lack of exposure to such conditions.

We also observed that school heads are unlikely to adopt iodine-biofortified legumes if perceived costs are high. Negative perceptions of the response costs, a component rarely included in PMT studies, is a barrier that must be tackled when designing and implementing food feeding programs, where external support becomes very relevant to ensure success. The same has also been highlighted previously in efforts to launch a school feeding program (Dejgård Jensen et al. 2013). However, there is optimism among parents, who show increased self-efficacy toward iodine biofortification, in line with previous studies (Cox and Bastiaans 2007; Cox et al. 2004; Henson et al. 2008, 2010b).

Given the aforementioned findings, a school feeding program that is based on iodine-biofortified foods should strive to increase awareness of iodine, its link with IDDS, and self-efficacy among stakeholders, while ensuring that the intervention cost is not a barrier in the participating schools.

8.5.2 SWOT-AHP Analysis by Key Stakeholder Groups

8.5.2.1 Positive Perceptions on Agronomic Iodine Biofortification

There is a high level of optimism about agronomic iodine biofortification among the stakeholders consulted, as their weighted values (overall priority scores) of the strengths and opportunities outweighed the weaknesses and the threats. As a key strength, the elite farmers' group perceived that the simplicity and ease of implementation of agronomic iodine biofortification is its top strength. While agronomic biofortification is implemented at farm level compared to the other forms of biofortification (genetic modification and conventional breeding), which are done at laboratory and field trial level, the high priority scored to the perceived ease of implementation of agronomic iodine biofortification by the farmers' other than other stakeholders' groups could be due to the fact that the farmers are directly involved in primary production and therefore more likely to be concerned with the ease of implementation of an intervention. Nonetheless, the importance of perceived ease of use and usefulness in the acceptance of a technology or an intervention, including biofortification, has been previously established (Mogendi 2016; Naspetti et al. 2017). Considering the majority of stakeholders consulted, the perceived *effectiveness in reducing chronic disease risk* (S4) and *iodine fertilizers can be blended with other plant nutrients* (S5) were the topmost strength factors, with highest priority scores. There is evidence for the effectiveness of USI in reducing IDDs in many countries, including Uganda (Andersson et al. 2010; Bimenya et al. 2002; Grimaldi et al. 2015) since its introduction in 1994. However, WHO has recommended finding alternative and complementary interventions for reducing IDDs, as high salt consumption has been linked to increased risks for cardiovascular diseases (Smoleń and Sady 2012; WHO 2011). As such, the stakeholders consulted viewed agronomic iodine biofortification to be a good complement to USI in reducing or preventing IDDs, as they perceived that consumption of iodine-biofortified foods would reduce the risks for chronic diseases like hypertension.

The argument that agronomic iodine biofortification has the potential to offer other plant nutrients in addition to iodine could be related to the fact that field and laboratory experiments on iodine biofortification have supplied iodine with carrier elements or compounds such as potassium iodide (KI) and potassium iodate ($KI0_3$) (Lawson et al. 2015, 2016; Piatkowska et al. 2016). Potassium is an essential element for plant growth (Wang et al. 2013), and potassium fertilizer have been in use in Uganda and a number of countries. The ability of iodine fertilizer to offer potassium or other nutrients needed for plant growth will be a big boost to poor farming communities. With the positive perception and relatively high importance assigned to this strength by the stakeholders, this could be a big motivating factor for acceptance and adoption of the technology.

Cultural acceptability of agronomic iodine biofortification is another key strength scored highly in the study. Given that agronomic iodine biofortification will directly involve farmers as primary producers and is a food-based intervention, cultural acceptability by consumers is very desirous. Cultural consideration is particularly important in promoting a food-based intervention because what is considered food or liked in one culture may be total rejected in another culture (Olum et al. 2017).

In the case of opportunities, the highest priority loading given to O4 (*high prevalence of IDDs*) is supported by previous studies (e.g. Bimenya et al. 2002) that showed that there was up to 60% of total goiter rate in Uganda with 30% visible goiter in school-aged children. The government of Uganda has made big investments in preventing IDDs that has led to a remarkable reduction in the deficiency burden since the introduction of the salt iodization strategy (FANTA-2 2010). However, as noted by the stakeholders consulted, there are still visible goiter cases in the community, an opportunity that clearly supports the promotion of agronomic iodine biofortification intervention. Given that the stakeholders consulted are resident in Uganda, this perception lends optimism that the intervention will be easily accepted once introduced in the community. Another outstanding opportunity generated from the stakeholder consultation was O2 (*existence of fertile soils deficient in iodine*). This is in agreement with previous studies that reported that Uganda is highly mountainous, which accelerates loss of iodine from the soil (FAO 2010b; Mogendi 2016). Given that consumption of iodine-rich foods is low in Uganda as the country is landlocked with low availability of seafoods that are rich in iodine, applying iodine fertilizers to produce iodine-rich foods (agronomic iodine biofortification) in the iodine deficient soil will be highly beneficial and accepted. It is further noted that *emerging fertilizer companies in Uganda* (O3) (to help market iodine fertilizer) and *existence of government support and extension services* (O1) are outstanding opportunities for implementing agronomic iodine biofortification. There are evidence of already existing government support for research and development of biofortified foods such as vitamin A enhanced orange-flesh sweet potatoes, and iron- and vitamin A-rich bananas (Bouis and Saltzman 2017; Saltzman et al. 2017), which shows hope of support for iodine biofortification. It further explains the high priority loadings assigned by the stakeholders to opportunity O1 (existence of government support and extension). Finally, it is noted that there is a supportive fertilizer policy in Uganda (O5) with other chemical fertilizers already in use there, which further assures of government regulatory support and opportunity for iodine biofortification through application of iodine fertilizer.

8.5.2.2 Negative Factors that Could Influence Agronomic Iodine Biofortification

Even if the overall perception of stakeholders consulted was dominated by optimism about agronomic iodine biofortification, a number of factors that could undesirably affect the implementation of the intervention were generated and evaluated.

Within the weakness category, W4 (*takes long to supply iodine*) and W3 (*overuse of fertilizer causes toxicity*) had the highest overall priority loading. The perception that agronomic iodine biofortification takes a longer time to supply iodine is not supported by scientific evidence, especially when compared to other types of biofortification (conventional breeding and GM technology), which have relatively longer development periods (Carvalho and Vasconcelos 2013). However, when compared to other existing micronutrient deficiency interventions such as consumption of industrially fortified foods or supplementations, agronomic biofortification, which only supplies iodine after the crops have been cultivated and harvested, could be a longer avenue to desired results. The adverse effect, especially on the environment, of overuse of chemical fertilizers has been previously established. Although this leads to accumulation of heavy metals (e.g. lead, arsenic), which could be carried along the food chain and alter other soil properties such as cation exchange capacity (Atafar et al. 2008), it can be controlled as it depends on the fertilizer application rate, as well as plant and soil conditions.

A related perceived weakness of agronomic iodine biofortification, which could equally be regulated by the amount of iodine fertilizer applied, was W5 (*iodine is volatile and is easily lost after fertilizer application*). The time and the environmental conditions when applying the iodine fertilizer could also help reduce the effect of this weakness. Nevertheless, iodine is known to be highly volatile and easily lost when it is applied exogenously (Hong et al. 2008). This feature has to be taken in consideration when designing the agronomic iodine biofortification intervention e.g. by careful selection of iodine carrier compound/element. The stakeholders also expressed fear over the fact that iodine fertilizers are not readily and commercially available in Uganda (W1). However, they also noted, under the opportunity category, that there are emerging fertilizer companies in Uganda (O3). Given that there is evidence of successful biofortification of food crops by applying iodine fertilizers (Gonzali et al. 2017; Lawson et al. 2015), the emerging fertilizer companies could have a task of importing or developing the iodine fertilizer in Uganda. This will require sensitization to create awareness and therefore demand for the fertilizer. The fear that fertilizers are expensive and not affordable by many farmers (W2) could be countered by designing small and affordable iodine fertilizer packs.

Low knowledge and awareness of many Ugandan farmers (T1) and the current general low use of fertilizers (T3) were the top ranked threats of agronomic iodine biofortification. These can be addressed by mass sensitization and awareness creation about the use and importance of fertilizers in crop production. The concern that the majority of farmers in Uganda are likely to have competing needs for increase in yield (production) other than improvement in the quality (iodine) (T5) could be because most farmers operate on a subsistent farming scale that makes their production low and geared toward increased production of food for household consumption with only excess sold. Nevertheless, agronomic biofortification does not negatively affect crop yield. In fact, most biofortification efforts target crops that are already known to have desired production attributes, such as high-yielding varieties (Singh et al. 2016). This makes this threat subject to farmer education and awareness. The fear that fertilizer application is affected by environmental factors such as temperature, relative humidity, and wind (T2) can be addressed by carefully planning the time and amount of iodine fertilizer application.

Summary

Micronutrient malnutrition, also known as hidden hunger, currently affects nearly half of the global population. Biofortification, the process of enriching staple food crops with micronutrients, is a key strategy for tackling micronutrient deficiencies. Empirical evidence exists to show the potential of biofortification for enriching crops with iodine. However, as is the case for most technological interventions, the success of biofortification for enriching crops with iodine depends on stakeholders' appreciation and acceptance. This chapter presents results from stakeholder studies, pointing out their intention to include iodine-biofortified legumes in school feeding programs in Kisoro District, South-West Uganda (Case 1) and their perceptions on agronomic iodine biofortification in Gulu, Northern Uganda (Case 2). The first case study applied the PMT to investigate the evaluation of school heads (40) and parents of schoolchildren (360) toward iodine deficiency (threat appraisal) and iodine-biofortified foods in school feeding programs as a coping mechanism to reduce the impact of iodine deficiency (e.g. on school performance). The second case study applied the hybrid SWOT-AHP method to evaluate perceptions of seven stakeholder groups.

Results from the two cases demonstrate that stakeholders are generally optimistic about the iodine biofortification strategy to improve iodine intake and address the prevalent IDDs. The first study established various socioeconomic factors of stakeholders that significantly influenced the constructs of the PMT and intention to use iodine-biofortified foods in school meals. Among the constructs of PMT, only the perceived vulnerability, self-efficacy and protection motivation, significantly predicted the intention to adopt iodine-biofortified foods. Study two founds that the stakeholders consulted value the strengths and opportunities (positive factors) more than the weaknesses and threats of agronomic iodine biofortification. Thereby, the effectiveness, ease to implement, and cultural acceptability were considered the most outstanding strengths of the intervention, while the high prevalence of IDDs, government support, and the availability of iodine deficient soils are key opportunities. Environmental effect of long-term use of fertilizers, limited use of the fertilizers, and low knowledge and awareness of farmers were key negative factors that could curtail the implementation of agronomic iodine biofortification in Uganda. The two case studies provide insight into key issues and priorities that need to be addressed for successful implementation of the iodine biofortification strategy in a developing country context.

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