

Acceptance and adoption of biofortified crops in low- and middle-income countries: a systematic review

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Context: Biofortification of staple crops is a promising strategy for increasing the nutrient density of diets in order to improve human health. The willingness of consumers and producers to accept new crop varieties will determine whether biofortification can be successfully implemented. **Objective:** This review assessed sensory acceptance and adoption of biofortified crops and the determining factors for acceptance and adoption among consumers and producers in low- and middle-income countries. **Data sources:** PubMed, Scopus, and Web of Science were searched for published reports. Unpublished studies were identified using an internet search. **Study selection:** From a total of 1669 records found, 72 primary human research studies published in English or Spanish met the criteria for inclusion. **Data extraction:** Data were extracted from each identified study using a standardized form. **Results:** Sensory acceptability ($n = 40$) was the most common topic of the studies, followed by determinants of acceptance ($n = 25$) and adoption ($n = 21$). Of crops included in the studies, sweet potato and maize were the most studied, whereas rice and pearl-millet were the least investigated. Overall, sensory acceptance was good, and availability and information on health benefits of the crops were the most important determinants of acceptance and adoption. **Conclusions:** Changes to the sensory qualities of a crop, including changes in color, did not act as an obstacle to acceptance of biofortified crops. Future studies should look at acceptance of biofortified crops after they have been disseminated and introduced on a wide-scale.

INTRODUCTION

Biofortification of staple crops is a promising strategy for increasing the micronutrient density of diets in order to improve human health.¹ The Copenhagen consensus in 2008 and the *Lancet* series on maternal and child malnutrition published in 2013 identified biofortification as one of the key interventions to reduce micronutrient deficiencies in low- and middle-income countries.²

The strategy was implemented for the first time in the mid-1990s³; for example, orange-fleshed sweet potato (OFSP) was used to reduce vitamin A deficiency in Guatemala.⁴ Since then, biofortification has received much larger financial investment through the HarvestPlus program, which was initiated in 2003 and has funded research projects and implementation programs on biofortification around the world.⁵ Biofortification is not, however, only being applied by

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HarvestPlus; it has also become part of government strategies and is used by local plant breeding organizations.⁶

Biofortification mainly focuses on the breeding of staple crops, such as maize, rice, beans, potatoes, millet, and cassava. Three different methods—conventional or classic plant breeding, agronomic approaches such as soil-fertilization, and genetic engineering—are used, with the majority of biofortification done by conventional plant breeding.⁶ Agronomic approaches are useful when the mineral concentration of the soil is a limiting factor for increased micronutrient concentration of the crop. Direct evidence of improved human health from biofortification through agronomic approaches and genetic engineering is lacking.^{7,8} Staple crops are targeted by biofortification efforts because they often have low micronutrient density and are consumed in large quantities by a large proportion of resource-poor populations.¹ Therefore improvement of the nutrient value of staple crops versus other crops is believed to have a large impact for those population groups that are difficult to reach with other interventions and is a valuable complement to direct nutrition interventions, like supplementation. The success of biofortification as a strategy largely depends on the willingness of consumers and producers to accept the newly bred crop varieties.⁶ Adoption of biofortified crops by producers will largely depend on factors such as yield, disease resistance, drought tolerance, and marketability. For consumers, the change in sensory traits in biofortified crops can be an important factor that influences adoption; for example, in provitamin A-rich crops, such as OFSP, orange maize, and yellow cassava, there will be a change in color.

The factors that determine acceptance (reflecting the perception among producers and consumers that an intervention is agreeable⁹) and adoption (reflecting the intention, initial decision, or action to try a new intervention⁹) of biofortified crops can be identified using a variety of distinct methods. Sensory studies, including preference testing, give information on sensory attributes that influence consumer acceptance. Cross-sectional questionnaire-based surveys reveal attitudes, constraints, and facilitators of consumer or producer acceptance and adoption of biofortified varieties. Effectiveness studies can show whether biofortified crops are acceptable and are adopted over a certain period of time, often comparing intensive and less intensive interventions. Experimental auctions can elucidate the willingness of consumers to pay for a biofortified crop compared with, for example, a locally available, nonbiofortified crop, indicating the possibility of a premium or the need for a discount when introducing biofortified varieties to ensure acceptance.¹⁰

Factors influencing acceptance of biofortified crops vary largely by type of crop and country but also by characteristics of consumers, such as age, sex, socioeconomic status, and being a disliker or liker of biofortified crops. Children under 5 years of age and women of childbearing age are considered most at risk of micronutrient deficiencies and are, therefore, often specifically targeted by nutrition interventions.¹¹

For this systematic review, studies were retrieved and aspects related to acceptance and adoption of biofortified crops in low- and middle-income countries were summarized and assessed. Key determinants that constrain or facilitate the implementation of this strategy were also identified in order to maximize the impact of ongoing and future biofortification programs.

SYSTEMATIC LITERATURE SEARCH

A systematic literature review was performed in accordance with the PRISMA Statement checklist and reporting guidelines¹² to identify studies on the acceptance and adoption of biofortified crops. PICO criteria were established to identify the inclusion and exclusion criteria (Table 1). A systematic search of the literature was conducted in April 2016 using the electronic databases PubMed, Scopus, and Web of Science with combinations of key words related to the 2 key topics of (1) *Biofortification* and (2) *Acceptance OR Adoption* (Table 2). Both key topics comprised several search terms in groups, and each group was made up of synonyms within a search term divided by using the Boolean expression “OR,” whereas groups were combined by using “AND.” For the final search, the key topics were combined with these groups and both abstracts and titles of articles were searched, except for those in Web of Science, where only the title was searched. This resulted in 3 database sets with article titles, which were screened independently by the authors A.M.B. and E.F.T. for relevance. When there were doubts about relevance or disagreement between reviewers, an article received the benefit of the doubt and was included in the next step of abstract review.

Abstracts of the initially selected articles were reviewed for exclusion criteria by all authors. These criteria were the following: not about biofortification with micronutrients; not a human study; not conducted in a low- and middle-income country; not a study of a staple crop (as defined in the search strategy: maize, cassava, sweet potato, potato, pearl millet, bean, sorghum, rice); not in English or Spanish; no mention of acceptability; and no original research.

The full text of all remaining publications was reviewed, with the review work divided among the authors. When data suitable for inclusion were found,

Table 1 PICOS criteria for inclusion and exclusion of studies

Parameter	Inclusion Criteria	Exclusion Criteria
Population	Humans	Animals, cell cultures
Intervention	Biofortified staple crops with micronutrients	Biofortified nonstaple crops, improved quality protein maize
Comparator	Different biofortified crops or standard “control” crop	None
Outcomes	Acceptance or adoption of biofortified crops	Efficacy or effectiveness without acceptance or adoption
Study design	Cross-sectional surveys, randomized controlled efficacy studies, or effectiveness studies	None

Table 2 Key topics with search terms used in systematic search strategy

Biofortification			Acceptance and Adoption Group 4
Group 1	Group 2	Group 3	
Biofort*	Crop*	Iron	Accept*
Bio-fortification	Food	Zinc	Willingnes*
Orange 5	Maize	Provitamin*	Choice
Yellow	Cassava	Pro-vitamin*	Sensory
GMO	Potato	Carot*	Preference
GM	OFSP	Beta-carot*	Adoption
	Sweet	Betacarot*	Impact
	Millet	Vitamin A	Uptake
	Pearl	Folate	Production
	Rice	Selenium	
	Bean	Phytat*	
	Sorghum	Phytic*	
	Lentils	Folic	

Abbreviations: GM, genetically modified; GMO, genetically modified organism; OSFP, orange flesh sweet potato.

data were extracted manually into a matrix and cross-checked by all authors. Disagreements or doubts were resolved by consensus.

In addition to the systematic literature search, key experts on the topics were contacted regarding relevant papers, unpublished work on the topic, and project descriptions available on the Internet. A “snowball” search, also known as an “other literature search,” whereby reference lists of papers were hand-searched to ensure that all relevant studies were identified, was also conducted. A similar data extraction procedure to that described above was used for this set of papers. Duplicates were removed. Figure 1 presents a flow diagram of the literature search process.

RESULTS

In total, 1563 records from the systematic database search and 106 records from the other literature search were found. After initial screening of the 1669 records, the full texts of 300 records were assessed for eligibility. A total of 72 studies were found to be eligible and were included in the review. Thirty-five of the selected studies were not found in the systematic database search: 8 were published in Spanish in nonindexed journals, 15 were

part of progress reports by organizations or provided as personal communication, 4 were nonpublished conference abstracts, and 3 were nonindexed master’s theses. Study populations mostly consisted of heads, spouses, or members of rural households, 18 years of age or older, either recruited randomly or at convenience around market places or shopping areas. Fourteen studies included children of different age ranges,^{13–25} (Tomlins et al., HarvestPlus, personal communication, 2016) and 1 study specifically targeted pregnant women.²⁶ Seven studies were conducted among university students.^{27–33} Four studies included a panel trained to recognize and differentiate sensory attributes.^{14,34–36}

Sensory acceptability

A total of 40 studies on the sensory acceptability of biofortified crops were identified (Table 3^{13–21,26–28,34–57}) and these involved various staple foods: sweet potato (n = 15), beans (n = 9), maize (n = 7), rice (n = 4), cassava (n = 4), and pearl millet (n = 1). Twenty-four studies were conducted in Africa, 12 were conducted in Latin America, and 4 were conducted in Southeast Asia. The most commonly used method was a sensory attribute study that used hedonic scales varying from 4 to 9 points; other methods used were structured interviews,³⁷ discrimination testing,^{20,38,39} and preference testing.^{16,20,26,38,40} In some studies, especially those including children and illiterate populations, facial hedonic scales were used (n = 13). In only 2 studies, the sensory evaluation was done after several days of testing of the biofortified product crop as part of a meal prepared at home.^{41,42}

Sweet potato

Consumers of traditional products. In eastern and southern Africa, sweet potato is traditionally prepared by boiling and is served as a side dish. Cooked varieties of sweet potato were evaluated for their sensory properties in Uganda (Tomlins et al., HarvestPlus, personal communication, 2016),^{35,43} Tanzania,¹⁹ and South Africa.¹⁵ In Uganda, deep orange sweet potato (containing the highest provitamin A content) was preferred

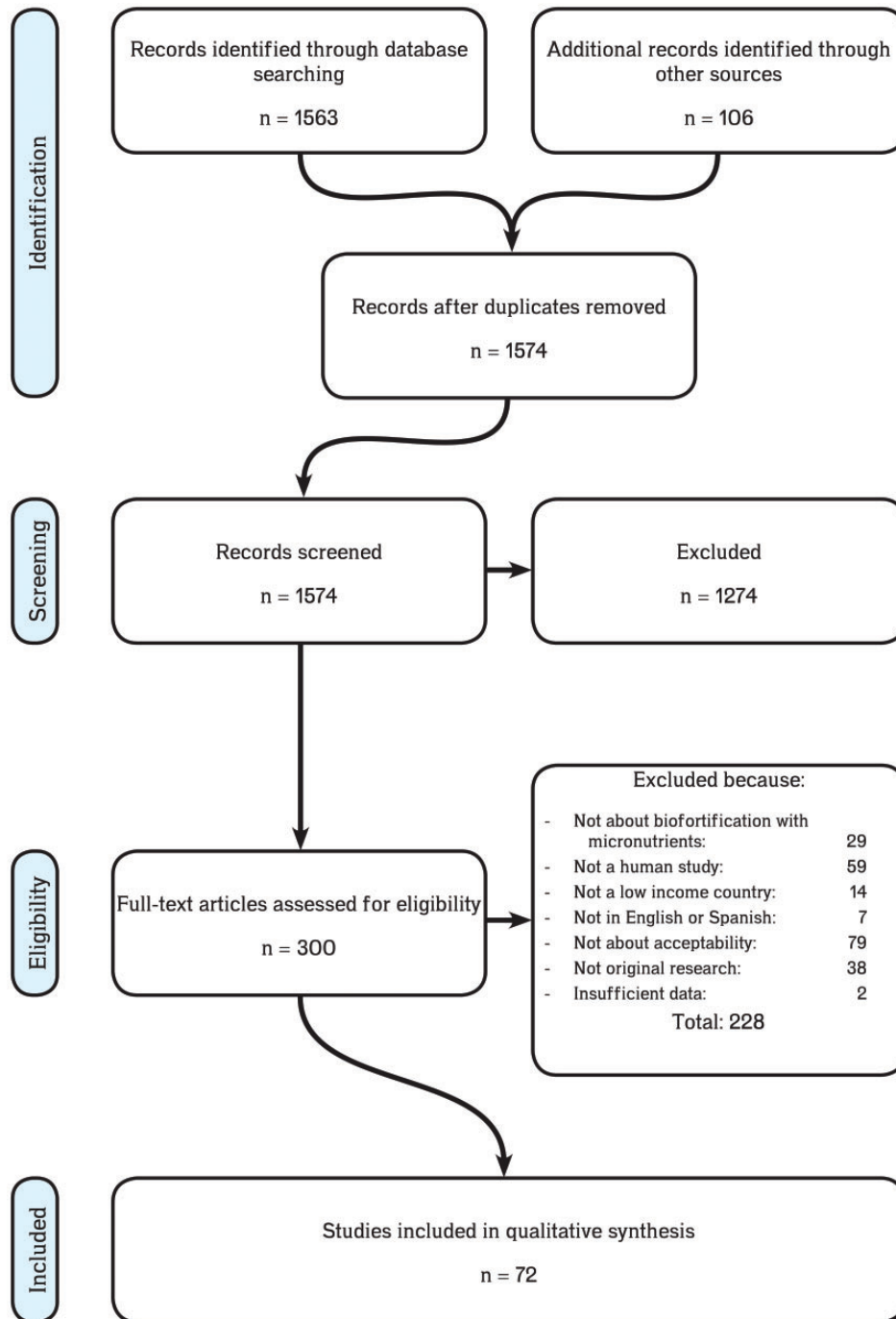


Figure 1 Flow diagram of the literature search process.

over yellow, orange, and white sweet potato by 52% of rural and urban consumers ($n = 467$).⁴³ In a small study, it was found that the sensory characteristics of white, yellow, purple, and orange sweet potato varied widely between cultivars.³⁵ Among primary school children ($n = 120$), 71% preferred orange over white sweet potato (Tomlins et al., HarvestPlus, personal communication, 2016), and 82% of adult rural and urban household members ($n = 475$) evaluated the deep orange

variety as being equally acceptable as white sweet potato (Tomlins et al., HarvestPlus, personal communication, 2016). In Tanzania, mothers liked orange sweet potato better than a purple variety, whereas school children liked both varieties similarly.¹⁹ In South Africa, acceptance was more related to sweet flavor, dry mass, and maltose content (as analyzed in the laboratory) than to color; wateriness was associated with the least accepted varieties.¹⁵ From these studies it can be concluded that

Table 3 Sensory evaluation of biofortified crops by consumers in low- and middle-income countries

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Sweet potato Tomlins et al. (2007) ¹⁹	Tanzania	Consumers: Schoolchildren, M + F: 5–18 y; n = 94 Mothers: 15–45 y; n = 59	Sensory attributes study (100-mm unstructured scale, interviews, and 7-point hedonic facial scale) for color, pumpkin flavor, texture, starchiness, and sweet taste of 30–50 g of cooked OFSP and PFSP	Mothers liked OFSP better than PFSP, but children liked both. Clusters with different preferences for different characteristics were observed	New cultivars should be screened; mothers have probably more influence on introduction than children
Low et al. (2008) ³⁷	Mozambique	Consumers: Market shoppers; n = 112	Structured interview and ranking of key characteristics of bread buns with 38% of white wheat flour replaced by boiled and mashed OFSP (golden bread)	Preference for golden bread because heavier texture, superior taste, and attractive golden appearance. With 47 consumers who purchased golden bread, preference was 98% because of color, 85% because of taste, and 78% because of texture	Golden bread buns are well accepted by consumers when sold at a similar price as white flour bread buns
Sivaramane et al. (2008) ⁴⁵	India	Consumers: Residents of rural area of Orissa State, 35% F, 26–40 y; n = 100	Sensory attributes study (9-point hedonic scale, nominal [0, 1] scale) for sweetness, color, texture, aroma, general appearance of 80 g of cofermented boiled OFSP puree (16%) and cow's milk with curd culture	Mean scores on sensory attributes on average were all > 7; consumers who find the curd acceptable had higher scores on color and texture than nonaccepters	Texture and color significantly and positively influenced consumer acceptability
Chowdhury et al. (2011) ⁴³	Uganda	Consumers: Rural and urban residents; n = 467	Sensory attribute study (9-point hedonic scale) for taste, appearance, and overall acceptability of 4 varieties of cooked SP: white SP, orange SP, deep orange SP, and yellow SP	52% of the participants preferred the deep orange SP, 26% the yellow SP, 13% the orange SP, and 9% the white SP	Deep orange SP is preferred over yellow, orange, and white SP
Rangel et al. (2011) ²¹	Brazil	Consumers: Schoolchildren, 10–12 y; n = 100	Sensory attributes study (5-point facial hedonic scale mixed scale) for liking and numeric scale (1–10) for grading and preference of 50 g of cake (conventional vs 40% SP flour)	Overall acceptability was good and scale ranking was high for both cakes. No difference in preference found	Cakes with SP flour are acceptable and are an important strategy to provide provitamin A
Romero et al. (2011) ¹³	Nicaragua	Consumers: Schoolchildren, mean age: 11 y; n = 290 (children) n = 33 (mothers)	Sensory attributes study (5-point facial hedonic scale) of 43 g of cake made with OFSP (24%), with and without leaf pulp (4%)	Acceptability was good with no difference between cakes, preference was similar between cakes	Both cakes were well liked. Inclusion of SP in preparation of the cakes is feasible
Tomlins et al. (2012) ³⁵	Uganda	Consumers: Semitrained panel; n = 10	Sensory attributes study (100-mm unstructured scale) for color, taste, flavor, texture, odor, and appearance of 11 varieties of cooked SP (white, yellow, purple, orange)	Color was correlated with carotenoid concentration in a logarithmic way. Carotenoid content correlated with dry matter and visual, odor, and textural characteristics. Cultivars differed widely regarding sensory characteristics	The logarithmic relationship between color and carotenoid concentration might result in orange varieties that are not necessarily high in carotenoids being preferred
Laurie et al. (2012) ¹⁴	South Africa	Producers and consumers: Local farmer groups and schoolchildren, > 10 y; n = 950	Sensory attributes study (5-point facial hedonic scale with facial expressions) for taste and yes/no for color, will to purchase and will to prepare OFSP juice, chips, doughnuts, and cooked leaves	Taste was liked best for doughnuts, followed by chips, leaves, and juice. The attributes color and willingness to buy and prepare the product scored high by > 80% of participants	All products were acceptable; preparation with deep frying was especially highly liked

(continued)

Table 3 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Nguyen-Orca et al. (2014) ²⁷	Philippines	Consumers: University students; n = 50	Sensory attributes study (7-point hedonic scale) for color, consistency, aroma, flavor, mouth feel, and general acceptability of a complementary food blend from 4 varieties of SP (cream, yellow, orange, and purple) with maize (55:45 ratio)	Orange SP was rated highest for color; both yellow and orange were rated highest for mouth feel, whereas consistency, aroma, and taste did not differ between samples. Overall, yellow (score: 5.6) and orange (score: 5.4) SP were liked over cream (score: 5.1) and purple SP (score: 4.5)	Yellow and orange SP blends, both high in provitamin A, were well accepted
Laurie et al. (2013) ¹⁵	South Africa	Consumers: Adult panel; n = 8 Schoolchildren, 50% F; n = 168 Adults, 50% F; n = 48	Sensory attributes study (5-point facial hedonic scale) for acceptability of color, acceptability of overall eating quality, as well as laboratory nutrient analysis, color and texture outcome for 9 orange-fleshed and 3 cream-fleshed cooked SP varieties	Most accepted varieties were associated with sweet flavor, dry mass, and maltose content, and least accepted varieties with wateriness. Acceptability correlated with maltose content, dry mass, and sweet flavor	Varieties with more dry mass are more acceptable
Fetuga et al. (2014) ²⁸	Nigeria	Consumers: University students; n = 100	Sensory attribute study (9-point hedonic scale) for overall acceptability of <i>amala</i> prepared from 3 SP varieties (2 yellow and 1 orange) with different pretreatment (parboiling/soaking) and drying methods	<i>Amala</i> prepared from yellow varieties were scored high (7.3–7.7) whereas orange variety scored low (3.3–3.8). Parboiling scored higher compared with soaking. Acceptability significantly (negatively) correlated with ash, fiber, yellowness, water solubility, sugars, and viscosity peak time	Yellow SP was most acceptable for preparation of <i>amala</i> , suggesting that variety was a key factor
Olapade et al. (2014) ⁴⁶	Nigeria	Consumers: n = 30	Sensory attributes study (9-point hedonic scale) for acceptability of appearance, taste, mouth feel, and overall acceptability of crunchy snacks made of flour of cream SP and yellow SP with 0%, 30%, and 50% maize flour	Addition of maize flour enhanced acceptance of both SP varieties. 70% cream SP scored highest together with 50% yellow SP. 100% SP was scored lowest for both SP	A mix of yellow SP with maize flour results in a more acceptable snack than a mix of cream SP with maize flour
Trejo-González et al. (2014) ⁴⁴	Mexico	Consumers: Adults; n = 38	Sensory attributes study (5-point hedonic scale) for crumb, crust color, firmness, and porosity; paired preference test with wheat bread; flour was replaced by various proportions of violet and orange SP flour (0%, 5%, 10%, 15%, 20%)	All sensory attributes (except crust color) were significantly different between control breads and bread with 15%–20% SP flour	Substitution of wheat flour with 5%–10% SP flour yielded acceptable dough and bread
Tomlins et al. (personal communication, 2016)	Uganda	Consumers: Schoolchildren, 5–12 y; n = 120	Sensory attributes study (7-point hedonic modified scale) for appearance, odor, taste, and texture of cooked white, yellow, and orange SP	Overall acceptance was good: 100% acceptance of orange variety and 71% preferred orange over white. Nutrition information was significant predictor of acceptance; repetition of nutrition information or repeated exposure was not	OFSP is acceptable for children. Providing nutrition information increases acceptance
Tomlins et al. (personal communication, 2016)	Uganda	Consumers: Rural and urban households, mean age: 26 y; n = 475	Sensory attributes study (9-point hedonic scale) for sensory attributes of appearance, odor, taste, and texture of 30–50 g of 4 different cooked varieties of SP (white to orange)	Overall acceptance was good with mean scores > 6. The deep orange variety was acceptable to 82% and liked the most, followed by yellow, orange, and white. 18% of participants found orange SP unacceptable	The visible trait of orange SP can be used to advertise, but for the 18% dislikers other interventions are needed

(continued)

Table 3 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Maize Stevens and Winter-Nelson (2008) ⁴⁹	Mozambique	Consumers: Market shoppers, 14–70 y, 69% F; n = 201	Sensory attributes study (5-point hedonic scale) for taste, appearance, texture, and aroma, and overall score of porridge (<i>nsima</i>) from milled orange and white near-isogenic lines of maize and local maize	Most participants preferred taste, texture, and appearance of local white maize <i>nsima</i> compared with other varieties. 33% rated taste of orange maize <i>nsima</i> as very good compared with 55% of local white maize. Orange scored higher on appearance, and aroma of orange was preferred over white varieties	Color is not a particular factor for acceptance
De Groote et al. (2010) ⁵⁰	Ghana	Consumers: Household heads and spouses, 18–90 y; n = 703	Sensory attribute study (5-point hedonic scale) for appearance, aroma, texture, taste, and overall appreciation of <i>kenkey</i> (steamed fermented maize dough) from white, yellow, and orange maize varieties	Average scores were all > 3. In the Ashanti Region, white maize received the highest score (followed by yellow and orange), whereas yellow maize (followed by orange and white) received the highest score in Central and Eastern Regions	Preference for maize color was regional and is not regarded as an obstacle in the major maize areas of Ghana
Pillay et al. (2011) ¹⁶	South Africa	Consumers: Rural school children and parents, 3–55 y; n = 212	Sensory attributes study (5-point facial hedonic scale) for texture, aroma, and flavor; and paired preference test with 3 types of porridge made from yellow maize and white maize	Preschool children, secondary school children, and adults preferred yellow maize, but primary school children were indifferent. Acceptability was most influenced by texture and flavor	Yellow maize has potential but only when combined with nutrition education, reduced market price, more availability, and improved sensory properties
Khumalo et al. (2011) ⁵¹	South Africa	Consumers: Rural households in Limpopo Province > 18 y; 100% F n = 48	Sensory attributes study (4-point facial hedonic scale) for aroma, color, consistency, hand feel, grittiness (mouth), and taste with maize porridge prepared from white sifted fortified and unfortified maize meal, hammer mill white and yellow maize meal with or without fiber, and white super maize meal	Scores for any of the sensory attributes did not differ between white and yellow maize with or without fiber, but maize without fiber (dehulled) was preferred. Overall, the whiter and finer the product, the more it was liked	Fine yellow maize was well accepted, although the super refined white maize was most preferred
Govender et al. (2014) ⁵²	South Africa	Consumers: Infant caregivers 16–65 y, 100% F; n = 60	Sensory attribute study (5-point facial hedonic scale) for taste, texture, aroma, color, and overall acceptability of soft porridge made from white maize and 2 yellow provitamin A-biofortified varieties (medium and deep orange)	No significant difference between scores for the different sensory attributes. Outcome was not influenced by age	No difference in sensory acceptability of the white maize and provitamin A-biofortified maize
Awobusuyi et al. (2015) ⁵³	South Africa	Consumers: Rural farmers, 30–51 y, M + F; n = 54	Sensory attribute study (9-point hedonic rating scale) for aroma, mouth feel, taste, color, and overall acceptability of <i>amahewu</i> , a fermented nonalcoholic maize-based beverage made from white maize or provitamin A-biofortified maize	No significant differences in mean scores between <i>amahewu</i> prepared from white or provitamin A maize for color, taste, and aroma. Overall acceptability was significantly higher for provitamin A maize	Acceptability of <i>amahewu</i> prepared from provitamin A-biofortified maize is slightly higher than that prepared from white maize

(continued)

Table 3 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Alamu et al. (2015) ³⁴	Nigeria	Consumers: Trained panel; n = 10	Sensory attributes study (9-point hedonic rating scale) for color, aroma, chewiness, taste, and appearance for boiled fresh orange maize of 2 hybrids with or without husk at 3 different maturation stages or 20, 27, and 34 d after pollination	Overall the hybrids were liked with average scores of 6.8. There was little difference between maize with or without husk, but optimum harvest time was 20 d after pollination	Orange maize hybrids are acceptable for fresh consumption
Beans Leyva-Martínez et al. (2010) ⁴⁷	Cuba	Producers and consumers: Adults, 25–65 y; n = 80	Sensory attributes study (4-point facial hedonic scale) for consistency, taste, and texture and triangle discrimination test and preference test for bean soup made with regular bean and biofortified (iron) beans	63% of participants were able to discriminate the biofortified beans from regular beans. Overall acceptability was good for both varieties; no preference was found	The population liked the improved variety. It has the potential to be grown and consumed and to prevent iron deficiency
Tofiño et al. (2011) ¹⁸	Colombia	Consumers: Adults and children; n = 273	Agronomic acceptance and sensory attributes study (children: 4-point hedonic facial scale; adults: 5-point hedonic scale) for consistency of the soup, color, taste, smell, and texture; and discriminatory testing of cooked biofortified (iron) beans and control beans	Agronomic performance of biofortified varieties is better. Overall acceptability in children and adults was good. In adults, biofortified bean scored higher. 88% of participants preferred biofortified beans. 68% of participants were able to differentiate	Biofortified bean SMN8 is well liked and has the potential to become the preferred type of bean for consumption and growing
Centeno et al. (2011) ⁴⁸	Nicaragua	Producers and consumers: Adults, 16–77 y; n = 76	Sensory attributes study (4-point facial hedonic scale) for sensory attributes of texture, smell, taste, and color and general acceptance of 3 biofortified beans and 1 control bean	Overall acceptability of beans was good. No preference was found, but control bean scored highest	Because the acceptability was similar for the beans, the improved varieties should be introduced to farmers to understand adoption
Cabal et al. (2014) ¹⁷	Colombia	Consumers: Children, 7–11 y	Sensory attributes study (5-point hedonic scale) for acceptability of appearance, color, aroma, flavor, softness, resistance, hydration ability, and perception of granules of cookies made of 100% wheat (control); 15% biofortified bean, 15% cassava, 70% wheat; and 20% biofortified bean, 15% cassava, 65% wheat	Both biofortified cookies scored higher in aroma, flavor, resistance, hydration ability, and perception of granules than the control cookie	Biofortified bean flour can be used as a substitute for wheat flour to a certain percentage without losing sensory acceptance
Oparinde et al. (2015) ⁴¹	Rwanda	Consumers: Household members, > 18 y; n = 572	Sensory attributes study (7-point hedonic scale) for color, bean size, taste, cooking time, storage quality, and ease of breaking after 7 days of home-use of RIB, WIB, and a local variety (Mutiki)	Overall, RIB were more liked (6.4–6.7) than the local variety (6.0–6.2) and the WIB (5.1–5.4), except for cooking time, for which WIB scored better. Scores for RIB were higher compared with control, whereas for WIB this difference was absent	RIB were superior over the local variety and WIB in sensory evaluation, even without information
Pérez et al. (2015) ⁴²	Guatemala	Consumers: Households in the northwest, mean age: 35 y, M + F; n = 360	Sensory attributes study (7-point hedonic scale) for size, taste, cooking time, cooked thickness, and toughness after home testing with nutrition information and 3 times repeated nutrition information of control and biofortified beans	Sensory attributes were scored positive except for bean toughness. Nutrition information resulted in a higher score for the iron bean for raw bean size and cooked bean toughness, but repeating did not matter	The high-iron bean variety is liked in a similar way to the traditional bean

(continued)

Table 3 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Carrillo-Centeno and Sánchez-Ruiz (2014) ⁴⁰	Nicaragua	Producers and consumers: Adults, mean age: 45 y, 30% F; n = 91	Sensory attributes study (5-point hedonic facial scale) for color, aroma, flavor, and texture, and preference test of 20 g of raw and cooked beans (INTA Ferroso [iron] and INTA Norte [regular])	No difference in acceptability between the 2 varieties. Regular bean was preferred for color, iron bean for shape and size	Because acceptability was good, the iron bean should be introduced and promoted for growing and consumption
Murekezi et al. (personal communication, 2016)	Rwanda	Producers and consumers: Rural and urban households near bean market sites, 29–59 y; n = 1809	Sensory attributes study (7-point hedonic scale) for attributes of 4 different types of cooked biofortified beans; multinomial probit and logit models with 4 different types of sharing nutritional information and a control group with no information sharing	Overall sensory scores of all beans were good. Various consumer segments exist. In 2 sites, providing nutrition information increased the probability of shifting consumers to the iron-bean-likers segment	The results can be used for targeting interventions in various parts of and consumer segments in Rwanda
Oparinde et al. (personal communication, 2016)	Rwanda	Consumers: Rural households and urban visitors of markets, mean age: 43 y; n = 809	Sensory attributes (7-point hedonic scale) for raw bean color, raw bean size, cooked bean size, taste, cooking time, and overall acceptability of raw and cooked beans of control and 2 biofortified (IB1 and IB2) beans and as intervention various types of nutrition information and endorsement	Overall acceptability was good (score > 4) in both rural and urban sites. Between the 2 biofortified varieties, raw bean size and cooked bean size scored differently. IB2 was liked more, with no difference regarding endorsement or length of nutritional information. Cooking time of the local variety was liked most	Biofortified beans were acceptable, and a program to promote these beans can use a short version of nutritional information
Rice De Bree (2009) ³⁸	China	Consumers: Rural women in Chuzhou District, mean age: 34 y; n = 40	Triangle discrimination and preference test of uncooked grains of zinc-biofortified rice, zinc-fortified extruded rice, and normal rice. Focus group discussions	Participants were able to perceive a difference between the 3 rice types ($P < 0.01$). The odd sample was correctly chosen in 84% of control vs biofortified, 92% of biofortified vs extruded fortified, and 55% of control vs extruded fortified. Control and zinc-fortified rice were preferred over zinc-biofortified rice	Biofortified rice was the least preferred. Acceptance can be increased when rice kernels are large and whole, the government endorses the rice, and it can be locally grown
Montecinos et al. (2011) ⁵⁴	Nicaragua	Consumers: Household heads; mean age: 41 y; n = 203	Sensory attribute study (4-point hedonic scale) for texture, smell, taste, color, and overall acceptability of cooked <i>Azucena</i> , a traditional landrace rice with elevated iron and zinc levels compared with a local rice variety	The scores for the local variety were slightly higher than for <i>Azucena</i> ($P < 0.05$) for texture, smell, taste, and color. 56% of consumers preferred the local variety over <i>Azucena</i>	<i>Azucena</i> was not readily accepted by the study population
Vergara et al. (2011) ³⁹	Panama	Consumers: Poor rural communities, 18–50 y; n = 90	Discrimination test with 30 g of cooked control and iron-biofortified rice	Only 30 of the 90 answers were correct, and therefore no significant difference between the 2 types of rice was found	Biofortified rice has potential and should be introduced in other communities and the agro-industry

(continued)

Table 3 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Padrón et al. (2011) ²⁶	Cuba	Consumers: Pregnant women (2nd and 3rd trimester), 15–55 y; n = 98	Sensory attributes study (4-point facial hedonic scale) for color, texture, taste, and smell and preference test with 20 g of cooked iron-biofortified rice and control rice	> 80% of the respondents liked or really liked the biofortified rice. The biofortified rice was preferred (73%) over control	The biofortified rice variety should be introduced in Cuba because it can possibly help in the prevention of anemia and zinc deficiency
Cassava Talsma et al. (2013) ²⁰	Kenya	Consumers: Caretakers, 97% F, mean age: 32 y; n = 30 School children, 63% F, 6–12 y; n = 30	Preference test and blinded triangle discrimination test with boiled and mashed yellow and white cassava	Caretakers and children were able to discriminate between yellow and white cassava; > 70% preferred yellow cassava. Characteristics of yellow cassava: attractive color, soft texture, sweet taste	Yellow cassava is acceptable to schoolchildren and their caretakers
Njoku et al. (2014) ⁵⁶	Nigeria	Producers and consumers: Adults in the southeast, > 20 y; n = 30 Consumers: Trained panel, adults; n = 12	Sensory attributes study (4-point hedonic scale) for color, taste, texture, mealiness, and appearance of <i>eba</i> made of <i>gari</i> from 3 yellow cassava varieties and 1 white cassava variety mixed with palm oil Sensory attributes study (9-point hedonic scale) for acceptability of mouth feel, taste, color, flavor, appearance, and of a gruel made of different mixtures of yellow cassava starch-based custard powder (90%–98%) with egg powder (2%–10%) measured at 0, 6, 12, 18, and 24 wk of storage	Yellow cassava was preferred over white because of the color, premium price, nutritional value, and texture	Yellow cassava can be adopted by farmers if made available
Awoyale et al. (2015) ³⁶	Nigeria	Consumers: Trained panel, adults; n = 12	Sensory attributes study (5-point hedonic scale) for color, feel, taste, and drinking quality of <i>gari</i> and color and feeling for <i>eba</i> made from white, light yellow, and deep yellow cassava, with and without prior information	Blend ratios and storage conditions affected the acceptance. At 24 wk, color and taste were disliked, which might be because of increase in moisture during storage	Yellow cassava custard can be stored for 24 wk and still be acceptable
Oparinde et al. (2014) ⁵⁵	Nigeria	Consumers: Rural cassava consumers, 65% M > 18 y; n = 671	Sensory attributes study (5-point hedonic scale) for color, feel, taste, and drinking quality of <i>gari</i> and color and feeling for <i>eba</i> made from white, light yellow, and deep yellow cassava, with and without prior information	Mean scores were > 3 and different across product types. In Imo State, white cassava scored highest, followed by deep yellow and light yellow. In Oyo State, light yellow cassava rated highest, whereas deep yellow was rated highest in color and feel. There is no effect of information on liking	Consumers rated the light yellow and deep yellow cassava differentially on all sensory attributes. Study area was important factor for preference, but the deep yellow was never preferred
Pearl millet Biol et al. (2015) ⁵⁷	India	Consumers: Rural consumers, M + F, mean age: 40 y; n = 452	Sensory attributes study (5-point hedonic scale) for grain color/size, and color, taste, layers, and ease of breaking of <i>bhakri</i> (thick flatbread) made of HIPM or LPM	Overall, HIPM was rated higher (4.2–4.9) for all attributes compared with LPM (3.5–4.2). Information (groups B and C) increased the scores for HIPM and decreased scores for LPM, except for grain color, which remained the same	Consumers evaluate HIPM more favorably than LPM varieties

Abbreviations: F, female; HIPM, high-iron pearl millet; IB1, iron bean 1; IB2, iron bean 2; LPM, local pearl millet; M, male; OFSP, orange-fleshed sweet potato; PFSP, purple-fleshed sweet potato; RIB, iron biofortified red bean; SP, sweet potato; WIB, iron biofortified white bean.

orange sweet potato, prepared in its traditional way by boiling, is well accepted from a sensory standpoint by both adults and children in the countries where the studies were conducted.

In Western Africa, tubers and roots are often processed into flour that is then used to prepare food products for consumption. In Nigeria, flour from yellow and orange sweet potato varieties was evaluated for use in the preparation of a local porridge called *amala*. The yellow variety (with lower provitamin A concentration) was more acceptable than orange varieties (with higher provitamin A concentration) by university students ($n = 100$). Sensory acceptability was correlated with ash, yellowness, water solubility, fiber, sugar, and viscosity peak time.²⁸

Consumers of nontraditional products. In 8 studies, OFSP was experimentally included in nontraditional products and evaluated for sensory properties. Low et al.³⁷ found that bread buns in which 38% of wheat flour was replaced by boiled and mashed OFSP (“golden bread”) were preferred over white flour bread buns. The buns were sold at 2 local markets in Mozambique irregularly for 2 years. During a 2-day study at these markets with 112 untrained market shoppers, 47% bought the golden bread buns, which were priced the same as the white flour buns. Bread with 5%–10% orange sweet potato flour was also evaluated as satisfactory in Mexico.⁴⁴ In India, rural consumers positively evaluated the sensory properties of curd prepared from cow’s milk and 16% cofermented boiled orange sweet potato puree.⁴⁵ School children in Nicaragua¹³ and Brazil²¹ found cake prepared with 24%–40% OFSP flour to be equally as acceptable as conventional cake. An instant complementary food blend (sweet potato/maize: 55:45 ratio) was evaluated by university students ($n = 50$) in the Philippines; blends that included orange or yellow sweet potato flour were ranked highest for color and mouth feel and were liked over blends that included cream and purple sweet potato.²⁷ In Nigeria, crunchy snacks made of yellow sweet potato and maize flour (50:50 ratio) were well accepted for consumption, whereas snacks made of 100% sweet potato flour (either cream or yellow) were least accepted by consumers.⁴⁶ From a sensory perspective, nontraditional food products (novel recipes) prepared with orange sweet potato varieties were generally liked.

Producers and consumers of nontraditional products. Laurie et al.¹⁴ evaluated the sensory acceptability of various OFSP products among local farmer groups and schoolchildren ($n = 950$) in South Africa. Of the products tested, doughnuts were most liked, followed by chips, cooked leaves, and juice.

Beans

Consumers. Among households in northwest Guatemala ($n = 360$), iron-biofortified beans were equally acceptable as control beans after a period of home testing.⁴² Among Colombian adults and children ($n = 273$), 88% preferred iron-biofortified beans to accompany a rice meal compared with control beans.¹⁸ Also in Colombia, iron-biofortified bean flour (15% and 20%) was used to replace wheat flour in the preparation of cookies, and these cookies were evaluated with higher scores overall by school children.¹⁷ In Rwanda, iron-biofortified red beans were liked better than either the local variety of beans or iron-biofortified white beans after 7 days of home testing of the beans ($n = 572$).⁴¹ In a later study, the same investigators found that the acceptability of iron-biofortified beans was again good and did not differ between urban and rural populations or in relation to the levels of nutrition information provided (Oparinde et al., HarvestPlus, personal communication, 2016).

Producers and consumers. Iron-biofortified beans prepared as soup were well accepted by bean producers and consumers ($n = 80$) in Cuba, and there was no difference in the acceptability of the iron-biofortified beans compared with the regular beans.⁴⁷ In Nicaragua, 2 studies conducted among bean farmers and consumers showed a similar acceptance of cooked iron-biofortified beans and control beans.^{40,48} Murekezi et al. (personal communication, 2016) also found that the sensory properties of iron-biofortified beans were acceptable in both the rural and urban areas of Rwanda ($n = 1809$). Furthermore, they found that provision of nutrition information increased the probability that consumers would shift to liking iron-biofortified beans and that more consumers who liked iron-biofortified beans were found in urban markets and among farmers.

Summary finding. It can be concluded that the sensory properties of iron-biofortified beans are well accepted among both consumers and producers in the populations studied thus far.

Maize

Consumers. For the studies of maize included in this review, only traditional preparation methods were evaluated. White maize refers to non-biofortified maize and yellow or orange maize refers to maize biofortified with provitamin A. Market shoppers ($n = 201$) in Mozambique preferred the taste and texture of white maize, whereas the aroma of orange maize was preferred.⁴⁹ In Ghana, sensory acceptance of *kenkey* (steamed fermented maize dough) prepared from white, yellow, and orange maize varieties

was compared among household heads or their spouses (n = 703). White maize was preferred the most and orange maize the least in the Ashanti Region, whereas yellow maize was most preferred in the Central and Eastern Regions.⁵⁰ In South Africa, maize porridge from fine yellow maize was well accepted, although women preferred porridge from white maize without fiber.⁵¹ In another study, yellow maize porridge was preferred over white maize porridge by preschool children, secondary school children, and adults, whereas primary school children were indifferent (n = 212).¹⁶ In a study with caregivers of infants (n = 60), the caregivers indicated no difference in sensory attributes between orange or white maize porridge.⁵² Also, no significant difference was found in the sensory perception of *amahewu* (fermented nonalcoholic beverage) prepared from white maize compared with that prepared from provitamin A-biofortified maize in a rural community (n = 54).⁵³ Overall, acceptance of 8 freshly boiled orange maize varieties was scored as 6.8 on a 9-point scale by a trained panel (n = 10) in Nigeria, but no comparison with a control maize was done.³⁴ In summary, yellow and orange maize is accepted from a sensory perspective, although there is some regional variation.

Producers and consumers. No studies that assessed producers' preferences for biofortified maize were identified.

Rice

Consumers. Rice biofortified with zinc was preferred less than normal rice and rice externally fortified with zinc by rural women (n = 40) in China.³⁸ Government endorsement of the rice and the possibility to cultivate the rice locally would likely enhance acceptance.³⁸ When comparing a traditional landrace rice with high iron and zinc concentration (*Azucena*) with a local rice variety, 56% of consumers in Nicaragua (n = 203) preferred the local variety.⁵⁴ Rice consumers (n = 90) in a poor area of Panama were not able to distinguish iron-biofortified rice from control rice.³⁹ Iron-biofortified rice was well accepted by pregnant women (n = 98) in Cuba, with 73% of the study population preferring the biofortified rice over the control rice.²⁶ Results from these 4 studies are divergent, and sensory properties of biofortified rice should be further investigated.

Producers and consumers. No studies that assessed producers' preferences for biofortified rice were identified.

Cassava

Consumers. School children (n = 30) and their caretakers in Kenya (n = 30) were able to discriminate

between yellow (provitamin A biofortified) and white (non-biofortified) cassava when tasting cooked and mashed cassava while blindfolded. More than 70% of the respondents preferred the yellow cassava.²⁰ A study conducted in Nigeria (n = 671) with 2 products that used cassava *gari* (roasted fermented cassava flour) and *eba* (dough ball prepared from fermented cassava flour) made from white (non-biofortified), light yellow (provitamin A biofortified), and deep yellow (provitamin A biofortified) cassava showed that liking of the light yellow cassava varied by location and that deep yellow varieties were not preferred.⁵⁵ Custard powder from yellow (provitamin A biofortified) cassava starch lost its acceptability after 24 weeks of storage, as evaluated by a Nigerian panel trained to recognize and differentiate food sensory properties (n = 12).³⁶

Producers and consumers. A study in Nigeria among cassava farmers (n = 30) residing in southeastern Nigeria showed that yellow cassava *eba* was preferred over white cassava *eba* because of color, premium price, nutritional value, and texture.⁵⁶

Summary finding. In summary, although yellow cassava seems to be acceptable from a sensory perspective, the number of studies is limited.

Pearl millet

Consumers. Flatbread (*bhakri*) prepared from high iron-biofortified pearl millet was rated with higher scores than that prepared from local varieties of pearl millet by Indian consumers (n = 452).⁵⁷ However, only this 1 study on the sensory acceptance of biofortified pearl millet was found.

Producers and consumers. No studies that assessed producers' preferences for biofortified pearl millet were identified.

Sociocultural drivers and determinants of acceptance and adoption

Twenty-one studies on the sociocultural drivers and determinants of consumer adoption of biofortified crops were found (Table 4^{20,22–25,51,52,58–60,61–69,70,71}). The crop most studied in this respect was sweet potato (n = 9), followed by maize (n = 5), cassava (n = 4), rice (n = 2), and beans (n = 1). Sweet potato, maize, and beans were only studied in Africa, cassava was studied in both Africa (Benin, Kenya) and Latin America (Brazil), and rice was only studied in a single Asian country (China). Four studies included genetically engineered crops.^{58–60,71} Data were mostly collected by

Table 4 Sociocultural drivers and determinants of acceptance and adoption for consumers of biofortified crops in low- and middle-income countries

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Sweet potato Mazuze (2004) ⁶¹	Mozambique	Producers and consumers: Adults who had received OFSP vines in 2000, Gaza Province, mean age: 42 y; n = 150	Cross-sectional study. Structured questionnaire (about growing and adoption of OFSP)	83% of respondents were aware of the nutritional benefits of OFSP. A larger share of land (83%–86%) was planted with white vs OFSP varieties, attributed to unavailability, limited propagation capacity, and lower drought tolerance of OFSP. Reasons for planting OFSP were perceived high yield, better taste, and desire to experiment with new varieties. Adoption rate varied per season from 38% to 71% and related to participation in field days and demonstration activities, the number of times vines were received, number of OFSP varieties, cultivated area, and rainfall	OFSP adoption can be improved by providing credit for animal traction, improving drainage systems, and providing access to more drought-tolerant vines. More research into post-harvest processing and storage of roots would help to reduce the low availability of roots due to seasonal planting
Low et al. (2007) ²⁴	Mozambique	Producers and consumers: Children, 4–38 mo, 47% F; n = 741	Quasi-experimental prospective controlled trial (2 y) Intervention: Vines distribution, training Outcome: Change in serum retinol concentration, OFSP plot size, OFSP consumption, production OFSP	Production expanded from 33 to 359 m ² ; participation in OFSP production and sales increased in intervention households but decreased in control households; 90% of intervention households grew OFSP compared with 11% in control; SP production increased from 73 kg to 127 kg (71% OFSP); Percentage households selling increased from 13% to 30%, but no increase for households; > 50% of children in intervention consumed OFSP at least 3 out of 7 d as compared with 4%–8% of control children	Integrated promotion of OFSP has potential to increase adoption of OFSP and increase consumption
Hotz et al. (2012) ²²	Mozambique	Producers and consumers: Children, 0–5 y, 47% F; n = 386 Caretakers, 100% F; n = 393	Randomized controlled effectiveness trial (2.5 y) with 3 arms: control, OFSP distribution plus 1 y or 2 y intensive training	77% adoption; share of OFSP cultivated area increased from 9% to 56%; OFSP intake significantly increased in intervention groups for 6–35 mo (46 g/d), 3–5.5 y (48 g/d), and women (97 g/d) compared with control; no difference in effect between the 2 intervention groups	OFSP is well adopted and consumed after introduction; group-level trainings in nutrition and agriculture could be limited to the first year of project without compromising impact
Hotz et al. (2013) ²³	Uganda	Producers and consumers: Children, 6–35 mo; n = 265 Children, 3–5 y; n = 578 Women, n = 578	Randomized controlled effectiveness trial (2 y) with 3 arms: control, OFSP distribution plus 1 y or 2 y intensive training	OFSP intake increased in both intervention groups ($P < 0.01$), accounting for 44%–60% of vitamin A intake at follow up. Prevalence of inadequate vitamin A intake was reduced among children 6–35 mo (> 30 percentage points) and women (> 25 percentage points), with no difference between intervention groups	SP was adopted and grown by farmers resulting in incorporation of OFSP into the diets of women and children with a measurable impact on vitamin A status in children
Fetuga et al. (2013) ⁶²	Nigeria	Producers and consumers: Households from Southwestern	Cross-sectional study. Structured questionnaire (OFSP processing, OFSP <i>amala</i> (stiff porridge) consumption, OFSP awareness)	48 (16%) and 46 (15%) respondents had heard of and seen OFSP; 31 had tasted it, and most of them (93.6%) liked the taste. Sex, age, or education level were not associated with OFSP awareness. 98.3% of respondents were not aware of the	Awareness of OFSP was very low among respondents and knowledge about its health benefits almost nonexistent. Strong indication that people were willing

(continued)

Table 4 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Gilligan et al. (2014) ⁶³	Uganda	Region of Nigeria, > 4 y; n = 300 Sweet potato processors n = 23 (17 farmers)	Household survey on adoption rate and comparison of intra-household bargaining power based on asset ownership and control over land use	health benefits of OFSP, but 75.7% were willing to taste if available. 15 of 23 respondents engaged in SP processing used yellow-fleshed SP. Color (n = 14), availability (n = 7), and taste (n = 2) were drivers of choice for the variety of SP. Current processing methods for preparing <i>amala</i> from SP result in inferior sensory quality (appearance and texture), which is solved by mixing SP flour with other flours (yam, cassava, plantain, and wheat) Adoption rate in season 1 was high (90%) but declined to 69% in season 4, varying per district, due to vines drying up, no access to new planting material, insufficient availability of labor available, and dislike of crop. Among female-headed households (11%), exclusive control over land was positively associated with OFSP adoption. This association was absent among male-headed households. OFSP adoption was associated with age of the head of household, knowledge of vitamin A, and total land area cultivated with sweet potato. Women with a high share of nonland assets ownership were less likely to grow OFSP	to consume OFSP if made available. In Nigeria, both awareness and availability should be targeted. Improvement and standardization benefit the use of OFSP in <i>amala</i> preparation, providing a cheaper alternative to <i>amala</i> prepared from other types of flour OFSP was well adopted in this region of Uganda. Female bargaining power does not unambiguously increase the probability that a household adopted OFSP in response to the project. The probability of adopting OFSP was lowest on parcels exclusively owned by men and largest on parcels jointly owned by males and females with women in the lead. Engaging with both men and women might be the best strategy to promote adoption Intensity of participation in extension activities is associated with larger project impact
De Brauw et al. (2015) ⁶⁹	Mozambique	Producers and consumers: Households in Zambezia Province, M + F; n = 720	Randomized controlled effectiveness trial (2.5 y) with 3 arms: control, OFSP distribution plus 1 y or 2 y intensive training	Children in households with more participation had higher dietary vitamin A density, and slightly higher mean micronutrient density and dietary diversity	Nutrition concerns cannot be depended upon to push the adoption of OFSP. OFSP must be competitive with white and yellow varieties in terms of agronomic, consumer, and economic characteristics (in terms of yields, taste, price, etc) if it is to be successful. Nutrition education campaigns must be an integral part of the promotion of OFSP
Yanggen and Nagujja (2006) ⁶⁴	Uganda	Producers and consumers: Adults in intervention and nonintervention areas in 4 regions; n = 160	Cross-sectional survey with questionnaires, key-informant interviews and focus group discussions (women only, men only, and mixed groups)	64% of farmers adopted OFSP in intervention compared with 22% in nonintervention areas. Main OFSP production constraints were pests and diseases (especially weevils), drought, and availability of vines (no commercial vine distribution), followed by lack of capital and labor. Major favorable characteristics farmers look for are yield, sweet taste, early maturity, and drought resistance, followed by consumer characteristics like tuber quality, good price, high dry matter, color, good storability, low fiber, and nutritional content. Nutrition content comes last as favorable characteristic, only mentioned by women	Nutrition concerns cannot be depended upon to push the adoption of OFSP. OFSP must be competitive with white and yellow varieties in terms of agronomic, consumer, and economic characteristics (in terms of yields, taste, price, etc) if it is to be successful. Nutrition education campaigns must be an integral part of the promotion of OFSP

(continued)

Table 4 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Machira et al. (2013) ⁷⁰	Kenya	Producers and consumers: Key persons involved in OFSP projects in antenatal care services in western Kenya; n = 66	Interviews and focus group discussion with key persons about an integrated nutrition, agriculture, and health intervention that delivers OFSP through antenatal care services in western Kenya	(as 4th most important) but not by men. Most important information sources were nongovernmental organizations, fellow farmers, and agricultural extension workers Food security and health benefits were most recognized by participants. Mothers indicated that their children were less susceptible to disease and were more energetic; shorter maturation and higher yield of OFSP were also valued. Health workers perceived higher antenatal care attendance and increased healthcare-seeking behavior as benefits. Challenges were distance to health facility, misperceptions (OFSP = contraceptive), need for continuous community sensitization, and increased workload with remuneration for community volunteers and vine multipliers	Perceived benefits and motivating factors outweighed challenges of integrating OFSP with antenatal care service
Maize Tschirley and Santos (1995) ⁶⁵	Mozambique	Consumers: Low-income urban households; n = 400	Cross-sectional study	22% of households consumed predominantly yellow maize. Consumers of yellow maize had substantially lower income than white maize consumers. Highest income consumers were the least likely to consume yellow maize	Yellow maize is well accepted, especially among poor consumers
Muzhingiri et al. (2008) ⁶⁶	Zimbabwe	Consumers: Rural and urban households; n = 316	Cross-sectional study (in-depth questionnaires, focus group discussion)	Yellow maize was known by most respondents but mainly from food aid. Link with food aid and bad taste (due to organoleptic changes during storage) were seen as negative aspects of yellow maize. Nutrition information on vitamin A and taste were significant contributors to acceptance	Acceptance could be improved if nutrition knowledge was increased
Khumalo et al. (2011) ⁵¹	South Africa	Consumers: Adult females from Limpopo Province, > 18 y; n = 48	Focus group discussions (consumer attitudes, perceptions, and practices) of maize porridge prepared from several types of white and yellow maize meal	Preference for yellow maize related to knowledge of the presence of vitamin A in yellow maize meal (acquired during previous training in 2004), availability (during drought as relief food), and price determined whether yellow maize is bought	Acceptability of yellow maize mainly related to nutritional reasons. Availability was the largest obstacle
Govender et al. (2014) ⁵²	South Africa	Consumers: Female infant caregivers; n = 21	Focus group discussions (acceptability of provitamin A–biofortified maize for preparing maize porridge for their infants)	Yellow maize is not sold in supermarkets, suggesting that white maize is of better quality. Yellow maize considered to be for poor people or animals. Affordability, availability, and health benefit were reasons for being willing to give provitamin A–biofortified maize porridge to their infants	Affordability, availability, and health benefit were important determinants of accepting provitamin A–biofortified maize as infant food
Schmaelzle et al. (2014) ²⁵	Zambia	Consumers: Children 5–7 y, n = 136	Randomized controlled feeding trial with 3 arms: porridge (<i>nsima</i>) of orange maize and placebo oil; of white maize and	Orange group consumed less <i>nsima</i> (276 ± 36 g) than white groups (288 ± 26 g and 288 ± 25 g, P = 0.08), with consumption fluctuation between weeks, and no difference in total food intake and	Implementation and adoption of new and biofortified foods is possible with promotion, especially in very traditional

(continued)

Table 4 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
González et al. (2009) ⁵⁸	Brazil	Consumers: Households in northeast Brazil, mean age: 40 y; n = 414	placebo oil; of white maize and vitamin A supplement Cross-sectional study on genetically engineered cassava. Structured questionnaire after explanation about genetically engineered yellow cassava	relish intake. Mothers and staff preferred orange maize because of softer structure and sweeter flavor than the white maize; because of texture it was difficult to use orange maize <i>nsima</i> to scoop up relishes 25% of respondents had ever heard about genetic engineering, 22% found it a possible health risk. Age, trust in authorities, perceived health risk, and access to media influenced consumer support of genetically engineered crops	cultures that are deeply connected to their food Attitudes toward genetically engineered biofortified yellow cassava is positive
González et al. (2011) ⁵⁹	Brazil	Producers and consumers: Adult farmers; n = 76 Adult farmers who received seeds for public awareness campaign in northeast Brazil; n = 40	Cross-sectional study. Participatory research and questionnaires evaluating adoption	15% of farmers planted the yellow cassava 1 y after the release (early adoption rate), and 62% said they would do so next year (potential/intentional adoption rate), because of the better nutritional content. Reasons for not adopting were low availability of seeds and taste. From the farmers who received seeds, 63% planted them. Key factors were receiving information, involvement in previous participatory research, and knowledge about nutritional advantages	To increase early adoption of yellow cassava, it is important to increase the nutrition knowledge, have high availability of seeds, and use information and socialization among producers
Uwiringiyimana (2012) ⁶⁷	Benin	Consumers: Mothers of primary school children, 15–49 y; n = 147	Cross-sectional survey. Questionnaire (intention to eat yellow cassava and its determinants)	90% had intention to prepare yellow cassava for their children 2 or more times a week. Health behavior identity, knowledge, and perceived susceptibility predicted intention to consume yellow behavior, as well as cues to action	Intention can be increased by increasing knowledge on vitamin A deficiency and health benefits of yellow cassava and increasing positive triggers as recommendations from influential people and educational campaigns
Talsma et al. (2013) ²⁰	Kenya	Consumers: Caretakers of schoolchildren, 90% F, 18–50 y; n = 140	Cross-sectional survey. Questionnaire (intention to eat yellow cassava and its determinants)	Almost all had intention to prepare yellow cassava for their children, of which 64% were willing to do so 2 or more times per week. Knowledge about provitamin A-rich cassava and its relation to health was a strong predictor of health behavior identity. Worries related to bitter taste and color, belief about being in control to prepare cassava, and activities such as information sessions about provitamin A-rich cassava and recommendations from health workers predicted intention to consume provitamin A-rich cassava	The yellow color is no barrier for consumption. Intention to consume can be increased by reducing barriers (like worries about color, taste, texture, and bitterness); by increasing knowledge on vitamin A deficiency and provitamin A-rich cassava; by empowering mothers to decide what to cook; and by involving health workers in the promotion of yellow cassava

(continued)

Table 4 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Rice					
De Steur et al. (2013) ⁷¹	China	Consumers: Adults in Shanxi Province, 20–69 y, M + F; n = 588	Cross-sectional study questionnaire (perceptions on genetically engineered folate-biofortified rice)	Taste and health are the most important attributes for rice purchase, followed by price and external appearance. Respondents answered correctly on 42% of the questions concerning knowledge of genetically engineered foods. 62% of respondents were in favor of genetically engineered folate biofortification of rice. A negative change in taste decreased this proportion to 28%, environmental impact decreased it to 29%, price decreased it to 35%, availability decreased it to 41%, external appearance decreased it to 46% and cultivation potential decreased it to 50% 66.5% in favor of nutritionally enriched rice; 39% had limited knowledge about genetically engineered food; 3 groups of consumers: enthusiasts (1.4%: health, lower pesticide use, males, rural, farmer), cautious (41%: positive on safety, females, urban); and opponents (45%: side effects, including biodiversity, females, low income, rural). Enthusiastic respondents have a more positive attitude	Initial acceptance rate would be halved if genetically engineered folate-biofortified rice would have a negative effect on taste, price, or the environment. Multiple attributes should be taken into account in the development of biofortified crops
De Steur et al. (2015) ⁶⁰	China	Consumers: Adults in Shanxi Province, 43% F; n = 451	Cross-sectional study. Questionnaire on genetically engineered rice, including false/true statements, 5-point hedonic scale statements, a knowledge score, 4 additional scores (benefits, risks, safety, price), overall trust scores for information channels or sources	Over the last 5 y, of the 93% households that grew beans, 29% respondents indicated to have grown an HIB variety. Out of the 84% of farmers who indicated to have grown beans in the second season of 2015, 21% have grown at least 1 HIB variety. Within the country this varied by location, with Eastern Province having higher adoption rates. Adoption rate was further determined by yield, easiness to farm the variety, commercial value, and availability of seeds. The main source of first planting material were the markets (41%) and social networks (23%)	There is a promising (segmented) market potential for second-generation genetically engineered products
Beans					
Asare-Marfo et al. (2016) ⁶⁸	Rwanda	Producers and consumers: Bean-producing households in 120 random villages, > 21 y, 65% F; n = 19 575	Cross-sectional impact assessment study by listing exercise to identify HIB growers among bean-producing households with questionnaires	Adoption rates of HIB varieties in Rwanda are very promising	

Abbreviations: F, female; HIB, high-iron bean; M, male; OFSP, orange-fleshed sweet potato; SP, sweet potato.

surveys and structured questionnaires (n = 14),^{20,28,58–68,71} sometimes in combination with focus group discussions (n = 3).^{51,52,64} In a few cases, the data were generated by an intervention study (n = 4)^{22–24,69} or a clinical trial (n = 1).²⁵

Sweet potato

Producers and consumers. Acceptance and adoption of sweet potato has been most extensively studied in Mozambique. A structured questionnaire given to farmers (n = 150) who had received OFSP vines in the year 2000 in Gaza Province, Mozambique, revealed that the adoption rate varied per season from 38% to 71%, although only a small proportion (14%–17%) of land was planted with OFSP 2 years after the vines were first provided. Adoption of the introduced OFSP variety was positively associated with participation in promotion activities, vine distribution, larger cultivated area, and less frequent flooding. The small proportion of land planted with OFSP was attributed to unavailability of vines, limited propagation capacity, and lower drought-tolerance of OFSP, whereas reasons for planting OFSP were yield, taste, and the desire to experiment with new varieties.⁶¹ A prospective controlled trial with a 2-year integrated promotion campaign for OFSP production and OFSP vine distribution led to increased adoption, consumption, production, and plot size of OFSP in intervention villages compared with control villages.²⁴ A later effectiveness study comparing OFSP distribution with a 1-year or a 2-year intensive training program showed similar results and also revealed that intensive promotion activities could be limited to 1 year instead of 2 years.^{22,69}

A very similar effectiveness study conducted in Uganda that compared OFSP distribution with a 1-year intensive training program and OFSP distribution with a 2-year intensive training program also showed that OFSP was well adopted and incorporated into the diets of women and children irrespective of the length of the training program.²³ Earlier work in Uganda compared farmers from an intervention area in which OFSP was introduced with farmers from a control area where OFSP was not introduced. Among 160 selected farmers, the adoption rate was 64% in the intervention area compared with 22% in the control area, with yield, taste, and price being the most important drivers for adoption.⁶⁴ Also in Uganda, another adoption study (n = 1176) revealed that adoption was high in season 1 (90%) but declined in each consecutive season to 69% in season 4. The researchers specifically addressed women's bargaining power and found that female and joint (wife and husband) ownership of parcels for OFSP cultivation was the best strategy to promote adoption.⁶³

A study conducted in 6 states in southwestern Nigeria revealed that only 48 (16%) of 300 respondents had heard of OFSP, with knowledge of OFSP unrelated to sex, age, or education level. Almost none of the respondents (1.7%) were aware of the health benefits of OFSP.⁶² In the same study, it was found that, of 23 respondents who were engaged in sweet potato processing, 15 used yellow-fleshed sweet potatoes, and 1 had once tried OFSP. Color, availability, and taste were mentioned as drivers of choice for the variety of sweet potato for processing.⁶²

Summary finding. In summary, it can be concluded that OFSP has been well accepted and adopted in countries where it has been actively spread and promoted, such as Mozambique and Uganda. Building on this, similar programs are currently underway in other African countries.^{72–74} An innovative project in western Kenya that delivers OFSP through antenatal care services proved to be beneficial for participants because the general health of the children as perceived by the children's mothers increased and antenatal clinic attendance was higher.⁷⁰

Maize

Consumers. A survey of urban households in low-income neighborhoods in Maputo, Mozambique (n = 400) showed that 22% of households consumed predominantly yellow maize biofortified with carotenoids. This was associated with lower levels of household income within these neighborhoods.⁶⁵ In Zimbabwe, a study of rural and urban households (n = 316) showed that yellow maize consumption was associated with food aid. The study also indicated that bad taste after storage impeded acceptance of yellow maize.⁶⁶ Participants (n = 48) in a study conducted in Limpopo Province, South Africa, indicated the presence of vitamin A in yellow maize meal as the reason for their preference.⁵¹ This awareness was the result of a research project involving the promotion of vitamin A-rich foods that had coincidentally been conducted earlier in the same area. Unavailability of yellow maize was mentioned as the main obstacle for its consumption. Another study conducted in South Africa among female caregivers of infants (n = 21) showed that these caregivers considered yellow maize to be for poor people or animals. Price, availability, and health benefit were important determinants of acceptance.⁵² In a randomized controlled feeding trial in Zambia, biofortified orange maize was well accepted by children, caretakers, and trial staff because of the softer structure and sweeter flavor.²⁵ In summary, biofortified yellow maize was liked by some groups and not by others, and biofortified

orange maize was well accepted for human consumption in 1 study.

Producers and consumers. No studies that assessed producers' sociocultural drivers and determinants of adoption of biofortified maize were identified.

Cassava

Consumers. A study of households of cassava buyers (n = 414) in northeastern Brazil that investigated acceptance of yellow cassava biofortified through genetic engineering showed a positive attitude toward acceptance.⁵⁸ Consumer support was influenced by older age, trust in authorities, high perception of general personal health risk, and access to media. Studies in Benin and Kenya revealed that the color of yellow cassava was not a barrier to consumption. Also, caregivers' knowledge of vitamin A deficiency and the health benefits of yellow cassava were important determinants of the intention to feed yellow cassava to children.^{20,67} These studies indicate that availability and information on the health benefits of yellow cassava are important determinants for its acceptance. However, this can only be explored further when yellow cassava becomes available on a larger scale.

Producers and consumers. Another study in Brazil was conducted on the adoption rate of conventionally bred yellow cassava among cassava farmers who were either exposed to 1) participatory research (n = 760) or 2) a promotion event after which farmers requested seeds (n = 158). The early adoption rate (< 1 y) was 15% in the participatory research group, although 62% indicated they planned to plant the biofortified yellow cassava the next year because of the better nutritional content. In the group that received yellow cassava seeds, 63% planted them. Key factors for adoption were availability, taste, involvement in participatory research, and knowledge about nutritional advantages.⁵⁹ This study also indicated that availability and information on the health benefits of yellow cassava are important determinants for its future acceptance, but this needs to be confirmed in further research once yellow cassava becomes available on a larger scale.

Rice

Consumers. A structured interview on perceptions about folate-rich rice that was biofortified through genetic engineering was conducted among rice consumers (n = 588) encountered near supermarkets, shopping areas, and outdoor markets in Shanxi Province, China.

Sixty-two percent of respondents viewed folate-rich rice favorably. Taste, environmental impact, price, availability, appearance, and cultivation potential were determinants of acceptance.⁷¹ In another study that included 451 rice consumers in the same area, 67% were willing to accept folate-rich genetically engineered rice, although knowledge of genetically engineered foods was low (39%) in the study population. Those strongly in favor of folate-rich genetically engineered rice (14%) mentioned health and lower pesticide use as reasons, whereas opponents of folate-rich genetically engineered rice (45%) were worried about environmental side effects.⁶⁰

Producers and consumers. No studies that assessed producers' sociocultural drivers and determinants of adoption of biofortified rice were identified.

Beans

Producers and consumers. In 2015, an impact assessment study in Rwanda was conducted among 19 000 bean-producing and bean-consuming households to quantify the adoption rates of growing high-iron bean varieties in a country where high-iron beans had been promoted and released for several years.⁶⁸ This study found that over the past 5 years, 29% of the farmers had been growing high-iron bean varieties. During the second growing season in 2015, 21% of the farmers who were growing beans were growing high-iron bean varieties. Adoption of the high-iron beans varied by location within the country and by variety, with yield, ease of farming the variety, availability of seeds, and commercial value of the beans among the most important determinants of adoption for a certain variety. Although this is the only study on adoption rates of beans, these results are promising and show that with a good support program high-iron beans can be well adopted.

Consumer adoption and marketability

Twenty-five studies on consumer adoption and marketability of biofortified crops were found (Table 5^{29-32, 37,41-43,49,50,55,57,58,65,75-82}). The crop most studied in this respect was maize (n = 8), followed by rice (n = 6), beans (n = 4), sweet potato (n = 3), pearl millet (n = 2), and cassava (n = 2). The studies were conducted in Africa (n = 16), Asia (n = 8), and Latin America (n = 2). All studies on genetically engineered crops (rice) were conducted in South Asia and Southeast Asia (n = 6).

The most common method used to assess the price that consumers were willing to pay for a certain amount of biofortified crop as compared with a regular control variety was the Becker-deGroot-Marchak (BDM)

Table 5 Predicted adoption of biofortified crops as evidenced by consumer willingness to pay in low- and middle-income countries

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Sweet potato Low and van Jaarsveld (2008) ³⁷	Mozambique	Consumers: Bakers in 3 rural villages; n = 8–10 (per village) Consumers: Adults at local markets, rural and urban, M (40%) + F (60%), mean age: 30 y; n = 308	Calculation of costs and revenues of producing bread buns with 38% of wheat flour replaced by boiled and mashed OFSP (golden bread) Choice experiment: 9 choice sets of the attributes pulp color (white/ orange), dry matter content (low/ medium/ high), size (small/medium/large), and price (M7.5/10/15/kg) with treatment 1 and 2: visual exposure to a bag of sweet potato of each variety. One bag was given to each participant based on their preference from the choice questions. Treatment 3 and 4: no exposure Valuation by choice experiment (17 scenarios) of 4 varieties of: 1 white sweet potato; 2 OFSP; and 1 yellow sweet potato, after (1) no nutritional info and asked to make real choices and commitments (n = 121); (2) nutritional info about OFSP and asked to make real choices and commitments (n = 115); (3) nutritional info and hypothetical assessments (n = 118); (4) nutrition information and "cheap talk" script and hypothetical assessments (n = 113)	Calculated net return to labor was 3 times higher for golden bread buns vs white wheat flour buns due to lower costs Price correlated negatively with preference. Dry matter was the most important attribute to the participants. Small-sized roots were more preferred in the rural area but not in the urban area. Consumers are willing to pay 51.3% more for OFSP relative to WFSP	Small-scale golden bread production is an economically viable option for creating a market for OFSP Dry matter is a key factor driving consumer acceptance. When dry matter, price, and size are equal, orange pulp color is preferred over white pulp color
Chowdhury et al. (2011) ⁴³	Uganda	Consumers: Rural (4 villages from each Kamuli and Luweero Districts; 40 random households per village) and urban (random at 2 market-places in Kampala) sweet potato consumers; M + F; n = 467	Valuation by choice experiment (17 scenarios) of 4 varieties of: 1 white sweet potato; 2 OFSP; and 1 yellow sweet potato, after (1) no nutritional info and asked to make real choices and commitments (n = 121); (2) nutritional info about OFSP and asked to make real choices and commitments (n = 115); (3) nutritional info and hypothetical assessments (n = 118); (4) nutrition information and "cheap talk" script and hypothetical assessments (n = 113)	In scenario (1) no difference in WTP for deep-orange vs white was found, whereas WTP for orange and yellow sweet potato was lower (–22% and –30%, respectively) compared with white. In (2) a premium was found for deep-orange variety relative to white (+25%). In (3) higher WTP for yellow (+40%), orange (+43%), and deep orange (+48%) vs white. In (4) higher WTP for yellow (+26%), orange (+26%), and deep orange (+52%) vs white. Respondents who preferred a variety in the sensory assessment were willing to pay more for that variety. Rural consumers had a higher WTP for OFSP varieties compared with urban consumers.	Consumers in Uganda are willing to pay similarly for biofortified (deep orange) varieties as for the traditional white variety, even without a promotional campaign. Provision of nutritional information translates into an increase in WTP for deep OFSP. Taste is an important attribute in WTP. Hypothetical scenarios translate into biased WTP; therefore, experiments with real transactions are superior
Maize Tschirley and Santos (1995) ⁶⁵	Mozambique	Consumers: Low-income urban households; n = 400	Price game assessing the percentage of respondents switching from white to yellow maize after a given discount rate	At a 14% discount, 25% of consumers would switch from white grain to yellow grain, whereas at a discount of 43%, 70% of consumers would switch. Lower-income consumers are more likely to switch at modest price discounts. At higher discount (> 43%), higher-income consumers are just as likely to switch to yellow maize	Reduced price is an important determinant of consuming yellow maize

(continued)

Table 5 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Rubey and Lupi (1997) ⁷⁷	Zimbabwe	Consumers: Urban households; n = 512	Focus group discussions and preference ranking (refinedness, product price, color, travel time for obtaining meal, product packaging)	The predicted share of households consuming yellow maize was 25% when sold at a 10% discount compared with white maize	Yellow maize is well accepted, provided that it is sold at a lower price than white maize and widely available
Stevens and Winter-Nelson (2008) ⁴⁹	Mozambique	Consumers: Marketplace shoppers, 69% F, 14–70 y; n = 201	Trading experiments based on acceptance to trade white maize for orange maize at different prices and willingness to trade white maize with tomatoes, orange, and white near-isogenic lines of maize	Acceptance rate of orange maize meal at all trade ratios was 44%; factors reducing acceptance for trade are being male, being a nonshopper, being a bad taste judge, finding local maize tastes better than orange maize, and frequently eating meat/fish. Household size, the presence of small children, dietary diversity, and perceived taste were determinants of trade acceptance	Existing preferences for white maize do not preclude acceptance of orange biofortified varieties
De Groote and Kimenju (2008) ⁷⁵	Kenya	Consumers: Urban maize consumers; n = 604	Contingent valuation in a semi-double-bounded model (acceptance of offered bids in 2 rounds)	Price, time saving, nutrient quality, and cleanliness were mentioned as factors determining choice for a particular maize product. Only 25% of respondents were willing to buy yellow maize at the same price as white maize. Acceptance increased with lower follow-up bids, with a maximum of 50%–58% of respondents being willing to pay for yellow maize at a 30% discount. Modeling showed 37% discount to be required for consumer acceptance (for supermarket respondents: 48%)	Consumers preferred white maize and would need a discount of 37% to buy yellow maize. People from western Kenya had the strongest preference for yellow maize. Consumers with higher education and income had a stronger preference for white maize. To market yellow maize for urban consumers in Nairobi, substantial price reductions would be necessary
De Groote et al. (2010) ⁵⁰	Ghana	Consumers: Adults from Ashanti, Central, and Eastern Regions, 18–90 y; n = 703	Individual auctions (BDM) and choice experiments and group auctions after being exposed to no information and later to 5-min radio message about the benefits of eating orange maize	In Ashanti Region, consumers' WTP is higher for white maize than for yellow and higher for yellow than for orange. In Central Region, WTP is higher for yellow than for white or orange. In the Eastern Region, WTP for yellow and orange maize is higher than for white. The difference in WTP between white and yellow maize was only significant in the Eastern Region. Provision of information increased WTP for orange maize relative to that for white maize and reduced WTP for white and yellow maize	A good information campaign based on radio message is likely to have an effect on consumer acceptance for orange maize

(continued)

Table 5 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
De Groote et al. (2011) ⁷⁹	Kenya	Consumers: Rural and urban adults in western and eastern Kenya, 70% F, mean age: 46 y (rural) and 34 y (urban); n = 651	Experimental auction: price WTP for normal rice and willingness to buy biofortified or fortified maize for same or reduced price	Respondents were willing to pay 42.6 KES for white maize, 25% more for fortified maize, and 10% less for yellow maize. Location, familiarity with yellow maize (as in the west), and awareness raised the price by 6% and 7% for yellow maize	White maize is preferred, but WTP for fortified maize was higher and therefore with nutrition education yellow maize can be potentially accepted
De Groote and Kimenju (2012) ⁸⁰	Kenya	Consumers: Urban adults, 45% F; n = 604	Experimental auction: willingness to buy biofortified maize for same or reduced price compared with normal maize	26% would buy yellow maize at same price as normal maize; even at discount, less than half would buy yellow maize. Price should be reduced by 37% for consumers to buy, with a larger discount for supermarket clients. Income and education had negative effect on WTP for yellow maize	Consumer preference for white maize is strong. For biofortified yellow maize to be accepted, a strong public awareness campaign is needed
Meenakshi et al. (2012) ⁷⁶	Zambia	Producers and consumers: Small-scale rural farmers, mean age: 44 y; n = 478	Experimental auction: WTP for orange, yellow, or traditional maize with or without (radio or through community leaders) education	WTP is slightly higher for orange maize compared with white maize, whereas yellow maize was sold at a discount. Nutrition education improves acceptability and WTP, no difference between locations and no difference between channel of information receiving	Orange maize is perceived differently than yellow maize and can compete with white maize
Beans Oparinde et al. (2015) ⁴¹	Rwanda	Consumers: Adults in Northern Province, > 18 y; n = 572	Experimental auction: WTP for RIB, WIB, and a local variety (Mutiki) after exposure to no information; 1-time information (1-min radio message) on gains/benefits of iron; repeated information on gains/benefits of iron; 1-time information on negative effects/disadvantages of low iron; repeated information on negative effects/disadvantages of low iron	WTP was 476 RWF/kg for the local variety, 490 RWF/kg for RIB, and 387 RWF/kg for WIB with similar ranking in all treatment groups. Without information (control group), participants were willing to pay a 7% premium for RIB and needed a discount of 11% for WIB. With information, a premium of 13%–17% would be paid for RIB, whereas a discount of 6%–14% was needed for WIB compared with the local variety. Type of information did not affect the premiums for RIB, whereas the frequency of information increased the premium from 23% to 39% for RWF. The premium on WIB, increased significantly by 85% for the frequent negative effects/disadvantages of low iron information	Without nutritional information, participants were willing to pay a 7% premium for RIB, whereas a 11% discount for WIB was needed. RIB can compete well with the local variety, and this can be enhanced with repeated nutritional information

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Table 5 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Pérez et al. (2015) ⁴²	Guatemala	Consumers: Adults in northwest Guatemala, mean age: 35 y; n = 360	Price game with 1 lb of control and bio-fortified beans for home testing after exposure to no information, 1-time nutrition information, and repeated nutrition information	WTP for biofortified beans was marginally higher in all information groups, influenced by order of exposure, age of respondent, and education level	The biofortified bean variety is liked in a similar way as the traditional bean
Oparinde et al. (personal communication, 2016)	Rwanda	Consumers: Adult visitors of urban bean market; n = 398	WTP by BDM (individual auctions) of raw and cooked beans of local variety, RIB, and WIB after no information and after nutrition information	Without nutrition information, consumers were willing to pay the same price for RIB as for the local variety and more for the WIB. Information improved the premium for both iron varieties by 13%–15%. Poverty did affect WTP for WIB but not for RIB	RIB could be targeted for the poor, whereas WIB could be targeted for the richer consumers. Nutritional information should be used to promote iron beans
Oparinde et al. (personal communication, 2016)	Rwanda	Consumers: Rural and urban adults, mean: 43 y; n = 578 (rural), n = 231 (urban)	Experimental auction: WTP for control and 2 iron biofortified (IB1 and IB2) beans, after no nutrition information, short nutrition information, short nutrition information + endorsement by village leader, long nutrition information, or long nutrition information with endorsement of village leader (for rural adults); and after no nutrition information or short information (for urban adults)	Overall, WTP was similar for the control and IB1 bean but was higher for IB2 bean. Nutrition information raised the WTP price by 9%–13% more for the IB2 than for the IB1 and was slightly higher in rural areas. Length of nutrition information or endorsement did not influence a premium pay	Biofortified beans were acceptable, and a program to promote these beans can use a short version of nutritional information
Rice Deodhar and Chern (2008) ³²	India	Consumers: Rural and urban adults in Gujarat, mean age: 37 y; n = 602 Students, academics, and businesspersons (via Internet), mean age: 29 y; n = 110	Contingent valuation consumer survey about golden rice (genetically engineered with provitamin A) with WTP based on sequential closed-ended binary choice questions by stated choice method	72% of group 1 and 28% of group 2 were somewhat or extremely willing to consume foods produced with genetically engineered ingredients. The middle-income class was most likely to accept genetically engineered foods, and females were more reluctant. Consumers were willing to pay a premium of 19.5% for golden rice	Most respondents were willing to consume genetically engineered foods, and a substantial premium would be paid for golden rice with enhanced nutritive value
Depositaro et al. (2009) ²⁹	Philippines	Consumers: University students in Los Banos, mean age: 19 y; n = 100	WTP by uniform-price auction after visual exposure to 500-g bag of regular rice or golden-colored rice (genetically engineered) with no information or with positive, negative, or 2-sided information	Without information, golden rice was bought at a premium of 40% above the normal market price. The marginal effect of information on WTP with no information as a reference was 0.06 for positive information, –0.40 for negative information, and –0.56 for 2-sided information	Golden genetically engineered rice was well accepted. The marginal effect of positive information vs no information on WTP for golden rice is minimal, whereas negative or 2-sided information decreases WTP substantially

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Table 5 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
De Steur et al. (2010) ⁷⁸	China	Consumers: Adult rice consumers in Shanxi Province, > 20y; n = 944	Willingness to accept, WTP for folate-rich genetically engineered rice	62% of respondents are willing to accept genetically engineered rice, 27% are indifferent, and 11% are reluctant. Respondents were on average willing to pay 34% more for 1 kg of genetically engineered rice than for conventional rice. Males, higher-educated people, and rural consumers were more likely to accept genetically engineered rice	Consumers are in general willing to accept genetically engineered rice and willing to pay a premium. Knowledge, sex, and sociodemographic indicators play a role in acceptance of genetically engineered rice
De Steur et al. (2012) ³¹	China	Consumers: Student rice consumers, mean age: 21 y; n = 132 Nonstudent rice consumers, mean age: 39 y; n = 120	Experimental auction with nonrepeated information treatments: bidding value for regular rice, folate-rich genetically engineered rice, and rice supplemented with folic acid	Female rice consumers are prepared to pay 33.7% more for folate-rich rice compared with regular rice. Offering a genetically engineered free folate substitute did not result in significant differences in bidding behavior. Students are less likely to buy and pay more for folate-rich rice. WTP is mainly determined by consumers' acceptance of genetic engineering and objective knowledge	Despite lower bids after information was provided about genetic engineering, the perceived benefits are high enough to compensate for potential negative reactions to genetically engineered food
De Steur et al. (2013) ³⁰	China	Consumers: Female student rice consumers, mean age: 21 y; n = 132 Female nonstudent rice consumers, mean age: 39 y; n = 120	Experimental auction with nonrepeated information treatments: bidding value for folate-rich genetically engineered rice vs conventional rice	Female students and women in general are willing to pay 25.8% and 40% more for folate-rich rice compared with regular rice. Provision of information on the folate benefits increases WTP for folate-rich rice. Information on genetic engineering did not reduce WTP in the nonstudent sample, but students reduced their bid significantly. Negative information has a larger effect on WTP in students, whereas positive information is more effective in nonstudents. Information on high prevalence of folate deficiency increases the bid value in both groups	There is a general positive effect of folate-related information; nonstudents are less concerned about genetic engineering. Conflicting information will lead to primacy bias in nonstudent sample, but students have an alarmist reaction. This highlights a need for segmented, targeted communication strategies on biofortification
De Steur et al. (2014) ³³	China	Consumers: Female student and nonstudent rice consumers, mean age: 21 y (students); 40 y (nonstudents); n = 126	Experimental auctions with nonrepeated information rounds: bidding value for folate-rich rice, folate-rich rice genetically engineered, and rice supplemented with folic acid	A general preference for folate biofortification is observed, regardless of whether genetically engineered. Premiums were: 33.9%, 36.5%, and 19%, respectively, for folate-rich rice genetically engineered, nongenetically engineered, and supplemented. Key determinants were the target group, the timing of auction, intention to consume genetically engineered food, and responsibility for rice purchases	Positive reactions to genetically engineered folate-rich rice support its potential as a complementary micronutrient intervention

(continued)

Table 5 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
Birrol et al. (2011) ⁸²	India	Producers and consumers: Millet-producing adults, 95% M; n = 360	Choice experiments with attributes: days to maturity, color, added nutritional value, and price of seed of hypothetical HIPM	Respondents could be divided in 3 segments; the 1st scored highest for the nutrition attribute followed by color; the 2nd one were more sellers than consumers and had lower preferences for nutrition and color and higher preferences for the price of the seed; the last segment preferred nutrition and color attributes, but to a lesser degree than those in the 1st segment	HIPM is valued most by large households that produce for themselves and have lower-quality diets. Households producing for market derive lower benefits from consumption characteristics. Farmers should be offered a pool of varieties that provide different attributes to maximize uptake
Birrol et al. (2015) ⁵⁷	India	Consumers: Rural pearl millet consumers in Maharashtra, mean age: 40 y; n = 452	Experimental auctions: bidding value for LPM and HIPM after no information; simulated video message on the importance of iron and HIPM, with HarvestPlus as the brand (internationally certified); information with a fictional brand name (locally certified at state level)	Even in the absence of information, consumers were willing to pay more for HIPM (13.6 Rs) compared to LPM (12.8 Rs). After nutrition information, WTP for HIPM increases significantly by 12% (2nd information) and 7% (3rd information), whereas WTP for LPM significantly decreased by 9% (2nd information) and 11% (3rd information). Overall, after 2nd information respondents were willing to pay 32.4% more for HIPM, whereas this was 28.6% for after 3rd information	Consumers assign a small but significant premium to HIPM relative to the local variety, even in the absence of nutrition information. International branding and certification results in the highest premium
Oparinde et al. (2014) ⁵⁵	Nigeria	Consumers: Adults in rural areas, 65% M, > 18 y; n = 671	Incentive-compatible experimental auctions: WTP for (light and deep) yellow cassava relative to white (local) cassava varieties with and without information from national or international delivery institutions	In Imo, consumers are willing to pay the most for the local <i>gari</i> and require a discount of 28% and 25% for light yellow and deep yellow cassava. In Oyo, consumers were willing to pay more for light yellow cassava: they would pay a premium of 6% for light yellow cassava and require a discount of 9% for deep yellow cassava. When information is provided, the discount in Imo for light yellow cassava becomes a premium (19%–20%), in Oyo, the discount for deep yellow cassava becomes a premium (26%–27%). In Oyo, after information, the consumer premium is larger for deep yellow cassava compared with light yellow cassava (20%–25%). Consumers in the southeast are indifferent to the	Without a nutrition information campaign, biofortified varieties are unlikely to be accepted in the southeast because they are associated with a substantial discount. Nutrition information results in a large and significant price premium for biofortified yellow cassava. The nature of delivery institution has only a small effect in 1 of the states

(continued)

Table 5 Continued

Reference	Country	Study Population	Method and Study Design	Results	Conclusion
González et al. (2009) ⁵⁸	Brazil	Consumers: Households in northeast Brazil, mean age: 40 y; n = 414	Cross-sectional study: structured questionnaire after explanation about genetically engineered yellow cassava	authority delivering the planting material, whereas consumers in the southwest prefer delivery through international authority WTP is 60%–70% higher for genetically engineered yellow cassava than normal cassava	Attitudes toward genetically engineered biofortified yellow cassava are positive

Abbreviations: BDM, Becker deGroot Marchak method; F, female; HIPM, high-iron pearl millet; IB1, high-iron bean 1; IB2, high-iron bean 2; KES, Kenyan shilling; LPM, local pearl millet; M, male; OFSP, orange-fleshed sweet potato; RIB, iron biofortified red bean; Rs, Rupees; RWF, Rwandan Franc; WFSP, white-fleshed sweet potato; WIB, iron biofortified white bean; WTP, willingness to pay.

method (Oparinde et al., HarvestPlus, personal communication, 2016).^{41,50,57} According to this method, a participant first places a realistic bid for the object on sale. Then a random price lot is drawn from a pre-established distribution. If the bid is higher than indicated on the price lot, the participant wins and pays the lot price for the object, but if the bid is lower, the participant is not allowed to buy the object. In this experiment, the bid equals the price that a consumer is willing to pay. In other studies, comparable binding price games were conducted.^{29,42,43,75,76} In a few studies, the price setting remained theoretical and did not require that the participant buy the object,^{32,77,78} which may have led to overestimation of premiums. One study assessed the profitability of including a biofortified food as an ingredient in a food product by comparing the costs and revenues of production with the reference product.³⁷ In 12 studies, the effect of providing information on the health benefits of biofortified crops on willingness to pay for such varieties was assessed (Oparinde et al., HarvestPlus, personal communication, 2016).^{29,30,41–43,50,55,57,76}

Maize

Consumers. Two studies conducted in urban areas of southern Africa in 1995 and 1997 showed that the price of yellow maize is an important determinant of consumer acceptance; approximately one-quarter of study participants would buy yellow maize at a 10%–15% discount, whereas more than half of study participants would switch to yellow maize at a discount of > 40%.^{65,77} Findings were similar in urban Kenya, where consumers would need a discount of 37% or more to buy yellow maize.⁷⁵ A study of rural and urban households (n = 651) in western and eastern Kenya showed that willingness to pay for biofortified maize was 25% higher than for ordinary (non-biofortified) maize, but for a 2-kg bag of yellow maize flour, participants were willing to pay only 90% of what they would pay for white maize flour.⁷⁹ Strong regional differences were found in Ghana, where rural consumers in the Ashanti Region would pay the most for white maize, whereas consumers in the Eastern Region would pay more for yellow and orange maize. Provision of nutritional information increased the price consumers were willing to pay for orange maize.⁵⁰ Existing preferences depend on consumer characteristics; Stevens et al.⁴⁹ showed in a study in Mozambique with market shoppers (n = 201) that household size, presence of small children, dietary diversity, and perceived taste determined acceptance in a trade experiment. In Kenya, supermarket clients also indicated a need for a larger discount for yellow maize compared with market buyers. Level of education

and income had a negative effect on willingness to pay for yellow maize.⁸⁰

Producers and consumers. In Zambia, rural farmers and villagers, who were selected for the study by the local chief (head of the village), were willing to pay slightly more for orange maize than white maize, and provision of nutrition information increased the price they were willing to pay.⁷⁶

Summary finding. Overall, these studies reveal that acceptance of yellow and orange maize is dependent on regional and consumer characteristics and is strongly determined by price. Provision of nutrition information may increase the acceptance of yellow and orange maize in some regions.

Rice

Consumers. University students (n = 100) in the Philippines were willing to pay a premium of 40% for a 0.5-kg bag of golden rice rich in provitamin A that was biofortified through genetic engineering; positive information did not substantially increase the premium, whereas negative or two-sided information about golden rice led consumers to require substantial discounts of 40%–56% in order to make a purchase.²⁹ In India, a survey of rural and urban households (n = 602) as well as students, academicians, and businesspersons (n = 110) showed that 70% and 28%, respectively, were willing to consume genetically engineered crops and were willing to pay a premium of 19.5% for golden rice. Those in the middle-income class were most likely to accept genetically engineered crops; females were more reluctant.³² De Steur et al.⁷⁸ found similar results in China with 62% of respondents (n = 944) willing to accept folate-rich rice biofortified through genetic engineering and willing to pay a premium of 34% for it.⁷⁸ Here, acceptance of genetically engineered rice was associated with being male, being highly educated, or living in a rural area. In other studies, it was shown that female rice consumers, female students, or women in general were prepared to pay more for folate-rich rice biofortified through genetic engineering.^{30,31,33} Positive information on genetic engineering increased willingness to pay for nonstudents, but negative information led to a large reduction of willingness to pay in students. Conflicting (positive and negative) information led to primacy bias in nonstudents, where the information presented first dominated the effect of information on the willingness to pay. Students had an alarmist reaction to two-sided information, treating it as negative information irrespective of the information sequence, which led to low valuations.³⁰

Producers and consumers. No studies that assessed producers' adoption and marketability of biofortified rice were identified.

Summary finding. Overall, there appears to be a potential market for genetically engineered rice in Asia. This should be further explored. Studies highlight the need for segmented, targeted communication strategies.

Beans

Consumers. A study among households in northwest Guatemala (n = 360) showed that participants were willing to pay slightly more for 1 pound of home-tested iron-biofortified beans than for control beans, irrespective of receipt of nutritional information.⁴² Three studies conducted in Rwanda revealed that in the rural north iron-biofortified red beans were sold at a 7% premium, whereas iron-biofortified white beans were sold at a discount of 11%.⁴¹ Provision of nutritional information increased the premium for iron-biofortified red beans to > 13% but did not substantially change the discount for iron-biofortified white beans. In contrast, urban consumers were willing to pay more for iron-biofortified white beans but were not willing to pay more for the iron-biofortified red beans (Oparinde et al., HarvestPlus, personal communication, 2016). Provision of nutritional information improved the premium for both iron-biofortified varieties to > 13%. Poverty was negatively associated with the price consumers were willing to pay for iron-biofortified white beans but not iron-biofortified red beans. Rural and urban visitors to Rwandan markets were willing to pay more for a specific type of iron-biofortified bean over another type or control. Again, nutrition information enhanced the price for the preferred iron-biofortified bean variety (Oparinde et al., HarvestPlus, personal communication, 2016). It can be concluded that iron-biofortified beans have the potential to be well accepted, but the acceptability of specific varieties may differ by population segment, and nutrition information may further increase acceptance.

Producers and consumers. No studies that assessed producers' adoption and marketability of biofortified beans were identified.

Sweet potato

Consumers. Low et al.³⁷ evaluated the economic viability of producing golden bread buns containing 38% biofortified OFSP versus white wheat flour buns for bakers in 3 rural villages in Mozambique. They calculated that the

net return to labor (revenue minus costs to produce and sell) was 3 times higher for golden bread buns, indicating that this is a promising marketing strategy for OFSP.³⁷ Also in Mozambique, a choice experiment (n = 308) conducted in both rural and urban settings revealed that consumers were willing to pay 51% more for OFSP relative to white varieties with dry matter being a key factor in driving consumer acceptance.⁸¹ In Uganda, a valuation by choice experiment revealed that rural and urban consumers in Uganda (n = 467) would pay similarly for deep orange and white varieties; however, after receiving nutritional information about OFSP, consumers were willing to pay a 25% premium for the orange variety.⁴³

Producers and consumers. No studies that assessed producers' adoption and marketability of biofortified OFSP were identified.

Pearl millet

Consumers. Consumers of pearl millet in 3 districts of Maharashtra in India (n = 452) were willing to pay a small premium for iron-biofortified pearl millet. Receipt of nutrition information and international branding contributed positively to the price consumers were willing to pay.⁵⁷

Producers and consumers. In another study in India, Birol et al.⁸² indicated that consumers could be divided into different segments. Iron-biofortified pearl millet was valued most by large households that produce for their own consumption and have lower-quality diets. Households that mainly produce for market sales derive lower benefits from consumption characteristics such as color and nutrition.⁸²

Although the number of studies on the acceptance of iron-biofortified pearl millet is limited, potential for acceptance of high-iron varieties exists.

Cassava

Consumers. Oparinde et al.⁵⁵ showed that among rural cassava consumers in Nigeria there are large regional differences in willingness to pay for biofortified provitamin A-rich cassava varieties with light yellow and deep yellow color. In Imo State, consumers needed a discount of > 25% for both varieties, whereas in Oyo State, light yellow cassava had a premium of 6%. Providing nutritional information changed the discount for light yellow cassava into a premium of 20% in Imo State and the discount for deep yellow cassava into a premium of 26% in Oyo State. The nature of the

delivery channel of cuttings (whether federal or international) had only a small effect on bidding values.⁵⁵ In Brazil, the contrary was found, with consumers willing to pay 60%–70% more for genetically engineered yellow cassava than for normal cassava.⁵⁸

Producers and consumers. No studies that assessed producers' adoption and marketability of biofortified cassava were identified.

DISCUSSION

This review summarizes the available evidence for the acceptance and adoption of biofortified staple crops in low- and middle-income countries with regard to sensory acceptability, sociocultural drivers, consumer adoption, and marketability. Most of the available information is for traditionally bred, provitamin A-biofortified sweet potato, maize, and cassava among African populations. These crops are generally well accepted from sensory and sociocultural perspectives, and consumers are willing to pay a (small) premium price for the biofortified crops compared with the nonbiofortified equivalents. Results are, however, context specific and depend on the intensity of the yellow color of the crop, type of food product, cultural status of the crop, season, and knowledge of vitamin A and health benefits.

In Nigeria, yellow varieties of cassava and sweet potato are more acceptable than orange, deep-yellow, or purple varieties in areas where multiple varieties are available.^{36,55} This preference is often associated with the inferior processing, cooking, and storage characteristics of the dark-colored varieties and not to color. Further breeding efforts to reduce these negative aspects is important. In southern and eastern Africa, traditionally prepared (boiled) OFSP is well accepted from both a sensory and cultural point of view. However, sensory/chemical properties related to dry matter and viscosity may hamper the acceptability of OFSP for use in traditional preparation methods in western Africa.²⁸ On the other hand, development of novel products with OFSP as an ingredient provides opportunities to create a market for OFSP.^{13,14,21,27,37,44–46} The nutritional value of such novel products should be given careful thought because it is not always clear what the nutrient retention of the final product is. Also, products that are high in fat, sugar, or salt should be avoided because these products can generate negative health effects related to metabolic and vascular health.

Despite the historic perception of inferiority of yellow maize as food for humans and its association with food aid, some studies indicate that this perception can be influenced by providing information about the

benefits of provitamin A in relation to health.^{25,50–52,76} This change in cultural acceptability may especially benefit poor consumers in sub-Saharan Africa because acceptance seems to be highest in this population segment.^{65,77,80} Also, some of the negative aspects of yellow maize, such as rancidity upon storage, can be overcome by breeding for different traits. One hurdle noted in the literature is the limited availability of yellow maize. In Zambia and Nigeria, orange maize varieties are now being introduced on a large scale, and acceptance of these varieties is generally good and not hampered by the orange color.^{25,34} Adoption studies should now monitor actual acceptance in these countries.

Season is another determining factor in the adoption of biofortified crops. In Mozambique, for example, the adoption rate of OFSP varied by season (38% in dry season–71% in wet season),⁶¹ and in Mozambique and Uganda the adoption rate was reduced in subsequent seasons after OFSP introduction,^{61,63} mainly because of unavailability of vines, limited propagation capacity, and lower drought-tolerance of OFSP. For yellow cassava, only 1 study provided information on adoption rates with farmers who were part of participatory research program, and it showed an early adoption rate of 15%, with 62% intending to plant yellow cassava the next year.⁵⁹ Although intention is assumed to be the best predictor of behavior,⁸³ it is unknown whether farmers indeed planted the biofortified cassava the next year. The effect of season on adoption and subsequent adoption in the years after introduction should be closely monitored.

Additionally, acceptance of specific varieties of biofortified crops may be segmented, as evidenced by the preference for iron biofortified white beans by urban consumers and iron biofortified red beans by rural consumers in Rwanda (Oparinde et al., HarvestPlus, personal communication, 2016). Preschoolers, secondary school children, and adults in South Africa¹⁶ preferred yellow maize, whereas primary school children were indifferent. In Mozambique, preference for orange maize was associated with household size and presence of small children.⁴⁹ In Kenya, being a supermarket client with higher education and income was related to a lower willingness to pay for yellow maize.⁸⁰ In India, large households producing food for their own consumption valued high-iron pearl millet more than households producing food mainly for markets.⁸² The importance of segmentation is specifically found in studies concerning genetically engineered biofortified crops. Acceptability of genetically engineered yellow cassava was higher among older persons, individuals with more trust in authorities, persons with access to media, and those with a higher perception of their

personal health risk.⁵⁸ In India, genetically engineered golden rice was more acceptable to the middle class than the upper class.³² University students in the Philippines and China were, in general, more reluctant to pay for genetically engineered rice,^{29,30} and higher acceptance of genetically engineered rice was associated with being male, being highly educated, or living in rural areas.⁷⁸ Although women were more reluctant to accept genetically engineered rice in 1 study conducted in China,⁷⁸ other studies showed that women were willing to pay more for it.^{30,31,33} This shows that genetically engineered biofortified crops need to be carefully positioned, taking the specific context and target population into consideration. Within the literature reviewed, second-generation genetically engineered crops form a specific category. In Asia, genetically engineered rice, either biofortified with β -carotene (golden rice) or with folate, is generally acceptable to consumers but provision of nutritional information plays a crucial role in acceptance of the crops. Communication strategies to promote genetically engineered crops need careful thought and design because some studies showed negative effects of conflicting information.^{29,30} Actual adoption of these crops remains to be shown after the crops have been introduced on a larger scale.

Studies consistently indicate that provision of nutrition information increases acceptance of and willingness to pay for biofortified crops. Studies in Mozambique and Uganda showed that a short nutrition education program yielded a similar level of adoption of OFSP as a program of longer duration.^{22,23,69} It may be that it is important to explain why a new variety is introduced (ie, nutritional and health reasons) but that after introduction other reasons may become more important to farmers and consumers, such as yield and taste.

This review has some limitations. The quality of the various papers was not taken into consideration in this systematic review, although there were large differences in the robustness and completeness of descriptions of participant selection, study design, research methods, control treatment, randomization, and handling of bias. In addition, it was not always clear whether the crops being studied were actually biofortified to a concentration sufficient to have a nutritional impact. For instance, yellow maize does not necessarily contain a substantial amount of β -carotene but may have its color due to non-provitamin A carotenoids. Similarly, the results on iron-biofortified rice in Latin America are questionable in this respect. Currently, there is no consensus about when a crop is actually biofortified and there is no Codex Alimentarius definition of biofortification. This formed a major limitation for summarizing the literature on acceptance and adoption of biofortified

crops. In most of the studies, participants were being exposed to the product for the first time. This may bias the findings because actual use of the product may reveal properties that remain unnoticed during a one-time exposure. Also, adoption studies were often done under strict intervention conditions that might have resulted in much higher adoption rates than are to be expected at the country level, and country-level adoption studies are lacking. As indicated, most of the studies in this review were not carried out among the groups most at risk of micronutrient deficiencies, such as young children and women of reproductive age. Whether factors determining the acceptability of biofortified crops by the studied population are similar for these vulnerable groups and to what extent the studied population influences the choices of the vulnerable groups needs to be further confirmed.

CONCLUSION

From a sensory perspective, biofortified crops seem to be acceptable to rural and urban populations, either when prepared following traditional methods or when used as an ingredient in nontraditional food products. Even a visible trait such as (yellow) color does not seem to be a major obstacle in itself, except partially for yellow maize due to its assumed inferiority and association with poverty. Availability of the crop and information on its health benefits are among the most important determinants of acceptance and adoption of biofortified crops. Studies also show that populations are willing to pay a (small) premium for biofortified crops, especially after being given information on the benefits to health. Most studies do indicate that there is a need for segmented targeted communication strategies due to the preference heterogeneity of respondents. Genetically engineered biofortified crops are a special case; studies on genetically engineered rice and cassava indicate that, in general, these crops are accepted, but this acceptance is highly influenced by negative information on genetic engineering technology. Overall, in many of the studies reviewed here, biofortified crops were not yet available to the populations being studied, and acceptance and adoption remained hypothetical. Many biofortified crops are now reaching the end of the development phase and are moving into the dissemination phase, which should result in more available evidence in the near future on replacement of current varieties with biofortified varieties and changes in consumer diets. At the moment, data on actual adoption are only available for sweet potato and, to a lesser extent, yellow maize based on large effectiveness studies. Future studies should look into the actual determinants of acceptance

and adoption during and after wide-scale introduction of biofortified beans, cassava, rice, and pearl millet.

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Declaration of interest. At the time of writing, E.F.T. was affiliated with HarvestPlus, International Center for Tropical Agriculture (CIAT), Cali, Colombia. HarvestPlus aims to improve nutrition and public health by developing and promoting biofortified food crops that are rich in vitamins and minerals, and providing global leadership on biofortification evidence and technology. HarvestPlus focuses on 3 micronutrients: iron, zinc, and vitamin A and in traditional plant breeding in collaboration with international research institutes and national research partners in target countries, such as the CIAT. I.D.B. is part of the team that develops the research program for Agriculture for Nutrition and Health (A4NH) within the Consultative Group for International Agricultural Research (CGIAR). A.M.B. is currently a grant holder for a study assessing the efficacy of yellow cassava on vitamin A status in preschool children in Nigeria, funded by HarvestPlus. The authors participated in a research project on biofortification acceptability included in this review. Their funders had no role in the design, implementation, analysis, or interpretation of the data.

Supporting Information

The following Supporting Information is available in the online version of this article available at the publisher's website.

Appendix S1 PRISMA checklist for the systematic review

REFERENCES

- Bouis HE, Hotz C, McClafferty B, et al. Biofortification: a new tool to reduce micronutrient malnutrition. *Food Nutr Bull.* 2011;32(1 suppl.):31–40.
- Ruel MT, Alderman H. Nutrition-sensitive interventions and programmes: how can they help to accelerate progress in improving maternal and child nutrition? *Lancet.* 2013;382:536–551.
- Bouis H. Enrichment of food staples through plant breeding: a new strategy for fighting micronutrient malnutrition. *Nutr Rev.* 1996;54:131–137.
- Solomons NW, Bulux J. Identification and production of local carotene-rich foods to combat vitamin A malnutrition. *Eur J Clin Nutr.* 1997;51(suppl 4):S39–S45.
- Bouis HE, Welch RM. Biofortification—a sustainable agricultural strategy for reducing micronutrient malnutrition in the global south. *Crop Sci.* 2010;50:S20–S32.
- Saltzman A, Birol E, Bouis HE, et al. Biofortification: progress toward a more nourishing future. *Glob Food Sec.* 2013;2:9–17.
- de Valença AW, Bake A, Brouwer ID, et al. Agronomic biofortification of crops to fight hidden hunger in sub-Saharan Africa. *Glob Food Sec.* 2017;12:8–14.
- De Steur H, Mehta S, Gellynck X, et al. GM biofortified crops: potential effects on targeting the micronutrient intake gap in human populations. *Curr Opin Biotechnol.* 2017;44:181–188.
- Peters DH, Tran NT, Adam T. *Implementation Research in Health: A Practical Guide.* Geneva, Switzerland: World Health Organization; 2013.
- Birol E, Meenakshi JV, Oparinde A, et al. Developing country consumers' acceptance of biofortified foods: a synthesis. *Food Secur.* 2015;7:555–568.
- Darnton-Hill I, Webb P, Harvey PW, et al. Micronutrient deficiencies and gender: social and economic costs. *Am J Clin Nutr.* 2005;81:1198S–1205S.
- Moher D, Shamseer L, Clarke M, et al. Preferred reporting items for systematic review and meta-analysis protocols (PRISMA-P) 2015 statement. *Syst Rev.* 2015;4:1. doi:10.1186/2046-4053-4-1.
- Romero AC, Morales EY, Silva CM, et al. Evaluación sensorial de tortas de camote (*Ipomoea batatas*) elaboradas con o sin hojas de camote, con niños en edad escolar en Nicaragua. *Perspect en Nutr Humana.* 2011;13:191–202.
- Laurie SM, Heerden SM Van. Consumer acceptability of four products made from beta-carotene-rich sweet potato. *African J Food Sci.* 2012;6:96–103.
- Laurie SM, Faber M, Calitz FJ, et al. The use of sensory attributes, sugar content, instrumental data and consumer acceptability in selection of sweet potato varieties. *J Sci Food Agric.* 2013;93:1610–1619.
- Pillay K, Derera J, Siwela M, et al. Consumer acceptance of yellow, provitamin A-biofortified maize in KwaZulu-Natal. *South African J Clin Nutr.* 2011;24:186–191.
- Cabal DG, Melo A, Lissbrant S, et al. Highly nutritional cookies based on a novel bean-cassava-wheat flour mix formulation. *Agron Colomb.* 2014;32:407–416.
- Tofiño A, Tofiño R, Cabal D, et al. Evaluación agronomica y sensorial de frijol (*Phaseolus vulgaris* L.) mejorado nutricionalmente en el norte del departamento de Cesar, Colombia. *Perspect en Nutr Humana.* 2011;13:161–177.
- Tomlins K, Ndunguru G, Stambull K, et al. Sensory evaluation and consumer acceptability of pale-fleshed and orange-fleshed sweetpotato by school children and mothers with preschool children. *J Sci Food Agric.* 2007;87:2436–2446.
- Talsma EF, Melse-Boonstra A, de Kok BPH, et al. Biofortified cassava with provitamin A is sensory and culturally acceptable for consumption by primary school children in Kenya. *PLoS One.* 2013;8:e73433. doi:10.1371/journal.pone.0073433.
- Rangel C, Moreira da Silva E, Salvador L, et al. Sensory evaluation of cakes prepared with orange-fleshed sweet potato flour (*Ipomoea batatas* L.). *Perspect en Nutr Humana.* 2011;13:203–211.
- Hotz C, Loechl C, de Brauw A, et al. A large-scale intervention to introduce orange sweet potato in rural Mozambique increases vitamin A intakes among children and women. *Br J Nutr.* 2012;108:163–176.
- Hotz C, Loechl C, Lubowa A, et al. Introduction of beta-carotene-rich orange sweet potato in rural Uganda resulted in increased vitamin A intakes among children and women and improved vitamin A status among children. *J Nutr.* 2012;142:1871–1880.
- Low JW, Arimond M, Osman N, et al. A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. *J Nutr.* 2007;137:1320–1327.
- Schmaelzle S, Kalivile C, Arcott SA, et al. Nutrient and nontraditional food intakes by Zambian children in a controlled feeding trial. *Food Nutr Bull.* 2014;35:60–67.
- Padrón V, Crestelo E, Caraballo R, et al. Preferencia y aceptabilidad de la variedad de arroz IACuba 30 con alto contenido de hierro y zinc por mujeres gestantes en Cuba—ProQuest. *Perspect Nutr Humana.* 2011;13:123–134.
- Nguyen-Orca MFR, Hurtada WA, Dizon EI. Nutritional value, functional components and acceptability of sweet potato (*Ipomoea batatas* L.) and corn (*Zea mays* L.) blends as instant complementary food. *Philipp J Crop Sci.* 2014;39:20–26.
- Fetuga G, Tomlins K, Henshaw F, et al. Effect of variety and processing method on functional properties of traditional sweet potato flour (“elubo”) and sensory acceptability of cooked paste (“amala”). *Food Sci Nutr.* 2014;2:682–691.
- Depositario DPT, Nayga RM, Wu X Jr, et al. Effects of information on consumers' willingness to pay for golden rice. *Asian Econ J.* 2009;23:457–476.
- De Steur HD, Buysse J, Feng S, et al. Role of information on consumers' willingness-to-pay for genetically-modified rice with health benefits: an application to China. *Asian Econ J.* 2013;27:391–408.
- De Steur H, Gellynck X, Feng S, et al. Determinants of willingness-to-pay for GM rice with health benefits in a high-risk region: evidence from experimental auctions for folate biofortified rice in China. *Food Qual Prefer.* 2012;25:87–94.
- Deodhar SY, Chern WS. Emerging markets for GM foods: a study of consumer's willingness to pay in India emerging markets for GM foods: an Indian perspective on consumer understanding and willingness to pay. Paper presented at: American Agricultural Economics Association Annual Meeting; July 27–29, 2008; Orlando, FL.
- De Steur H, Feng S, Xiaoping S, et al. Consumer preferences for micronutrient strategies in China. A comparison between folic acid supplementation and folate biofortification. *Public Health Nutr.* 2014;17:1410–1420.
- Alamu EO, Maziya-Dixon B, Menkir A, et al. Effects of husk and harvesting time on provitamin A activity and sensory properties of boiled fresh orange maize hybrids. *J Food Qual.* 2015:387–395.
- Tomlins K, Owori C, Bechoff A, et al. Relationship among the carotenoid content, dry matter content and sensory attributes of sweet potato. *Food Chem.* 2012;131:14–21.
- Awoyale W, Sanni LO, Shittu TA, et al. Effect of storage on the chemical composition, microbiological load, and sensory properties of cassava starch-based custard powder. *Food Sci Nutr.* 2015;3:425–433.
- Low JW, van Jaarsveld PJ. The potential contribution of bread buns fortified with beta-carotene-rich sweet potato in central Mozambique. *Food Nutr Bull.* 2008;29:98–107.
- De Bree A. *Acceptability of Zinc Fortified Rice by Women in Rural Chuzhou District, China* [master's thesis]. Wageningen, the Netherlands: Wageningen University; 2009.
- Vergara O, Buitrago IC, De Caballero EV, et al. Evaluación sensorial de arroz biofortificado, variedad IDIAP Santa Cruz 11, en granjas autosostenibles del patronato de Nutrición en la provincia de Coclé, Panama. *Perspect en Nutr Humana.* 2011;13:147–160.
- Carrillo-Centeno P, Sánchez-Ruiz M. Sensorial Evaluation Study of a Variety of Nutritionally Improved Beans (INTA Ferroso) vs. a Conventional Variety (INTA Norte) in the Northern Zone of Nicaragua. *HarvestPlus LAC; Cali, Colombia,* 2014.
- Oparinde A, Birol E, Murekezi A, et al. *HarvestPlus Working Paper 18: Consumer Acceptance of Biofortified Iron Beans in Rural Rwanda: Experimental Evidence.* Washington DC: HarvestPlus; 2015.
- Pérez S, Oparinde A, Birol E, et al. Consumer acceptance of an iron bean variety in northwest Guatemala: the role of information and repeated messaging. Paper presented at: IOAE 2015; 9–14 August 2015; Milan, Italy.
- Chowdhury S, Meenakshi JV, Tomlins KJ, et al. Are consumers in developing countries willing to pay more for micronutrient-dense biofortified foods? Evidence from a field experiment in Uganda. *Am J Agric Econ.* 2011;93:83–97.
- Trejo-González AS, Loyo-Gonzalez AG, Munguia-Mazariegos MR. Evaluation of bread made from composite wheat-sweet potato flours. *Int Food Res J.* 2014;21:1683–1688.
- Sivaramane N, Panda S, Ray R, et al. Modeling consumer acceptability of beta-carotene rich sweet potato curd. *J Sens Stud.* 2008;23:791–803.
- Olapade AA, Ogunade OA. Production and evaluation of flours and crunchy snacks from sweet potato (*Ipomoea batatas*) and maize flours. *Int Food Res J.* 2014;21:203–208.
- Leyva-Martínez RM, Pachón H, Chaveco-Pérez O, et al. Evaluación sensorial de frijol (*Phaseolus vulgaris* L.) mejorado nutricionalmente en dos comunidades cubanas. *Agron Mesoam.* 2010;21:281–288.
- Centeno PC, Chow Z, Cuadra S, et al. Aceptación de tres líneas de frijol (*Phaseolus vulgaris* L.) mejorado nutricionalmente por los consumidores nicaragienses. *Perspect en Nutr Humana.* 2011;13:179–189.
- Stevens R, Winter-Nelson A. Consumer acceptance of provitamin A-biofortified maize in Maputo, Mozambique. *Food Policy.* 2008;33:341–351.
- De Groote H, Tomlins K, Haleegoah J, et al. Assessing rural consumers' WTP for orange, biofortified maize in Ghana with experimental auctions and a simulated radio message. Paper presented at: African Association of Agricultural Economists & Agricultural Economics Association of South Africa 48th Conference; September 19–23, 2010; Cape Town, South Africa.
- Khumalo TP, Schönfeldt HC, Vermeulen H. Consumer acceptability and perceptions of maize meal in Giyani, South Africa. *Dev South Afr.* 2011;28:271–281.
- Govender L, Pillay K, Derera J, et al. Acceptance of a complementary food prepared with yellow, provitamin A-biofortified maize by black caregivers in rural KwaZulu-Natal. *South African J Clin Nutr.* 2014;27:217–221.
- Awobusuyi TD, Siwela M, Kolanisi U, et al. Provitamin A retention and sensory acceptability of amahewu, a non-alcoholic cereal-based beverage made with provitamin A-biofortified maize. *J Sci Food Agric.* 2016;96:1356–1361.
- Montecinos KL, Godoy JA, Centeno PM, et al. Evaluación sensorial de arroz (*Oryza sativa*) variedad azucena en la región autónoma del Atlántico Norte en Nicaragua. *Perspect en Nutr Humana.* 2011;13:135–146.
- Oparinde A, Banerji A, Birol E, et al. *HarvestPlus Working Paper 13: Information and Consumer Willingness to Pay for Biofortified Yellow Cassava: Evidence from Experimental Auctions in Nigeria.* Washington, DC: HarvestPlus; 2014.

56. Njoku D, Egesi C, Gracen V. Identification of pro-vitamin A cassava (*Manihot esculenta Crantz*) varieties for adaptation and adoption through participatory research. *J Crop Improv.* 2014;28:361–376.
57. Birol E, Asare-Marfo D, Karandikar B, et al. Investigating demand for biofortified seeds in developing countries: high-iron pearl millet in India. *J Agrribus Dev Emerg Econ.* 2015;5:24–43.
58. Gonzalez C, Johnson N, Qaim M. Consumer acceptance of second-generation GM foods: the case of biofortified cassava in the north-east of Brazil. *J Agric Econ.* 2009;60:604–624.
59. Gonzalez C, Perez S, Cardoso C, et al. Analysis of diffusion strategies in northeast Brazil for new cassava varieties with improved nutritional quality. *Exp Agric.* 2011;47:539–552.
60. De Steur H, Liqun G, Van Der Straeten D, et al. The potential market for GM rice with health benefits in a Chinese high-risk region. *J Food Prod Mark.* 2015;21:231–243.
61. Mazuze MF. Analysis of Adoption and Production of Orange-fleshed Sweetpotatoes: the Case Study of Gaza Province in Mozambique [master's thesis]. East Lansing, MI: Michigan State University; 2004.
62. Fetuga GO, Tomlins K, Bechoff A, et al. A survey of traditional processing of sweet potato flour for amala, consumption pattern of sweet potato amala and awareness of orange-fleshed sweet potato (OFSP) in South West Nigeria. *J Food Agric Environ.* 2013;11:67–71.
63. Gilligan DO, Kumar N, McNiven S, et al. IFPRI Discussion Paper 01353: Bargaining Power and Biofortification: The Role of Gender in Adoption of Orange Sweet Potato in Uganda. Washington, DC: International Food Policy and Research Institute (IFPRI); 2014.
64. Yanggen D, Nagujja S. CIP Working Paper: The Use of Orange-Fleshed Sweetpotato to Combat Vitamin A Deficiency in Uganda. A Study of Varietal Preferences, Extension Strategies and Post-harvest Utilization. Lima, Peru: International Potato Center; 2006.
65. Tschirley DL, Santos AP. Who Eats Yellow Maize? Preliminary Results of a Survey of Consumer Maize Preferences. East Lansing, MI: Michigan State University; 1995.
66. Muzhingi T, Langyintuo AS, Malaba LC, et al. Consumer acceptability of yellow maize products in Zimbabwe. *Food Policy.* 2008;33:352–361.
67. Uwiringiyimana V. Identifying Factors Determining the Intention to Consume Yellow Cassava Among School-Age Children in Djidja, Benin [master's thesis]. Wageningen, the Netherlands: Wageningen University; 2012.
68. Asare-Marfo D, Herrington C, Alwang J, et al. HarvestPlus Listing Exercise Report: Assessing the Adoption of High Iron Bean Varieties and Their Impact on Iron Intakes and Other Livelihood Outcomes in Rwanda. Washington, DC: HarvestPlus; 2016.
69. De Brauw A, Eozenou P, Moursi M. HarvestPlus Working Paper 16: Program Participation Intensity and Children's Nutritional Status: Evidence from a Randomized Control Trial in Mozambique. Washington, DC: HarvestPlus; 2015.
70. Machira Y, Levin C, Grant F, et al. Feasibility and acceptability of integrating vitamin A rich orange fleshed sweet potato into antenatal care services in Western Kenya. *Ann Nutr Metab.* 2013;63:645.
71. De Steur H, Blancquaert D, Gellynck X, et al. How negative product attributes alter consumer perceptions of folate biofortified rice in a high risk region of China. *Int J Biotechnol.* 2013;12:269–287.
72. Phorbee O, Ayoola B, Njoku J, et al. CIB Brief: Orange-Fleshed Sweetpotato on the Home Grown School Feeding Menu in Nigeria. Lima, Peru: International Potato Center; 2015.
73. Sindi K, Ndirigie J. CIP Brief: Scaling Up Sweetpotato through Agriculture and Nutrition (SUSTAIN) in Rwanda. Lima, Peru: International Potato Center; 2015.
74. Chipungu F. CIB Brief: Integrating Orange-Fleshed Sweetpotato in Zambia (Oct 2011–Sept 2015). Lima, Peru: International Potato Center; 2015.
75. De Groote H, Kimenju SC. Comparing consumer preferences for color and nutritional quality in maize: Application of a semi-double-bound logistic model on urban consumers in Kenya. *Food Policy.* 2008;33:362–370. doi:10.1016/j.foodpol.2008.02.005.
76. Meenakshi JV, Banerji A, Manyong V, et al. Using a discrete choice experiment to elicit the demand for a nutritious food: willingness-to-pay for orange maize in rural Zambia. *J Health Econ.* 2012;31:62–71.
77. Rubey L, Lupi F. Predicting the effects of market reform in Zimbabwe: a stated preference approach. *J Agric Econ.* 1997;79:89–99.
78. De Steur H, Gellynck X, Storozhenko S, et al. Willingness-to-accept and purchase genetically modified rice with high folate content in Shanxi Province, China. *Appetite.* 2010;54:118–125.
79. De Groote H, Kimenju SC, Morawetz UB. Estimating consumer willingness to pay for food quality with experimental auctions: the case of yellow versus fortified maize meal in Kenya. *Agric Econ.* 2011;42:1–16.
80. De Groote H, Kimenju SC. Consumer preferences for maize products in urban Kenya. *Food Nutr Bull.* 2012;33:99–110.
81. Naico ATA, Lusk JL. The value of a nutritionally enhanced staple crop: results from a choice experiment conducted with orange-fleshed sweet potatoes in Mozambique. *J Afr Econ.* 2010;19:536–558.
82. Birol E, Asare-Marfo D, Karandikar B, et al. HarvestPlus Working Paper 7. A Latent Class Approach to Investigating Farmer Demand for Biofortified Staple Food Crops in Developing Countries: The Case of High-Iron Pearl Millet in Maharashtra, India. Washington, DC: HarvestPlus; 2011.
83. Ajzen I. The theory of planned behavior. *Organ Behav Hum Decis Process.* 1991;50:179–211.