Methods matter: a meta-regression on the determinants of willingness-to-pay studies on biofortified foods

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Following the growing evidence on biofortification as a cost-effective micronutrient strategy, various researchers have elicited consumers' willingness to pay (WTP) for biofortified crops in an effort to justify and determine their adoption. This review presents a meta-analysis of WTP studies on biofortified foods, either developed through conventional breeding or using genetic modification technology. On the basis of 122 estimates from 23 studies (9507 respondents), consumers are generally willing to pay 21.3% more for biofortified crops. Because WTP estimates are often determined through different valuation methods and procedures, a meta-regression was carried out to examine the role of potential determinants. Aside from contextual factors, such as type of food crop, target nutrient, and region (but not breeding technique), various methodological factors significantly influence premiums, including the type of respondent, nature of the study, study environment, participation fee, and provided information. The findings allow researchers to better anticipate potential methodological biases when examining WTP for (biofortified) foods, while it gives policy makers a broad understanding of the potential demand for different biofortified crops in various settings.

Keywords: biofortification; economic valuation; willingness to pay; meta-analysis; consumer

Introduction

Biofortification, the enhancement of bioavailable micronutrient concentrations in edible staple crop tissues (through agronomic biofortification, conventional plant breeding, and genetic engineering[1]), is frequently discussed as a sustainable food-based approach in the fight against hidden hunger.[2,3] Various conventionally bred biofortified foods are already on the market (e.g., provitamin A–biofortified maize, sweet potato, and cassava; iron-biofortified beans and pearl millet; zinc-biofortified rice and wheat),[4] while nutrition evidence is growing[5] (e.g., efficacy of iron-biofortified pearl millet,[6] provitamin A–biofortified maize[7] or cassava;[8] effectiveness of provitamin A–biofortified orange flesh sweet potato[9,10]). However, when it comes to genetically modified (GM) biofortified crops, the market launch of "golden rice" and progress on similar GM crops have been delayed owing to the apparent aversion and controversy surrounding the use of biotechnology.[11] Nevertheless, recent studies on GM biofortification have demonstrated its potential nutrition[12] and socioeconomic impacts.[13]

Regarding the latter, research on consumer demand for biofortified foods plays a crucial role because the success of their implementation relies on the reactions of their key beneficiaries. While studies on consumer acceptance and hedonic liking have already provided insights into consumers' intention to consume biofortified foods,[14,15] willingness-to-pay (WTP) studies are of particular

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interest, as they measure the economic value a consumer attaches to a biofortified food, which can be considered as a proxy indicator of actual purchase behavior, notwithstanding potential discrepancies.[16,17] Economic valuation research on biofortification takes a broad approach addressing various foods, micronutrients, and countries. This is a logical consequence of the substantial progress in the development of conventional and GM-biofortified foods,[4,13,18] with the former being introduced in more than 50 target countries,[19,20] as well as the widespread burden of micronutrient deficiencies[21] and the global need for a wide range of biofortified foods.[22] When looking at reviews on consumers' WTP for organic,[23] functional,[24] or GM foods,[25] contextual factors, such as study location, setting (urban versus rural), targeted nutrient, crop, and breeding technique (conventional versus GM), may also lead to differences in the amount consumers are prepared to pay for biofortified foods.

Even though such economic valuation studies have clearly demonstrated their relevance in agribusiness and food applications,[26] there are different ways to measure WTP, while various methodological choices have to be made when aiming to elicit consumers' WTP. These refer to the nature of the study, method of data collection, method of value elicitation, study environment, participation fee, type of respondents, and provided information.

First of all, a distinction is made according to the nature of the research (i.e., nonhypothetical versus hypothetical WTP studies, respectively, for commercialized or nonmarket goods). Values derived from the former are generally higher, owing to the lack of monetary incentives attached to the hypothetical valuation question, a phenomenon often referred to as *hypothetical bias*.[27–30] Similar issues include the selection of the data-collection method and the value-elicitation method. With respect to the former, researchers opt for an experimental research design and/or a survey-based approach (e.g., mail, online, in-person survey), where the estimated WTP values reflect revealed or stated preference values, respectively.[31,32] Contingent valuation, for example, is the standard stated value–elicitation (or preference) method that uses a survey with, for example, a dichotomous choice or open-ended format to obtain self-reported WTP.[33,34] Experimental auctions, on the other hand, use the benefits of both revealed and stated methods by simulating an active market with real products and money. Depending on the bidding procedures and auction mechanism, different auction types have been developed and validated, such as the Becker–Degroot–Marschak (BDM), random price, second price, and *n*th price auction[35] (for a review of value-elicitation methods, see Refs. 17 and 36). Although all value-elicitation methods should generate similar results, the opposite is often found in food-valuation studies.[34] Even studies comparing different auction types have reported value differences,[37,38] which illustrates the potential impact of the value-elicitation method on empirical outcomes.

Furthermore, the study environment (i.e., home-use versus central-location testing) is often connected to the aforementioned type of valuation method. For example, in dispersed rural populations, BDM is sometimes preferred over other auction mechanisms, as it allows for eliciting valuations from individuals (home-use testing) and because carrying out group auctions (central-location testing) can be expensive and time-consuming.[39] Another reason is that laboratory auctions may require higher participant fees, which have shown to positively affect valuations,[40–42] a phenomenon known as an *income endowment effect*.[43] Such monetary incentives may be of particular relevance when considering students rather than adults,[44] despite the fact that both types of respondents, commonly targeted in WTP research, are not expected to bid significantly differently.[45]

Finally, alongside the measurement of WTP for a food product, researchers often provide specific information on product or process attributes, either at once or during different information treatments, often distributed to different subsamples. Previous research demonstrated the important role of benefit and risk communication when consumers evaluate healthy/controversial foods,[46] such as functional[24] or GM foods.[43,47] Another type of information refers to the use of a cheap talk script as an effective procedure to reduce the aforementioned hypothetical bias.[48,49]

This paper aims to conduct a systematic review and meta-analysis on studies that elicited WTP for biofortified food in both developed and developing countries. Thereby, we applied a meta-regression for analyzing the methodological and contextual factors that explain WTP estimates.

Methodology

Search strategy

A search up to February 2016 was conducted in the Information Sciences Institute (ISI) Web of Science and AgEcon databases for economic valuation studies on consumers' WTP for biofortified foods. A Boolean search–based syntax was used, based on a combination of keywords related to the WTP measurement or conventional/GM biofortification: ((“GM” or “genetically modified” or “genetic modification” or “transgenic” or “GM food” or “GM foods” or “GM crop” or “GM crops” or “golden rice” or “biofortified” or “biofortification” or “vitamin” or “mineral” or “yellow maize” or “orange maize” or “vitamin A maize” or “yellow cassava” or “vitamin A cassava” or “orange sweet potato” or “iron beans” or “iron pearl millet” or “zinc rice” or “zinc wheat") and (“purchase intention” or “purchase intentions” or “purchase intent” or “preference” or “preferences” or “valuation” or “valuations” or “WTP” or “willingness-to-pay” or “WTA” or “willingness-to-accept” or “acceptance")). In addition, reference lists of the reviewed studies, as well as earlier reviews on consumer studies on conventional[14] and GM-biofortified foods,[13] were checked to ensure that no (older) related study was omitted. Specific attention was given to publications (working papers) from HarvestPlus, since they are at the forefront of not only developing conventional biofortified foods but also conducting related socioeconomic research. This combined search strategy was used to minimize skewness that would occur in our meta-regressed results, potentially due to publication bias.[50]

Figure 1 presents the flow diagram of the selection process. The initial search for studies from databases based on the presence of one or more of the keywords, performed by two researchers simultaneously, resulted in 4851 records. After removing 57 duplicates, 4794 records were subjected to title review, after which 511 papers were selected for abstract review. Only research papers in English, German, or French that reported findings on WTP on the basis of primary data sources were included. This resulted in 101 full articles that were assessed for eligibility in order to select studies that qualify for data extraction. Therefore, each selected study must have reported (data to derive) a percentage premium or a mean WTP estimate. Owing to the lack of information on confidence intervals or standard errors, mean estimates (i.e., WTP expressed as percentage premium) are derived or calculated, as usually done in meta-analysis for socioeconomic research.[51] On the basis of the average WTP value, a percentage premium could be readily derived through the following formula:

$$\%\ \text{Premium}_{(\text{biofortified})} = \frac{\bar{x}_{WTP(\text{biofortified})} - \bar{x}_{WTP\ \text{or market price (non-biofortified)}}}{\bar{x}_{WTP\ \text{or market price (non-biofortified)}}} \times 100.$$

Whenever a premium was not reported directly based on this expression (e.g., studies that used regression models to estimate WTP), we followed the approach of Naico and Lusk[52] to calculate the percentage premium from the coefficients. Studies that had reported WTP as a percentage of a sample that would pay a given amount only (e.g., Ref. 53) or studies focusing on consumer or sensory acceptance (rates) were excluded (e.g., Ref. 54). We ended up with 23 studies that fulfilled the inclusion criteria and, therefore, formed the basis of the review and meta-regression.

Data extraction

Data extraction involved obtaining premiums (% WTP) as the dependent variable of interest as explained above. As only a limited number of studies reported both point estimates (mean WTP) and corresponding precisions, we alternatively use the reported sample sizes as a proxy of precision, similar to what Lusk *et al.*[25] suggested. In sum, we obtained 122 individual WTP (% premium) estimates from 23 studies, each with a corresponding sample size. In most cases, multiple nonoverlapping WTP estimates of a single study could be included because they were based on samples based on one or more methodological (e.g., valuation method, target group, information treatment) or contextual variable (e.g., target nutrient or crop).

In addition, the previously mentioned contextual and methodological characteristics were included as independent variables for each study. These data formed the basis of our metadata set comprising 14 broad (methodological/context-related) variables: type of food, nutrient, breeding technique, region, country, study setting, type of respondents, data collection method, value-elicitation method, nature of the study, study environment, participation fee, and type of information given. Further coding was performed on the aforementioned variables to

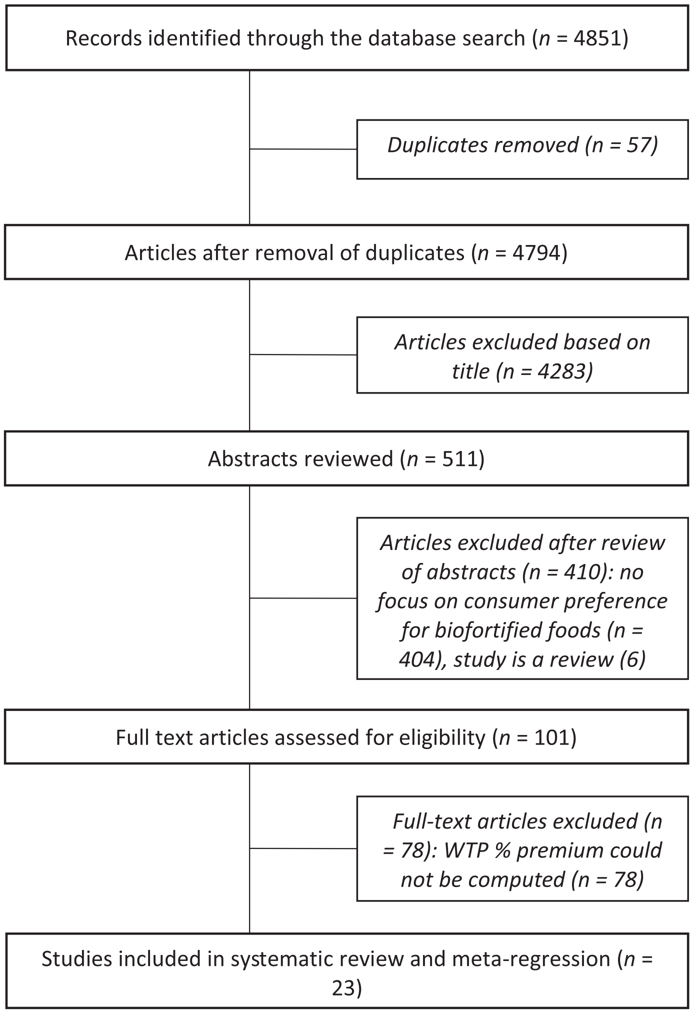

Figure 1. Flow diagram of selection of WTP studies on biofortified crops.

create a total number of 73 dummy variables from which a selection was used for regression analysis (Table 3). Since we extracted more than one WTP estimate from several studies, a cluster variable was developed to take into account the grouping of those estimates in the analysis. A sample size variable was included as a part of a weighting variable.

Statistical analysis

Using STATA software, summary statistics were computed by independent samples *t*-tests for dichotomous variables and one-way analysis of variance (ANOVA) for variables with more than two categories. A meta-regression was run to analyze the variation in the reported WTP estimates. Specifically, a weighted least squares (WLS) linear regression model was used, adapted from Harbord and Higgins[55] and Ringquist,[56] and following guidelines to conduct economic meta-analysis.[57] This procedure was deemed appropriate for two reasons. First, we failed to extract standard errors of WTP estimates from all primary studies that would otherwise have enabled us to apply statistical methods that use related inverse variances for weights.[58,59] Instead, we used sample sizes as weights, which similarly addresses possible heteroscedasticity that would be attributed to varying study designs, methodologies, independent variables, and the pooling of estimates from different studies.[60,61] Second is the issue of multiple WTP estimates from the same study.

Because such estimates were likely to be correlated, we have clustered the regression standard errors and reported robust regression estimates.[56,62] Given that extracted estimates came from a variety of studies, particularly in the way they were conducted, random-effect weights were used to address such heterogeneity.[59]

Model specification

Our model specification involved two steps. The first step was to reduce the 73 dummy variables into a manageable number that would minimize chances that we overfit the model and ensure that the suggested final model is parsimonious, as recommended by the Cochrane collaboration.[63] Thereby, new dummy variables were created to distinguish staple from nonstaple foods, stated from revealed preference methods, vitamins from minerals, and developing from nondeveloping context (see footnote to Table 3). All dummy variables were then regressed onto WTP (% premium) as the dependent variable, weighted by the sample size with robust standard errors. After controlling for multicollinearity between variables and on the basis of variance inflation factors, each meta-regressor with a value greater than 10 was dropped. Some of the removed variables, such as nature of the study, were highly correlated with sample size as the weighting variable (e.g., by which a few hypothetical estimates cover a large number of respondents (Table 2)). As a consequence, 13 variables (seven methodological and six context-related variables) were retained for further analysis.

Furthermore, statistical outliers (i.e., absolute standardized residual >3) and influential points (i.e., Cook's distance >1) were investigated.[64] Only one observation, from a study by Corrigan *et al.*,[65] could be considered as an outlier (standardized residual = 3.45), but it was retained since it was not an influential point (Cook's distance = 0.07).

Results and discussion

Overview of studies

The 23 selected WTP studies were carried out between 2001 and 2014 (Table 1). Together, these studies elicited 122 estimates from a total aggregated number of 9507 respondents, which further confirms the recent growth of (socioeconomic) research on biofortification. Among the estimates extracted, the majority (30 estimates) were derived from the multiple-goods study of Colson *et al.*,[66] followed by the work of De Steur *et al.*[67] (14 estimates).

While 21 studies targeted staple foods, only two studies focused on either vegetables or fruits. The number of targeted nutrients varied, with most of the studies (15 studies) dealing with provitamin A–biofortified foods, as compared with relatively lower numbers of studies on folate (3), vitamin C (2), iron (2), and protein (1). In terms of the applied breeding technique, a similar number of studies elicited WTP for GM-biofortified (12) versus conventional biofortified foods (11). Regarding the research location, most studies have been conducted in Africa and Asia, each of which was covered by nine studies: Ghana, Kenya (2), Mozambique, Nigeria, Rwanda, Tanzania, Uganda, and Zambia and China (4), the Philippines (2) and India (3). The other studies targeted North America (United States; 3), South America (Brazil), and Oceania (New Zealand; 1). When matching the regional distribution of WTP studies to the priority regions of biofortification, a similar dominance of Africa and Asia is found. However, South America is hardly represented in our dataset, calling for more WTP research in those areas.

There is substantial variability in terms of mean WTP among the selected studies. In general, nearly all estimates are positive, reflecting a premium for biofortified foods. Aside from one study reporting an overall negative value, average premiums fall between 0% and 10% (four studies), between 10% and 20% (eight studies), between 20% and 40% (nine studies), and above 40% (three studies). It is important to state, however, that for most of the studies, a presented premium in this table only reflects an overall average of different estimates within a single study (e.g., when different valuation methods are applied (e.g., contingent ranking versus contingent valuation[68]), different breeding techniques are compared (intra- versus transgenic)[66] or specific information treatments were given.

Summary statistics

Table 2 provides an overview of the summary statistics of the variables entered in the meta-regression, including significant mean WTP differences between groups. When looking at the overall weighted mean, consumers are prepared to pay on average 23.7% more for biofortified foods as compared with nonbiofortified foods. The

Table 1. **Systematic review on consumers' WTP for biofortified crops and key characteristics of selected studies, in chronological order**

Study	Crop	Target nutrient[a]	Breeding technique	Country	Year of data collection	Sample size	WTP estimates extracted	Mean overall % premium[b]
Lusk[71]	Rice	Vitamin A	GM	United States	2001	574	1	19.5
Li *et al.*[77]	Rice	Vitamin A	GM	China	2002	599	1	38.0
Lusk & Rozan[78]	Rice	Vitamin A	GM	United States	2004	501	1	38.0
Deodhar *et al.*[79]	Rice	Vitamin A	GM	India	2006	712	1	19.5
De Groote *et al.*[80]	Maize	Vitamin A	Conventional	Kenya	2003	581	2	6.3
Corrigan *et al.*[65]	Rice	Vitamin A	GM	Philippines	2006	160	8	36.7
Depositario *et al.*[72]	Rice	Vitamin A	GM	Philippines	2006	100	4	15.0
Gonzalez *et al.*[68]	Cassava	Vitamin A	GM	Brazil	2006	414	2	67.0
De Steur *et al.*[81]	Rice	Folate	GM	China	2008	944	1	34.0
Naico *et al.*[49]	Sweet potato	Vitamin A	Conventional	Mozambique	2008	308	8	51.3
De Groote *et al.*[82]	Maize	Vitamin A	Conventional	Kenya	2005	500	4	−10.5
Chowdhury *et al.*[70]	Sweet potato	Vitamin A	Conventional	Uganda	2006	467	8	38.3
Colson *et al.*[66]	Broccoli	Vitamin C	GM	United States	2007	98	10	21.9
	Tomato						10	14.9
	Potato						10	13.0
Meenakshi *et al.*[83]	Maize	Vitamin A	Conventional	Zambia	2008	478	5	9.6
Kassardjian *et al.*[73]	Apple	Vitamin C	GM	New Zealand	2005	146	1	48.0
Banerji *et al.*[84]	Maize	Vitamin A	Conventional	Ghana	2008	578	6	11.6
De Steur *et al.*[67,c]	Rice	Folate	GM	China	2011	251	14	33.2
De Steur *et al.*[85,c]	Rice	Folate	Conventional	China	2011		2	38.3
De Groote *et al.*[39]	Maize	Protein	Conventional	Tanzania	2008	120	2	30.0
Kajale[86]	Rice	Vitamin A	GM	India	2009	154	1	3.8
Oparinde *et al.*[87]	Cassava	Vitamin A	Conventional	Nigeria	2011	671	12	5.2
Banerji *et al.*[88]	Pearl millet	Iron	Conventional	India	2012	705	3	18.3
Oparinde *et al.*[89]	Beans	Iron	Conventional	Rwanda	2013	572	5	14.6

[a]Pro-vitamin A (or β-carotene)–biofortified crops aim to address vitamin A deficiency. For an overview of conversion factors of β-carotene to vitamin A, see Haskell,[91] and, for golden rice, see Tang *et al.*[92]
[b]This column only presents average premiums, mainly derived from multiple values within a single study.
[c]Both studies use the same experimental design, but the latter study only targeted a part of the dataset. Some of the values were derived from raw data of the study or other publications related to the same study.[90]
GM, genetically modified.

unweighted mean (21.6 %), which reflects a simple average premium, is about 2% lower. As such, both summary estimates indicate that biofortified foods are generally well accepted by consumers, who are even willing to pay a substantial premium for them.

Significant differences were observed for four variables (i.e., nature of the study, elicitation method, type of information, and country). As expected, the mean premium in hypothetical scenarios (40.3%) was significantly higher than in nonhypothetical studies (18.31%), indicating the presence of a potential hypothetical bias, in line with previous reports in the food-valuation literature.[49,69] Regarding the methods of elicitation, large variations in WTP were found, with premiums ranging from 8.7% (BDM) to 70.0% (contingent ranking). Additionally, the type of information led to statistically different values, with the highest premiums for positive information (38.7%) and the lowest for negative information (–3.2%). Finally, there is a significant difference among countries; consumers in Brazil expressed the highest mean premium (67%) while those in Kenya expressed the lowest (–1.9%).

Smaller, nonsignificant differences were reported for mean premium values according to the type of respondent, data collection method, study environment, use of participation fee (yes/no), provision

Table 2. **Metadata on WTP for biofortified crops with description of variables and summary statistics**

Methodological variable	Sample size	No. of estimates (%)	Mean % premium (SD)	Contextual variable	Sample size	No. of estimates (%)	Mean % premium (SD)
Type of respondent			***P* = 0.803**	Region			***P* = 0.141**
Students	771	21 (17.21)	23.05 (32.89)	Asia	3874	35 (28.69)	25.41 (26.47)
Adults	11,993	101 (82.79)	21.26 (29.31)	North America	1663	32 (26.23)	18.11 (29.51)
Method of data collection			***P* = 0.798**	South America	828	2 (1.64)	67.00 (4.24)
Experiment	7871	112 (91.80)	20.81 (30.31)	Oceania	146	1 (0.82)	48.00 (0.00)
In-person survey	3106	7 (5.74)	31.87 (27.66)	Africa	6253	52 (42.62)	18.84 (31.52)
Mail survey	1075	2 (1.64)	28.75 (13.08)	Country			***P* = 0.041***
Mixed methods	712	1 (0.82)	19.50 (0.00)	China	2296	18 (14.75)	25.48 (12.56)
Nature of study			***P* = 0.003****	United States	1663	32 (26.23)	18.11 (12.80)
Hypothetical	5506	18 (14.75)	40.34 (35.41)	Kenya	1081	6 (4.92)	−1.90 (9.50)
Nonhypothetical	7258	104 (85.25)	18.31 (27.67)	India	1318	5 (4.10)	18.16 (12.80)
Method of value elicitation			***P* = 0.044***	Philippines	260	12 (9.84)	28.33 (42.75)
Contingent valuation	3767	8 (6.56)	26.33 (20.98)	Brazil	828	2 (1.64)	67.00 (4.24)
Contingent ranking	414	1 (0.82)	70.00 (0.00)	Mozambique	308	8 (6.56)	43.63 (39.51)
Choice experiment	2356	27 (22.13)	33.49 (36.28)	Uganda	934	8 (6.56)	38.29 (49.65)
Auction (uniform price)	200	8 (6.56)	28.34 (51.98)	Tanzania	120	2 (1.64)	29.00 (14.14)
Auction (random price)	844	32 (26.23)	16.35 (30.41)	New Zealand	146	1 (0.82)	48.00 (0.00)
Auction (2nd price)	899	17 (13.93)	25.57 (13.62)	Zambia	478	5 (4.10)	14.04 (7.64)
Auction (BDM)	3572	28 (22.95)	8.65 (16.33)	Ghana	1410	6 (4.92)	9.62 (31.99)
Random-utility method	712	1 (0.82)	19.50 (0.00)	Nigeria	1350	12 (9.84)	6.08 (16.55)
Study environment			***P* = 0.910**	Rwanda	572	5 (4.10)	15.40 (5.25)
Home-use testing	3880	18 (14.75)	20.83 (20.79)	Setting			***P* = 0.220**
Central-location testing	8884	104 (85.25)	21.69 (31.20)	Rural	5628	42 (34.43)	15.95 (24.31)
Participation fee			***P* = 0.427**	Urban	3793	54 (44.26)	22.49 (33.59)
Given	5945	33 (27.05)	18.03 (23.75)	Rural & urban	3343	26 (21.31)	28.71 (28.89)
Not given	6819	89 (72.95)	22.88 (31.80)	Food			***P* = 0.138**
Information			***P* = 0.186**	Rice	4497	34 (27.87)	25.87 (26.73)
Given	8197	85 (69.67)	16.14 (27.50)	Maize	3089	19 (15.57)	9.18 (20.60)
Not given	4567	37 (30.33)	23.93 (30.64)	Pearl millet	452	3 (2.46)	22.50 (13.99)
Type of information			***P* = 0.005****	Cassava	278	14 (11.48)	14.79 (26.88)
Positive	6785	50 (40.98)	37.87 (30.27)	Beans	572	5 (4.10)	15.40 (5.25)
Negative	215	11 (9.02)	−7.01 (11.76)	Potato	196	10 (8.20)	14.70 (32.15)
Conflicting	1155	22 (18.03)	7.66 (17.19)	Sweet potato	1242	16 (13.11)	40.96 (43.43)
Objective	42	2 (1.64)	24.45 (16.33)	Broccoli	196	10 (8.20)	22.11 (31.59)
				Tomato	196	10 (8.20)	15.39 (29.75)
				Apple	146	1 (0.829	48.00 (0.00)
				Target nutrient			***P* = 0.936**
				Vitamin A	9189	64 (52.46)	22.46 (34.75)
				Folate	1697	17 (13.93)	24.74 (12.57)
				Vitamin C	734	31 (25.41)	18.34 (30.27)
				Protein	120	2 (1.64)	29.00 (14.14)
				Iron	1024	8 (6.56)	18.06 (9.23)
				Breeding technique			***P* = 0.521**
				GM	5808	65 (53.28)	23.20 (29.42)
				Conventional	6956	57 (46.72)	19.70 (30.42)
Overall mean WTP % premium[a]				21.28 (SE 3.74) (CI: 13.87–28.68)			

NOTE: * and ** indicate statistical significance at 5% and 1% level, respectively.

[a]Constant obtained from the WLS regression model without meta-regressors (null model).

BDM, Becker–Degroot–Marschak method; CI, confidence interval; GM, genetically modified; *P*, *P* value; SE, standard error; WTP, willingness to pay.

Table 3. Metaregression models on the contextual and methodological determinants of WTP for biofortified foods, by WLS model

Variables		β	SE	*P* value
Constant		12.52	19.57	0.529
Methodological				
Type of respondent	*Student*[a]	–15.01	1.27	<0.001***
Value-elicitation method	*Stated preference*[b]	2.21	9.50	0.818
Study environment	*Home-use testing*[c]	–29.67	7.97	<0.001***
Participation fee	*Given*[d]	28.40	6.25	<0.001***
Information type 1	*Positive information*[e]	15.95	5.93	0.014*
Information type 2	*Negative information*[e]	–44.40	9.72	<0.001***
Information type 3	*Conflicting information*[e]	–28.16	8.05	0.002**
Contextual				
Food	*Staple*[f]	4.70	0.02	0.00–0.0010***
Target nutrient	*Vitamin*[g]	–20.20	6.38	0.004**
Breeding technique	*Conventional*[h]	–7.38	9.67	0.453
Region	*Developing*[i]	25.38	9.04	0.010**
Setting	*Rural*[e]	–6.09	7.25	0.410
Setting	*Urban*[e]	10.52	8.90	0.249
Number of observations		122		
R^2		0.60		

Note: All variables are dummy variables (1,0); category (1) is expressed in italics (2nd column). *, **, and *** indicate statistical significance at 5%, 1% and 0.1% level, respectively.
[a]Student samples, as compared to adult samples.
[b]Stated (contingent valuation, contingent ranking, choice experiment), as compared with revealed preference methods (all types of experimental auction, random-utility method).
[c]Home-use testing, as compared to central-location testing.
[d]Given participation fee, as compared to no participation fee.
[e]As compared with other categories of a variable, that is, 0 = otherwise (see Table 2 for reference categories).
[f]Staple (rice, maize, pearl millet, cassava, beans, potato, sweet potato), as compared to nonstaple foods (broccoli, tomato, apple).
[g]Vitamins (vitamin A, folate, vitamin C), as compared with iron and protein.
[h]Conventional, as compared with GM breeding.
[i]Developing (Ghana, Kenya, Nigeria, Mozambique, Uganda, Rwanda, Tanzania, Zambia, Brazil, China, India, Philippines) regions/countries as compared with developed countries (United States, New Zealand).
β, regression beta coefficient; SE, standard error.

of information (yes/no), region, setting, crop type, target nutrient, and breeding technology. It is also important to note that the lack of a relationship between the size of the premium and the number of WTP estimates/studies shows that popular methods and contexts do not necessarily lead to high values or vice versa.

Determinants of WTP for biofortified foods

The findings of the meta-regression are shown in Table 3. Our model is considered robust, based on the observed goodness of fit (i.e., explaining 60% of the variance in WTP). Subsequent descriptions are based on results from this WLS model, where six methodological and three contextual dummy variables were statistically significant.

Regarding the former, significant differences were observed in nearly all variables. Although previous studies did not report differences in (GM) food valuations between student and adult samples,[25,45] students are likely to pay less (–15.0 %) for biofortified foods in our data set. While some may argue that using a student sample offers a cheap and representative solution to analyze the general population, our results more or less contradict this, emphasizing the importance of examining the reasons behind differences according to the type of respondent.

When it comes to stated value-elicitation methods, consumers express (not significantly) higher valuations as compared with the revealed methods. One potential explanation of the insignificance may be that the nature of the study (hypothetical or not) has a much larger impact on the outcomes of valuation studies. Although the nature of the study could not be included in the regression, it seems to be more important than the elicitation method, as shown by the significantly larger WTP values in hypothetical studies in Table 2. As such, the risk of hypothetical bias remains a critical issue in WTP measurement. To address this problem in hypothetical studies, integrating a cheap talk script into hypothetical valuations is a good potential solution. Although not presented here, the few studies that specifically examined the role of cheap talk[70,71] concluded that it can substantially reduce WTP and thus mitigate the risk of hypothetical bias. Nevertheless, it is important to note that hypothetical products can be still effectively valued in simulated market situations (e.g., as a way to inform developers about the market potential of nonmarket goods, as some of the included GM food studies have demonstrated).[65–67,72,73]

The findings also reveal that central-location testing leads to significantly higher values as compared with home-use testing. One could postulate that the former creates a more artificial environment, in which more efforts are required from the participants, which may lead to differences in bidding behavior, regardless of study context.

Furthermore, offering a reward in the form of a participation fee positively affected premiums for biofortified foods, resulting in a 28.4% higher premium. The role of participation fees appears to be more important than generally assumed, which calls for research that examines or at least better controls for the effect of income endowment.

Another crucial effect is related to the type of information. In line with the aforementioned literature, providing positive information about biofortified foods leads to significantly higher values, while—in the case of GM breeding—negative information, especially when provided without counterarguments, has a negative effect on WTP. In any case, communication campaigns are recommended to highlight nutrition (and GM food) benefits, rather than attempting to communicate risks.

Regarding the contextual variables, findings show that, except for the breeding technique used and setting, three dummy variables were significant. First of all, consumers' WTP significantly increases by 4.7% when targeting biofortified staple foods rather than nonstaple foods. Among the former are rice, maize, cassava, pearl millet, beans, Irish and sweet potato, that is, foods that many people particularly in developing countries consume on a regular basis. Therefore, these more positive values may be attributed to high levels of familiarity with such kinds of foods as well as the (perceived) efficacy of using staple crops as vehicles for biofortification.[13]

Second, when vitamins are targeted, WTP is lower. As the variation between WTP studies on iron- and vitamin-biofortified foods is relatively small (see Table 2), this outcome can be mainly attributed to the inclusion of a biofortification study on quality protein.

Third, consumers from developing countries are generally prepared to pay significantly more (+25.4%) for biofortified foods than those from developed countries. The importance of degree of development, rather than degree of urbanization (setting), is not a complete surprise. Both rural and urban areas in developing regions are largely affected by malnutrition and micronutrient deficiencies in particular, and hence are in need of implementation of nutrition-sensitive interventions, such as biofortification. However, future research should aim to integrate affordability into their study design, in order to verify whether their actual purchase behavior would reflect their statements during these cross-sectional studies.

The indifference between GM and conventional biofortified food valuations implies that overall preference for biofortified foods is not influenced by the manner in which they are produced. This could be an impetus to developers using genetic breeding techniques to continue targeting and highlighting consumer-oriented traits, even for addressing consumer segments that are still averse to biotechnology in general.

Conclusions

To the best of our knowledge, this study can be considered the first systematic review and meta-analysis on WTP for biofortified foods. While it incorporates the larger body of research that deals with conventionally bred biofortified foods, it also included biofortified foods developed through GM technology. As such, it goes beyond previous meta-analyses on WTP for GM foods, conducted in 2005[25] and 2009,[74] which mainly focused on farmer-oriented traits. Another important contribution is the use of a meta-regression to evaluate the effect of both contextual and methodological explanatory variables on WTP for biofortified foods. This methodological angle allows us to identify various reasons why heterogeneity exists in WTP estimates for (biofortified) foods, beyond the usual suspects (e.g., targeted product, setting, or other context-specific characteristics).

The average premium for biofortified food, across all estimates and studies, is 21.3%. While Lusk *et al.*, in their meta-analysis on WTP for (mainly) GM foods with farmer benefits,[25] reported an overall 23% premium for non-GM food relative to GM food (mainly with improved farmer traits), we have found relatively high WTP values for both GM and non-GM-biofortified crops. These findings demonstrate positive consumer reactions, even in samples that are generally expected to be averse of GM technology, such as African and European countries. Although key contextual factors influence WTP, with higher values for staple foods in developing markets, methodological choices play an even more important role. Thereby, adult samples, hypothetical study designs, participation fees, and positive information increase premium values. As methods appears to matter for food valuations, more research is needed to further examine the reasons behind methodological differences[43] and to improve methods and procedures related to WTP measurement.

It is important to state that all studies target single biofortified foods. Although research as well as delivery strategies are increasingly focused on a multibiofortification approach, enhancing the levels of various micronutrients in one crop,[75,76] or on a biofortified food basket approach, delivering multiple biofortified crops together,[4,20] future WTP studies urgently need to anticipate these developments. Thereby, the selection of study locations could be further aligned to (potential) target markets (e.g., based on the biofortification priority index of HarvestPlus[22]). This has been demonstrated for Africa and Asia, but not for South America, calling for a shift or extension of the geographical spread in WTP research. Furthermore, it is also worth investigating what (e.g., socioeconomic) determinants affect WTP in each of the studies, rather than targeting study characteristics as determinants.

An important limitation of this review is that no confidence intervals or standard errors for WTP estimates could be derived from most studies. This would have made it possible to use inverse variances as weights, which are thought to provide more precise estimates from a meta-analysis and regression. Furthermore, many potential independent variables that were derived from the studies could not be included in their original form, as explained under the meta-regression model specification. It is possible that relevant information was lost.

Nevertheless, the findings of our meta-analysis lend support to its commercialization as an agriculture-based strategy to improve nutrition and human health. Even when a controversial technique, such as agricultural biotechnology, is applied, consumers generally attach a substantial economic value to biofortified crops. Given its nature as a potential health policy intervention, however, all premiums should be interpreted as indicators of preference, purchase intention, and future demand, rather than as a means for price setting. In this way, biofortification can hold its promise as a well-accepted health intervention to address deficiencies under challenging conditions of low socioeconomic levels.

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Conflicts of interest

The authors declare no conflicts of interest.

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