Trends in Food Science & Technology 39 (2014) 116–134

TRENDS IN FOOD SCIENCE & TECHNOLOGY

Review

Conceptual framework for *ex-ante* evaluation at the micro/macro level of GM crops with health benefits

Hans De Steur[a,*], Dieter Blancquaert[b,2], Willy Lambert[c,3], Dominique Van Der Straeten[b,2] and Xavier Gellynck[a,1]

[a]Department of Agricultural Economics, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, B-9000 Ghent, Belgium (Tel.: +32 9 264 5945; fax: +32 9 264 6246; (e-mails: hans.desteur@ugent.be; hansdesteur@hotmail.com; xavier.gellynck@ugent.be)

[b]Laboratory of Functional Plant Biology, Department of Physiology, Ghent University, K.L. Ledeganckstraat 35, B-9000 Ghent, Belgium (emails: dieter.blancquaert@ugent.be; dominique.vanderstraeten@ugent.be)

[c]Laboratory of Toxicology, Department of Bioanalysis, Ghent University, Harelbekestraat 72, B-9000 Ghent, Belgium (email: willy.lambert@ugent.be;)

Socio-economic research plays an important role to successfully introduce novel, controversial goods, such as GM food. This review presents a conceptual framework to explore the market potential of GM food with health benefits at both micro and macro level. While the former examines consumer acceptance and willingness-to-pay, the latter assesses the health impacts and cost-effectiveness. Thereby, underlying theories, methods and empirical research underpinning each line of inquiry are reviewed. By compiling results from eight socio-economic studies, Folate Biofortified Rice is taken as a case to illustrate how the framework contributes to assess its market demand as well as cost-effectiveness.

Introduction

Since its introduction in 1995, Genetically Modified (GM) crops have become one of the fastest adopted technologies in agriculture, resulting in a total cultivated area of 170 million ha, adopted by more than 14 million farmers in 25 countries (James, 2012). This Gene Revolution focused solely on the adoption of GM crops with improved agronomic traits, like insect resistance and drought tolerance. As such, it mainly benefited farmers and particularly small-scale farmers in developing countries (Anthony & Ferroni, 2012; Raney, 2006). As compared to the positive impacts and the remarkable growth, the use of GM technology in food remains heavily debated. This led to a large, growing body of research on consumer reactions towards GM foods worldwide, which aims to better understand the drivers behind acceptance or reluctance (Bredahl, 2001; Costa-Font, Gil, & Traill, 2008), as well as willingness-to-pay (WTP) for GM or GM-free foods (Lusk, Jamal, Kurlander, Roucan, & Taulman, 2005).

Although the currently commercialized GM foods may also positively affect consumers, e.g. through their positive impacts on household income, rural employment, health (Qaim, 2009), or food prices (Brookes, Elobeid, Tokgoz, & Yu, 2010), they all are missing a crucial aspect to attract the consumer, i.e. a direct, tangible benefit (Engel, Frenzel, & Miller, 2002). Nevertheless, following the Gene Revolution and its farmer-oriented crops, GM technology is more and more applied to enhance the vitamin or mineral concentrations in staple crops, i.e. the so-called GM biofortified crops. Besides single biofortified crops, like

* Corresponding author.
[1] Tel.: +32 9 264 5945; fax: +32 9 264 6246.
[2] Tel.: +32 9 264 5185; fax: +32 9 264 5333.
[3] Tel.: +32 9 264 8121; fax: +32 9 264 8183.

http://dx.doi.org/10.1016/j.tifs.2014.06.010

Folate Biofortified Rice (FBR) (Storozhenko *et al*., 2007) and Golden Rice (Paine *et al*., 2005), research and development increasingly focuses on multi-biofortification by stacking several micronutrient traits (De Steur, Gellynck, Blancquaert, *et al*., 2012; Naqvi *et al*., 2009). Such foods have direct benefits for consumer health and, thus, hold the potential to be a valuable intervention for alleviating the global burden of micronutrient malnutrition (Bouis, 2002), which is affecting roughly two billion people. However, because these crops are developed with a controversial technology, governments, decision-makers, health planners and researchers look for information on consumer reactions, as well as the potential impacts of introducing it as a health intervention. In other words, from a policy point of view, economic evaluation is needed to assess whether GM biofortified foods are worthwhile to implement, while knowledge of its demand is needed to evaluate the market potential of such novel, controversial crops.

Unlike conventional biofortified foods, GM biofortified foods are still under development. Therefore, little is known about their acceptance and purchase intentions (Gonzalez, Johnson, & Qaim, 2009; Lusk, 2003), as well as their public health impacts and cost-effectiveness (Stein, Sachdev, & Qaim, 2006), especially in poor, developing regions at high risk of micronutrient malnutrition. This paper aims to simultaneously address these knowledge gaps by providing a scientifically sound conceptual framework to evaluate *ex-ante* the market potential of GM foods with health benefits, like GM biofortified crops. Therefore, emphasis is put on four key lines of inquiry, i.e. acceptance, willingness-to-pay, health impacts and cost-effectiveness. While acceptance and WTP are examined at the individual consumer level (micro), the potential health impacts and cost-effectiveness is assessed for a society as a whole (macro). Even though the perceptions of other stakeholders also influence the success and coverage rate of introducing these and other GM foods, it is crucial to explore the *ex-ante* potential at consumer level. Not surprisingly, market failure of novel food products or technologies is often caused by a lack of, or inadequate *ex-ante* consumer research (Lusk & Hudson, 2004). Moreover, as the asynchronous and asymmetric approval of authorized GM foods demonstrates, consumer preferences also play an important role for political support and farmer adoption.

The next part presents the micro/macro conceptual framework as well as the underlying theories and methods. For each of the targeted lines of inquiry, the current state-of-the-art in consumer research on biofortified and GM foods is described. To underline the framework's potential, this paper also applies it to a specific case, namely FBR. Therefore, we reviewed and compiled the findings of various studies that evaluated its socio-economic potential in China.

Conceptual framework

Fig. 1 outlines the conceptual framework for determining the market potential of GM crops with health benefits at micro and macro level. Building upon the large body of consumer research on GM foods, the micro-level pillar broadly addresses two key research topics: acceptance and WTP. The studies on acceptance of GM foods with health benefits are mainly oriented towards the analysis of its key determinants, especially knowledge, consumer perceptions and socio-demographic indicators. Thereby, segmentation analysis is often proposed to further define the potential market for a particular GM food. Moreover, because the majority of GM food research with consumers focuses on the evaluation of the benefits or risks associated with the improved trait, this framework goes beyond this by exploring the influence of potential negative changes of regular product attributes, such as taste and appearance. As a second step of consumer market analysis, WTP for GM foods with health benefits is examined. As the selection of the value elicitation method to define consumers' WTP is crucial, it is worthwhile to derive and compare WTP values from different approaches. Therefore, both non-hypothetical (revealed) and hypothetical (stated) preference methods are included. When measuring WTP, the influence of socio-demographic indicators, GM food knowledge and acceptance, information about the improved trait or the applied technology, and, through the selection of different valuation methods, design characteristics is deemed important.

The macro-level analysis evaluates GM food with health benefits as a potential health intervention through three subsequent steps: (1) quantification of the current burden of disease; (2) assessment of the health gap between a situation before and after the introduction of the health intervention, the so-called health impact or effectiveness; and (3) measurement of the cost-effectiveness through the comparison of the health intervention costs and health benefits.

Although current socio-economic research on GM foods with (or without) health benefits generally focuses on only one analytical level, results at the micro-level can be integrated in macro-level analysis. This is particularly the case when aiming to measure the effectiveness of its introduction, as this is partially determined by the number of people that are favorable to, and willing to pay for the targeted product.

In the subsequent sections, the different components of the conceptual framework and the rationale to investigate them are discussed in relation to the current research literature. It is important to note that this framework only provides the key concepts. Therefore, concepts will be further defined according to the investigated research topic, e.g. knowledge about GM food, or reference will be made to specific measures, e.g. the DALY concept as a health impact indicator.

Acceptance

The concept of acceptance measures whether a consumer is favorable to GM food with health benefits. Due to the direct consumer benefits, these products are expected

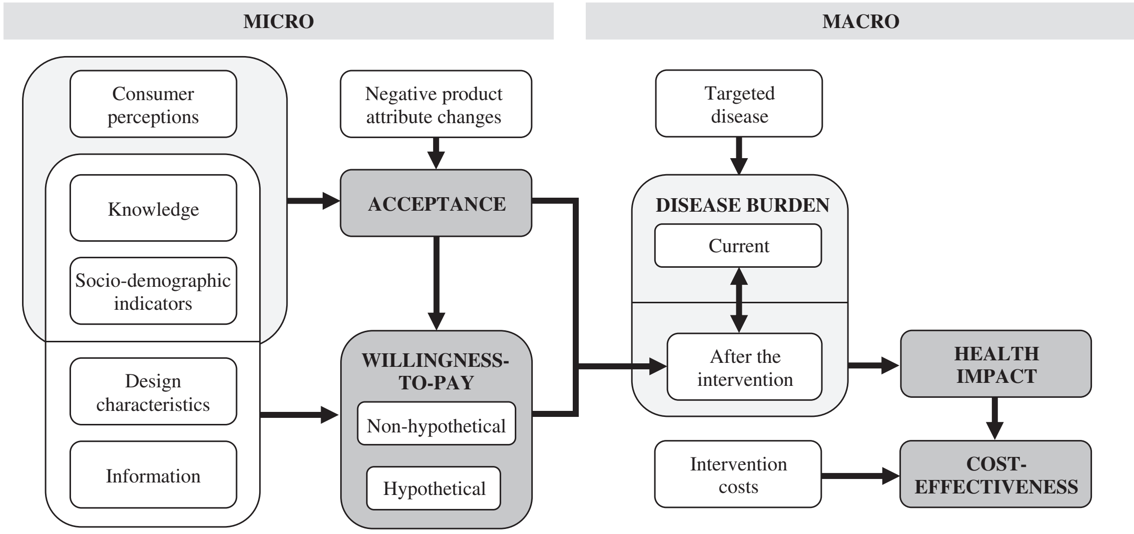

Fig. 1. Conceptual framework for evaluating the market potential of GM foods with health benefits, partially adopted from Costa-Font *et al.* (2008) and Stein *et al.* (2005).

to be more warmly embraced than GM food with improved agronomic traits and may be able to compensate for the negative perception that might be associated with the GM technology (Anand, Mittelhammer, & McCluskey, 2007; Frewer, Howard, Hedderley, & Shepherd, 1997; Hossain, Onyango, Schilling, Hallman, & Adelaja, 2003; Lähteenmäki *et al.*, 2002; Lusk *et al.*, 2005; O'Conner, Cowan, Williams, O'Connell, & Boland, 2005; Schnettler, Sepulveda, & Ruiz, 2008). Scientific research to underpin the higher acceptance rate of GM foods when health benefits are present, is scarce (Lusk, 2003), but steadily growing. Only few studies explored consumer acceptance of a biofortified foods, e.g. conventionally bred provitamin A enriched corn (De Groote & Kimenju, 2008; Stevens & Winter-Nelson, 2008) and GM rice with a high folate content (De Steur *et al.*, 2010b).

The analysis of acceptance of GM food products with health benefits addresses two challenging issues in consumer research: the investigation of its underlying determinants and the effect of potential negative attribute changes associated with the applied GM technology, aside from the improved health attribute. Below, both aspects are elaborated with reference to the conceptual framework, existing and comparable research in the field.

Determinants of GM food acceptance

The framework of consumer acceptance is mainly derived from the explanatory GM food acceptance model (Costa-Font *et al.*, 2008) and scientific evidence on acceptance of GM and/or biofortified food crops. In their review, Costa-Font *et al.* (2008) developed a framework that builds on the attitude model of Bredahl, Grunert, and Frewer (1998) and Fishbein's multi-attribute theory (Fishbein, 1963). It considers GM food attitudes and acceptance as complex constructs, which are determined by consumer perceptions of benefits and risks, general attitudes, knowledge and socio-demographic factors. In line with previous research (Pope, Voges, Brown, & Forrest, 2004; Verdurme & Viaene, 2003), the framework emphasizes the role of the two GM related concepts, namely knowledge and consumer perceptions of GM food. Besides the aforementioned determinants, attitude formation may also be affected by the investigated study population, as cross-country studies have shown (Bredahl, 2001; Costa-Font & Gil, 2009), the targeted product or trait (De Steur, Blancquaert, *et al.*, 2013; Frewer *et al.*, 2013; Huang, Qiu, Bai, & Pray, 2006), or general beliefs (Costa-Font *et al.*, 2008; Saher, Lindeman, & Hursti, 2006).

Although GM food knowledge is considered as a key determinant of acceptance (Chen & Li, 2007; Costa-Font & Mossialos, 2007), its inclusion (e.g. mediated through consumer's literacy) (Rodríguez-Entrena & Salazar-Ordóñez, 2013; Saher *et al.*, 2006) as well as the direction of its effect remains a topic for discussion (House *et al.*, 2004; Kassardjian, Gamble, & Gunson, 2005). Due to the discrepancy between objective and subjective GM food knowledge, with the latter typically higher than the former (Costa-Font *et al.*, 2008; Ganiere, Chern, & Hahn, 2006; Ho, Vermeer, & Zhao, 2006; House *et al.*, 2004; Li, Curtis, McCluskey, & Wahl, 2002; Verdurme, Viaene, & Gellynck, 2003b), it is crucial to make a distinction between both components.

Cognitive variables such as consumer perceptions of GM food have an important influence on consumer acceptance (Baker & Burnham, 2001; Bredahl *et al.*, 1998; Li *et al.*, 2002), especially if they refer to benefits and risks (Costa-Font *et al.*, 2008; Frewer & Shepherd, 1995; Roosen et al., 2005). Moreover, several authors opted for a multi-item scale for evaluating perceptions of risks, benefits, safety and price impact (Verdurme & Viaene, 2001);

knowledge, labeling and trust (Pope *et al*., 2004); benefits, health or environmental risks, safety and trust (Verdurme, Viaene, *et al*., 2003); or product- and process-related beliefs (Bredahl *et al*., 1998). In their review, Frewer, *et al*. (2013) further demonstrated the use of various categories of perceptions in consumer research on GM foods.

While several authors do not consider socio-demographic indicators (alone) as strong predictors of GM food acceptance (Anand *et al*., 2007; Baker & Burnham, 2001; Bredahl *et al*., 1998; Kontoleon & Yabe, 2006; Li *et al*., 2002), most studies found various significant effects (Chen & Li, 2007; Hoban, 1998), even on biofortified foods (De Groote & Kimenju, 2008). For example, women (Moerbeek & Casimir, 2005; Siegrist, Cvetkovich, & Roth, 2000), older people (Ganiere *et al*., 2006) and those with a low education (Hoban, 1998; Traill *et al*., 2004) or a low income level (Yee *et al*., 2008) are generally more skeptical of GM food. However, there is still discussion about the strength and the sign of these determinants (Costa-Font *et al*., 2008).

Consumer segmentation is often used as a marketing technique to further analyze the variance of consumer reactions to GM food. In the end, market strategies are required to efficiently target the consumer in the market. Identifying consumer segments is a prerequisite to reach this goal. Table 1 present the results of a review on studies that clustered the market for GM food in general, or specific GM food products in particular. While most consumer research on GM food acceptance can be understood as a binary segmentation analysis (yes/no), this table goes beyond this by presenting studies that identified more than two groups of consumers, who also differ from each other with respect to underlying determinants of acceptance.

According to the review of Costa-Font *et al*. (2008), the consumer's reaction towards GM food can be generally classified into three groups: 'pessimistic', 'risk-tolerant' or 'information searchers', and 'optimistic'. The majority of studies focus on agronomic traits, while consumer oriented traits are only targeted in the case of cholesterol reducing GM dairy spread (O'Conner *et al*., 2005) and GM oil seed as a source of omega-3 fatty acids (Cox, Evans, & Lease, 2008). Zhang, Huang, Qiu, and Huang (2010) also demonstrated that there is a group of Chinese consumers (14%) who attaches importance to nutrition benefits. When looking at European studies, including the Eurobarometer reports, the results confirm a large, growing opposition or skepticism towards GM food. Except for the large indifferent segment in Germany, the size of the opposed cluster is about two times as large as the optimistic segment. In the United States, however, such a reluctant segment is less represented (Ganiere *et al*., 2006).

GM food segments are typically based on socio-demographic, attitudinal and behavioral differences, but also refer to GM related determinants, such as knowledge and consumer perceptions (Christophe, Bruhn, & Roosen, 2008; Verdurme & Viaene, 2003; Zhang *et al*., 2010).

Acceptance of negative GM food attributes

Consumers evaluate GM food products by the attribute changes caused by the GM technology, rather than the technology itself (Ganiere *et al*., 2006). When linking Fishbein's multi-attribute theory to GM food, acceptance not only depends on knowledge and consumer perceptions of GM food, but also on the reactions towards its specific product attributes (Bredahl *et al*., 1998; Rimal, Moon, & Balasubramanian, 2007; Siegrist, 2008). According to Lancaster (1966), consumers maximize utility through the combination of product attributes. Nevertheless, research on GM foods solely focused on the evaluation of the product-enhancing attributes of GM food, such as the nutritional benefits.

However, applications, such as GM biofortification, who are initially aimed at improving the health of consumers, may involve other product attribute changes, such as an undesired appearance or taste. Therefore, it is crucial to keep the GM product as natural as possible (Onyango, Govindasamy, Hallman, Jang, & Puduri, 2006; Siegrist, 2008; Tenbült, De Vries, Dreezens, & Martijn, 2005). Improving the provitamin A level in corn, for example, results in a yellow color and alters its sensory characteristics, which hampered consumer acceptance in Africa (Stevens & Winter-Nelson, 2008). Furthermore, aspects related to its introduction, such as the availability, the cultivation potential, the environmental impact and the price, could play a role (Verdurme, Gellynck, & Viaene, 2003). If consumers are not favorable to these new properties or impacts, it may compensate for the positive perceptions of the benefits.

Willingness-to-pay

Following acceptance, the next step to evaluate the potential demand of novel GM food products is to determine its economic value for consumers. WTP for a GM food product is generally expressed in terms of the dollar premium or discount consumers place on it. When the improved trait of a GM crop is oriented towards consumers, research on consumers' preferences focuses on eliciting their premium. While there is a large body of economic valuation studies on GM food with agronomic traits (Dannenberg, 2009; Hall, Moran, & Allcroft, 2006; Lusk *et al*., 2005), evidence on conventional (Chowdhury, Meenakshi, Tomlins, & Owori, 2009) and GM biofortified crops (Lusk, 2003) continues to mount. However, in both cases, the evidence shows that WTP most likely exceeds valuations of GM food products without health benefits. Or, as is the case in Europe, the discount one demands for GM foods with health traits is lower than for improved agronomic traits (Costa-Font, Tranter, & Gil, 2012).

Table 2 classifies the most commonly used WTP values, as defined by the applied methodology. One can broadly conceptualize these values as either stated or revealed preferences, which measure WTP, respectively, directly or indirectly (Balistreri, McClelland, Poe, & Schulze, 2001; Blamires, 1997; Lusk & Shogren, 2007; Pearce &

Table 1. Overview of market segmentation studies on GM food acceptance, per product category, research location, name and size (% of sample) of the identified clusters, and source.

Product category	Location	Identified clusters (% respondents)	Source
GM food	EU-15	1 Trade-off (18%) 2 Relaxed (14%) 3 Skeptical (62%) 4 Uninterested (6%)	4th Eurobarometer Survey[b] (Gaskell *et al.*, 2004)
	EU-15;-25;-27	*Cluster name (EU-15; EU-25; EU-27)* 1 Optimistic (22%; 27%; 23%) 2 Pessimistic (50%; 54%; 61%) 3 Undecided (28%[c]; 16%; 16%)	5th, 6th & 7th Eurobarometer Surveys[b] (Gaskell, Allum, & Stares, 2003; Gaskell *et al.*, 2006; Gaskell *et al.*, 2010)
	Belgium	1 Halfhearted (34.5%) 2 Enthusiasts (23.5%) 3 Balancers (26.5%) 4 Green opponents (15.5%)	(Verdurme & Viaene, 2003)
	China	1 Neutral (46.5%) 2 Knowledgeable (18.1%) 3 Biotechnology learners (26.9%) 4 Price-conscious (8.5%)	(Li, Wahl, & McCluskey, 2003)
	China	1 Food safety (31%) 2 Nutritional technologist (14%) 3 GM Skepticism (26%) 4 GM for non-food promoter (29%)	(Zhang *et al.*, 2010)
	Germany	1 Supporters (25%) 2 Indifferent (47%) 3 Opponents (28%)	(Christophe *et al.*, 2008)
	Greece	1 Opposition (38%) 2 Potential (10.8%) 3 Early adopter (41.3%) 4 Extreme opposition (9.8%)	(Arvanitoyannis & Krystallis, 2005)
	South Korea	1 Open mindedness (29%) 2 Convenience/familiarity seekers (47%) 3 Biotechnology opponents (24%)	(Onyango *et al.*, 2006)
	United States	1 Proponents (4.7%) 2 Non-opponents (61.0%) 3 Moderate opponents (22.7%) 4 Extreme opponents (11.7%)	(Ganiere *et al.*, 2006)
	United States	1 Risk avoiders (33%) 2 Risk dismissers (23%) 3 Balanced but interested (44%)	(Radas, Teisl, & Roe, 2008)
	United States	1 Ambivalent–biotech (42%) 2 Antibiotech (6%) 3 Biotech–normer (38%) 4 Biotech individual (14%)	(Silk, Weiner, & Parrott, 2005)
GM apples	New Zealand	1 Price sensitive (15.3%) 2 True believing (13.0%) 3 Appreciative (23.3%) 4 Middle of the road (18.3%) 5 Opposed (16.3%) 6 Concerned (13.7%)	(Kaye-Blake, O'Connell, & Lamb, 2007)
GM chocolate & GM tomatoes	New Zealand	*Cluster name (chocolate; tomato)* 1 Price sensitive (7%; 13%) 2 Price & technology insensitive (40%; 25%) 3 Anti-GM, not benefit sensitive (30%; 21%) 4 Neophobic (c: 12%; t: 11%)	(Gamble, Muggleston, Hedderley, Parminter, & Richardson-Harman, 2000)[d]
GM corn flakes	United States	1 Brand buyers (40.5%) 2 Safety seekers (30.3%) 3 Price pickers (29.2%)	(Baker & Burnham, 2001)
GM dairy spread[a]	Ireland	1 Pro-2nd generation (29.4%) 2 Anti-2nd generation (24.4%) 3 2nd generation accepters (14.4%) 4 2nd generation rejecters (31.8%)	(O'Conner *et al.*, 2005)

Table 1 (*continued*)

Product category	Location	Identified clusters (% respondents)	Source
GM derived animal foods	UK	1 Opponents (7.6%) 2 Cautious (41.3%) 3 Optimists (51.1%)	(Kontoleon & Yabe, 2006)
GM corn	South Africa	1 Anti-GM, brand aware (35%) 2 Brand unaware, farmer sympathetic (20%) 3 GM consumer benefit, brand aware (25%) 4 Brand aware, Pro-GM (20%)	(Vermeulen, Kirsten, Doyer, & Schönfeldt, 2005)
GM oil seed[a]	Australia	1 Conservatives (28%) 2 Confident protectors (51%) 3 Anti-GM (20%)	(Cox *et al.*, 2008)
GM tofu	Taiwan	1 Conventional Buyer (45%) 2 GMO Buyer (32%) 3 Non-GMO buyer (23%)	(Jan, Fu, & Huang, 2007)
GM rice[a,b]	China	1 Enthusiastic (14.2%) 2 Cautious (41.2%) 3 Opposed (44.6%)	(De Steur, Liqun, *et al.*, 2014)

EU, European Union; GMO, genetically modified organism.

[a] To our knowledge these are the only segmentation studies solely focusing on GM products with consumer benefits. The GM rice study is the only cluster analysis on GM biofortified crops.

[b] 4th, 5th, 6th and 7th Eurobarometer Surveys are conducted in 1999, 2002, 2005 and 2010, respectively.

[c] In the 5th Eurobarometer ‘undecided’ is replaced by ‘risk-tolerant’.

[d] Although the authors discovered three additional, smaller segments with respect to GM tomatoes, only the common clusters are shown.

Özdemiroglu, 2002). Although values derived from experimental auctions are sometimes categorized as revealed preferences, they actually combine the strengths of both revealed and stated preference methods (Lusk & Shogren, 2007). While in theory all methods should obtain the same value, a discrepancy often occurs in practice (Balistreri *et al.*, 2001). As this is particularly the case for GM food studies (Lusk *et al.*, 2005), the most applied methods will be discussed below.

WTP for GM food is mainly determined by stated preference methods, such as open-ended and closed-ended contingent valuation (Lusk *et al.*, 2005). While the open-ended format directly measures the amount one is willing to pay, the single or double-bounded dichotomous choice closed-ended format includes a take-it-or-leave-it bid in advance, with (double) or without (single) follow-up (Bishop & Heberlein, 1979; Hanemann, 1984; Langford & Bateman, 1993). As the outcomes of these approaches are often different (Hanemann & Kanninen, 1999), one should carefully select the technique based on the nature of the investigated product, the characteristics of the targeted sample, the applied statistical technique and the cost of the survey (Venkatachalam, 2004). Other stated preference methods, such as discrete choice experiments, are often less applicable to estimate economic values of novel food products, due to its complexity, the limited possibility of including important determinants of buying behavior (Lusk & Hudson, 2004), or because of the low explained variation (Lusk & Shogren, 2007), but are generally accepted as multi-attribute modeling tools to measure trade-offs between various factors.

Although hypothetical methods are still commonly applied in GM food research (Lusk *et al.*, 2005), inferring stated preferences for novel products has been shown to lead to an overestimation of consumers' true value, partially because the former does not attach monetary consequences to the participant's responses (Balistreri *et al.*, 2001; Huffman, Rousu, Shogren, & Tegene, 2007; List & Gallet, 2001). This hypothetical bias is considered one of the key shortcomings of stated value elicitation methods (Loomis, 2011). As a consequence, non-hypothetical preference methods are often proposed as a valuable tool for eliciting one's true WTP (List & Gallet, 2001). Experimental auctions, for example, address important challenges of the stated (e.g. hypothetical bias) and revealed preference methods (e.g. indirectly deducting WTP from empirical patterns), while improving the conventional contingent valuation approach (Lusk & Shogren, 2007). Not surprisingly, this method becomes more and more used in the field of novel food products, among which GM foods (Colson & Rousu, 2013).

Besides the choice of valuation method, also the applied value measure, WTP versus WTA (willingness-to-accept, i.e. the compensation one is prepared to accept to sell a product), is an important topic for discussion. A clear divergence with substantially higher WTA values is often found when applying hypothetical methods (Plott & Zeiler, 2005; Venkatachalam, 2004), non-hypothetical methods (Brown, 2005; Shogren *et al.*, 2001), or both (Horowitz & McConnell, 2002), known as the endowment effect. This WTP/WTA gap also occurs when eliciting values for GM foods (Lusk *et al.*, 2005). For an overview of these and

Table 2. Overview of the main types of value elicitation methods, based on the applied value elicitation method and empirical setting, and applications to GM biofortified foods.

	Value elicitation method	Description	Applications to GM biofortified foods
Hypothetical	**Stated preference methods**	Elicits values for a non-market good or service, derived from indirect (i.e. choice modeling) or direct surveys (i.e. contingent valuation).	
	Contingent valuation Open-ended[a] Closed-ended[b]	Obtains statements that are contingent on the hypothetical scenario that is presented. Asks how much someone is willing to pay for a good. Asks whether someone is willing is to pay a certain amount for a good, with or without a follow-up question (i.e. respectively single or double-bounded dichotomous choices).	(De Steur *et al.*, 2010b) (Gonzalez *et al.*, 2009; Li *et al.*, 2002; Lusk, 2003)[e]
	Choice modeling Conjoint analysis Contingent ranking Choice experiments[c]	Multi-attribute valuation techniques that elicit values for multiple attributes of a non-market good by asking respondents to rate, rank or choose a set of attributes (levels). Techniques that infer a value from hypothetical choices for varying sets of product attributes, either by contingent rating or paired comparisons. Ranking a series of alternative options, e.g. product profiles, in order of preference. Valuation techniques, among which discrete choice experiments, where respondents have to make trade-offs and indicate their preferred option out of a set of alternatives.	(Gonzalez *et al.*, 2009) (Canavari & Nayga, 2009; Corrigan *et al.*, 2009)
Non-Hypothetical	**Revealed preference methods**	Derives someone's implicit value for a market good or service through the observation of preferences revealed by actual market behavior. In other words, one infers values for a good that indirectly exists in the market from actual choices.	
	Market data analysis	Deriving values (price responses) from observed market data through information on purchases of consumer panels, or household or store scanner data on transactions.	
	Travel cost method[d] Hedonic pricing[d] Random utility models	Measures the value for a good/service by determining the cost of travel in order to access it. Measures the implicit (hedonic) price of a non-market good/service through the value of surrogate goods/services (e.g. house prices) and the relative impact of their attributes. Analyzes choice behavior in a utility maximizing framework to derive values from implicit trade-offs among attributes and costs of alternatives (e.g. discrete choice models).	
	Experimental auctions Laboratory auctions[a] Field auctions	Simulates an active market in order to elicit values for non-market goods, either in a laboratory or a natural context (e.g. supermarket), where real products are auctioned for money. As such, this method is more often proposed as a valuable, more accurate value elicitation method as compared to survey based (stated) preference methods. Key value elicitation mechanisms are: English auction; BDM, Becker-Degroot-Marschalk; (random) nth price auction, 2nd price (Vickrey) auction and collective auction.	(Colson & Huffman, 2009; Colson, Huffman, & Rousu, 2011; Corrigan *et al.*, 2009; De Steur, Buysse, *et al.*, 2013; De Steur, Feng, *et al.*, 2014; De Steur, Gellynck, Feng, *et al.*, 2012; Depositario *et al.*, 2009)

[a] Selected valuation method in the reviewed case-studies.
[b] Commonly applied formats are dichotomous choice, payment card (i.e. asking for maximum WTP from a list on a card) and bidding game.
[c] Although choice experiments are hypothetical in nature, there is an increased interest in non-hypothetical variants.
[d] Both methods are typically used for environmental valuations (e.g. costs for accessing natural sites or for avoiding damage; valuing pollution through house price variations based on the proximity to industrial sites).
[e] Contingent valuation studies are based on a double-bounded dichotomous choice format.

Source: Own compilation. Classification and definitions based on Bateman *et al.* (2002), Breidert, Hahsler, and Reutterer (2006), Hanley, Shogren, and White (2006), Lusk and Shogren (2007), UN, EC, IMF, OECD, and World Bank (2005) and Venkachalam (2004).

other issues in economic valuation research, such as sampling bias, strategic bias, anchoring bias (product/information), order effects, social desirability bias and income endowment effects, we refer to the reviews of Venkatachalam (2004) on contingent valuation methods and De Steur, Feng, Xiaoping, & Gellynck (2014); De Steur, Liqun, Van Der Straeten, Lambert, & Gellynck (2014); De Steur *et al.* (2014) on experimental auctions (see also the handbook of Lusk and Shogren (2007)), i.e. two of the most applied methods in GM food studies.

Determinants of WTP for GM foods

Notwithstanding the importance of determining the level of WTP, identifying its determinants is considered one of the key directions of future valuation research on GM foods (Lusk, 2011). In line with the literature on acceptance, WTP for GM food is expected to be influenced by knowledge, consumer perceptions and socio-demographic indicators (Bredahl *et al.*, 1998; Costa-Font *et al.*, 2008; De Groote & Kimenju, 2008; Han & Harrison, 2006; House *et al.*, 2004; Verdurme, Viaene, *et al.*, 2003), although evidence on the effect of the latter is inconclusive (Lusk, Fox, Schroeder, Mintert, & Koohmaraie, 2001; Umberger & Feuz, 2004). Acceptance has a positive effect on WTP for GM technologies (Colson & Huffman, 2009) or GM food products (Kassardjian *et al.*, 2005). Besides, WTP estimates for GM foods also vary according to the type of GM technology (e.g. animal versus plants), food product and geographical region (Dannenberg, 2009; Lusk *et al.*, 2005).

In the case of GM foods with health benefits, which increases consumers' WTP (Dannenberg, 2009; Lusk *et al.*, 2005), information is expected to play an important role. Auctions, for example, allow to define the effect of the provision of specific information about product and process characteristics. Key information treatments refer to product (e.g. nutrition content and associated health benefits) or process characteristics (e.g. information regarding GM technology) (Depositario, Nayga, Wu, & Laude, 2009). Although health related information is expected to raise WTP, awareness of the GM technology may counter this effect. Due to the controversy surrounding the use of GM technology in food products, there is a large body of research on the role of specific GM information. While positive GM information increases consumers' WTP for GM food products (Colson & Huffman, 2009), and vice versa, there is less consensus about the direction of conflicting information effects (Colson & Huffman, 2009; Corrigan, Depositario, Nayga, Wu, & Laude, 2009; Depositario *et al.*, 2009; Parkhurst, Shogren, & Dickinson, 2004; Rousu, Huffman, Shogren, & Tegene, 2004).

When applying value elicitation methods on (GM) foods, especially in an experimental setting, the characteristics of the research design (recruitment method, timing, sample/panel size, bidding procedures) could account for differences in values (De Steur *et al.*, 2014). In experimental auctions, for example, commonly reported effects are the time-of-the-day effect (Hoffman, Menkhaus, Chakravarti, Field, & Whipple, 1993), panel size effect (Umberger & Feuz, 2004), training effect (Drichoutis, Nayga, & Lazaridis, 2011), multiple-good valuation effect (List, 2002), top-dog effect (Corrigan & Rousu, 2006) and bidder affiliation (List & Shogren, 1999). Also the applied value elicitation mechanism (Lusk, Feldkamp, & Schroeder, 2004; Lusk & Shogren, 2007) and bidding method, i.e. endowment (and up- or downgrade) versus full bidding approach (Corrigan & Rousu, 2006; Loureiro, Umberger, & Hine, 2003), may account for value differences.

Health impact and cost-effectiveness

While the analysis of acceptance and WTP provides insight in the consumer reactions to GM food with health benefits, one needs to realize that such crops may only be supported and implemented when the generated health effects verify the allocated resources. An economic evaluation is an essential tool to determine an intervention's potential health impact and cost-effectiveness. Here, the widely applied Disability-Adjusted Life Year (DALY) approach is integrated in the cost-effectiveness analysis (CEA) to measure the burden of disease before and after the intervention and to compare costs and benefits. The rationale behind the selection of the DALY concept and CEA will be discussed below.

Burden of disease

When evaluating health interventions that aim to address a specific disease in a society, like GM biofortification intends to do with micronutrient malnutrition, and to adequately inform decision-makers and health planners about the potential of such strategies, it is essential to analyze the current status of the targeted disease, i.e. the burden of disease.

In their 1993 World Development Report, the World Health Organization (WHO) and the World Bank introduced the Disability-Adjusted Life Year (DALY) as a health unit to analyze the burden of disease (World Bank, 1993). Since then, the DALY framework is the standard measurement tool in the WHO Global Burden of Disease (GBD) reports, including those on micronutrient malnutrition, and has been widely applied to compare health interventions (Musgrove & Fox-Rushby, 2006). It quantifies the burden of a disease as a single index, i.e. the number of DALYs lost. This number reflects both mortality and morbidity, as it is defined as the sum of years of life that are lost (YLL) and the years of life that are lived with a disability due to the disease (YLD) (Murray & Lopez, 1996).

The effectiveness of GM crops with health benefits

By comparing the burden of disease without or with the (potential) introduction of a health intervention, potential health impacts can be assessed. As Fig. 2 shows, this can

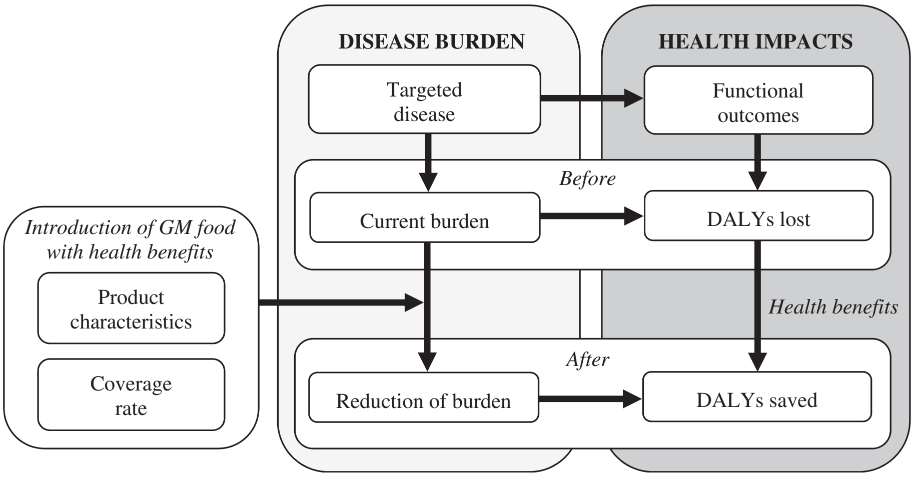

Fig. 2. Health impact assessment of GM food with health benefits. Application of the DALY framework, adopted from Zimmermann and Qaim (2004) and Meenakshi *et al.* (2010).

be done by applying the DALY approach. In comparison with the burden of disease (in DALYs lost), the effectiveness is expressed in DALYs gained. It represents the contribution of the intervention to alleviate this burden. The effectiveness of introducing GM food with health benefits mainly depends on the product characteristics and the potential coverage rate of the intervention, which refers to consumers' acceptance (derived from the micro-level analysis) and access (based on farmers' acceptance or willingness-to-adopt) (Stein *et al.*, 2005). By taking into account the dose–response relationship, i.e. the effect of the improved trait on specific outcomes of the targeted disease, one can estimate the potential effectiveness.

The DALY framework is well recognized and recommended (Musgrove & Fox-Rushby, 2006), especially for developing countries/regions (Evans, Tan-Torres Edejer, Adam, & Lim, 2005; World Bank, 1994), and is widely applied in health impact studies on biofortified crops (Meenakshi *et al.*, 2010). Thereby, the focus is mainly on crops tackling key micronutrient deficiencies, like iron, zinc and vitamin A deficiencies.

The cost-effectiveness of GM crops with health benefits

While an intervention's effectiveness refers to the improved health outcomes, a full economic evaluation brings in the cost factors associated with this intervention. In principle, an economic evaluation aims to compare the consequences (e.g. health impacts) and costs of an intervention, in order to contribute to priority-setting and to facilitate decision-making about the resource allocation (Drummond, Sculpher, Torrance, O'Brien, & Stoddart, 2005).

Table 3 gives an overview of the different approaches to describe the burden of disease and to evaluate health interventions. This overview does not aim to be exhaustive, but focuses on the most applied evaluation methods in economic health literature.

Basically, there are two main approaches in economic health literature: cost-effectiveness analysis (CEA) and cost-benefit analysis (CBA). Their objective is to identify interventions that maximize the effectiveness per unit of cost, i.e. the (health) value for money, rather than focusing on minimizing the costs, like cost-minimization analysis does. The major difference between CEA and CBA is that the former expresses cost-effectiveness in natural health units, while such health outcomes are converted into monetary values in the latter (Johannesson, 1995). The most important strength of cost-effectiveness, i.e. avoiding the monetization of health effects, is often considered its main weakness. Although one can attach a monetary value to a DALY or another health unit by using, for example, country-specific annual per capita incomes (WHO, 2001; Zimmermann & Qaim, 2004), a standardized international value for a DALY, i.e. US$ 1000 (World Bank, 1994), or a WTP value threshold for incremental risk reductions (Willan, O'Brien, & Leyva, 2001), proponents of CEA are questioning this approach on ethical grounds and the uncertainty regarding the level of the assigned value (Johannesson, 1995; Laxminarayan, Chow, & Shahid-Salles, 2006; Willan *et al.*, 2001). Due to the necessity of reporting health consequences, economic evaluation studies of health interventions are mainly based on CEA (Grosse, Teutsch, & Haddix, 2007; Ngorsuraches, 2008; WHO, 2000). Although CBA certainly has its merits over CEA, e.g. improved attractiveness, easier to comprehend, inclusion of non-health benefits and comparability between different sectors (Coast, 2004; Musgrove & Fox-Rushby, 2006), the latter will be selected in order to maintain the non-monetary dimension of the DALY framework, instead of using a purely economic indicator.

Together with the Quality-Adjusted Life Years (QALY) framework, the DALY framework is one of the most

Table 3. Approaches of burden of disease analysis, health impact assessment and economic evaluation, and applications to GM biofortified foods.

Approach	Description	Health unit	Cost unit	Standard measure	Applications to GM biofortified foods
Burden of disease					
Health approach, e.g. DALY framework	Estimation of the burden of a disease through health outcome measures. The DALY framework, for example, calculates the number of DALYs lost.	Natural units	/	DALYs lost[a]; QALYs lost; mortality; morbidity	
Cost approach, e.g. cost-of-illness analysis (COI)	According to the COI, the importance of the disease burden is evaluated by the direct and indirect costs that are associated to the disease.	/	Monetary units	US$	
Intervention					
Health impact					
Health approach, e.g. DALY framework	The health impact is evaluated in terms of improved health outcomes. The DALY framework, for example, estimates the number of DALYs lost that can be averted through an intervention.	Natural units	/	DALYs saved[a]; QALYs saved; deaths averted	(De Steur *et al.*, 2010a)
Cost analysis					
Cost approach, e.g. CMA	Cost-minimization analysis (CMA) analyzes the intervention costs in order to identify the least expensive intervention; also known as cost analysis, cost identification, programmatic cost analysis, cost outcome analysis or cost consequence analysis.	(Equal benefits)	Monetary units	US$	
Economic evaluation					
CEA, Cost-effectiveness analysis	All costs are related to a single health index, i.e. the outcome measure, and expressed as the additional cost spent per unit of health outcome.	Natural units	Monetary units	Reduced prevalence; US$ per DALY saved[a]; US$ per QALY saved	(Chow, Klein, & Laxminarayan, 2010; De Steur, Blancquaert, *et al.*, 2012; De Steur, Gellynck, *et al.*, 2012; Stein *et al.*, 2006)[b]
CBA, Cost-benefit analysis	Both costs and benefits are converted into monetary units and outcomes are expressed as the value of the benefits per dollars expended; sometimes referred to as benefit-cost analysis	Monetary units	Monetary units	Benefit-cost ratio (B/C) Net benefit (B−C) Internal rate of return (IRR)	(Chow *et al.*, 2010; Stein *et al.*, 2006; Zimmermann & Qaim, 2004)[b,c]

CBA, Cost-benefit analysis; CEA, Cost-effectiveness analysis; CMA, Cost-minimization analysis; COI, cost-of-illness analysis; DALY, disability-adjusted life year; QALY, quality-adjusted life year.
[a] Selected valuation measure in the applications, including the reviewed case-studies.
[b] Except for Chow *et al.* (2010), all studies included a burden and health impact assessment.
[c] All studies estimated the IRR, while Stein *et al.* (2006) also determined the benefit-cost-ratio.
Source: Own compilation, based on Ngorsuraches (2008) and Drummond *et al.* (2005). Descriptions based on the CDC economic evaluation glossary index (CDC, 2011).

applied cost-effectiveness approaches for health interventions (Evans *et al.*, 2005). Both QALYs and DALYs are considered as Health-Adjusted Life Years methods, i.e. techniques to describe both mortality and morbidity of a health condition as a single number (Gold, Stevenson, & Fryback, 2002). Due to the inclusion of preference weights ('utilities') for the quality of life, these standardized health measures are often categorized under cost-utility analyses (CUA), an extended CEA (Ngorsuraches, 2008). When controlling for age-weighting and discounting, a QALY (health gain) is considered the opposite of a DALY (health loss). While the former uses a 'health related quality of life' weight, the latter uses its inverse, i.e. 'disability' weights.

Although using QALYs has its own advantages, there is evidence that it leads to higher health impact figures, especially in the case of childhood diseases (Sassi, 2006), and may result in a different ranking of cost-effective interventions (Arioldi, 2007). The selection of the DALY approach was mainly motivated by the historical use of DALYs in World Bank (World Bank, 1993) and WHO reports on developing countries (Evans *et al*., 2005) as well as in biofortification studies (Meenakshi *et al*., 2010). Although this health indicator is often criticized, e.g. less transparent to decision makers (Arnesen & Kapiriri, 2004), it is widely recognized as an economic evaluation tool without the need to attach a monetary value to a health benefit.

Costs that are generally included in economic evaluations on conventional (Meenakshi *et al*., 2010) and GM biofortification (De Steur, Gellynck, Blancquaert, *et al*., 2012; Stein *et al*., 2006) refer to R&D, the regulatory process, backcrossing of the desired trait into local varieties, social marketing efforts and maintenance breeding. Costs associated with environmental risk management, among which co-existence measures to avoid cross-pollination and segregation measures to avoid trade disruptions, as well as labeling costs are not captured in current models. This emphasizes the need for advanced cost-benefit ramifications in future research.

The cost-effectiveness is generally expressed in a standardized unit, i.e. US$ per gained DALY, which enables the comparison of different health interventions. Thereby, one could use a fixed cut-off level for cost-effective interventions (Laxminarayan *et al*., 2006; Tan-Torres Edejer *et al*., 2003), such as the US$ 150-threshold of the World Bank (1993) or per capita income levels, as proposed by the WHO (Evans *et al*., 2005).

Reviewing the case of Folate Biofortified Rice in China

The aforementioned conceptual framework has been used to determine the market potential of folate biofortified rice as a particular GM food crop with health benefits. By reviewing the results of eight *ex-ante* socio-economic studies, this section demonstrates the applicability and relevance of this framework. The focus is on folate biofortified rice as a potential, alternative health intervention to alleviate the burden of folate deficiency. China and Shanxi Province are selected as the research locations at, respectively, macro and micro level. Besides being the world leader in rice production and consumption, China is also one of the largest GM crop producers and is heavily involved in research and development of GM rice (Wang & Johnston, 2007) and GM biofortified crops (Campos-Bowers & Wittenmyer, 2007; Pray & Huang, 2007). But more importantly, with an estimated affected population of about 260 million, folate deficiency is a major public health problem in China (De Steur *et al*., 2010a). As a consequence, about 9% of all Neural-Tube Defects, i.e. folate deficiency's main adverse health outcome, occur in China. Folate biofortification is particularly relevant for Shanxi Province, where 44% of all women lack folate in pregnancy (Ren *et al*., 2007), leading to an estimated record number of 6.5 Neural-Tube Defects per day (Dai *et al*., 2002).

Micro-level analysis of FBR: acceptance and willingness-to-pay

Table 4 summarizes the key findings of the micro-level evaluation of FBR in Shanxi Province, China. While the analysis of acceptance and stated preference is based on a standardized survey with 944 rice consumers (De Steur *et al*., 2010b), the experimental auctions on WTP encompass 252 women of childbearing age (De Steur, Gellynck, Feng, Rutsaert, & Verbeke, 2012). The design characteristics and the rationale of the methodological choices are described in more detail in the reviewed studies. Besides reviewing published evidence, we also present novel findings based on their datasets.

The population-based consumer survey on FBR in Shanxi Province reports a high acceptance rate (62.2%), as compared to a low level of reluctance (11.2%) and indifference (26.6%) (De Steur *et al*., 2010b). When looking at those who accept FBR, a negative change in key rice attributes could outweigh their perception of the improved health attribute (De Steur, Blancquaert, *et al*., 2013). In some cases, like a decrease in taste and negative effects on the environment, the coverage rate of introducing FBR would be drastically reduced, up to a level that is 55% lower than the initial acceptance rate.

A closer look into the data reveals three distinct consumer segments: enthusiasts (14.2%), opponents (41.2%) and cautious consumers (44.6%) (De Steur, Liqun, Van Der Straeten, Lambert, & Gellynck, 2014). These segments do not only differ in terms of GM knowledge, perceptions and acceptance, but also in the acquisition of, and their trustworthiness in GM information. Therefore, the low representation of the optimistic segment is mainly due to its high scores on each selected variable, rather than it is an indication of FBR's low acceptance. As such, the cautious segment is not really reluctant, but only less optimistic. GM food knowledge, attitudes and acceptance are highest in the group of enthusiasts. The cautious hold an intermediate position between enthusiastic and reluctant consumers.

In correspondence with reviews on determinants of GM food acceptance (Bredahl *et al*., 1998; Verdurme & Viaene, 2001), acceptance of FBR is influenced by the sociodemographic indicators, GM knowledge and consumer perceptions. Being male, farmer, young or highly educated, or having a positive view on the risks or benefits increases the probability to be favorable towards FBR. Also objective knowledge of GM food, together with perceptions of the potential risks and benefits, plays an important role. The subjective knowledge component, which generally exceeds ones' objective knowledge, is insignificant.

As expected, there is a discrepancy between WTP derived from stated preference methods or experimental auctions. Based on the survey data on acceptance (De Steur *et al*., 2010b), women of childbearing age stated to be prepared to pay 46.7% more for rice when it would be biofortified with folate. This is significantly higher than the 33.7% premium in the experimental auctions (De Steur, Gellynck, Feng, *et al*., 2012). A similar observation is made for reluctance, as there are less women opposed to buying FBR in a hypothetical (11.3%) than in a non-hypothetical setting (17.5%). Although specific design characteristics might account for

Table 4. Review of four micro-level evaluation studies on FBR in Shanxi Province, China. Key findings on acceptance (determinants, impacts of negative rice attributes) and willingness-to-pay (determinants, information effects).

Acceptance

Significant determinants[a]	Likelihood ratio tests χ^2	Impacts of negative rice attributes[b]	% Reduction of acceptance
Gender (male)[b]	6.90*	Taste	54.82
Age (young)[b]	10.61*	External appearance	26.05
Farmer status (farmer)[b]	9.78*	Price impact	44.53
Education level (high)[b]	7.84*	Availability	34.73
Obj. GM knowledge (high)[c]	11.74***	Cultivation potential	19.61
GM food benefits (positive)[c]	5.93*	Environmental impact	53.54
GM food risks (positive)[c]	6.31*		
Model	102.03***		
Nagelkerke's R^2	0.25		

WTP

Determinants[c]	Coefficients		Information effects[d]	t-value
	Choice	Level		
Target group (non-student)[b]	0.63*	2.50*	Folate benefits	6.82***
Auction type (2 products)[g]	0.12	−0.25	GM technology	3.77***
Farmer family (yes)[b]	0.22	0.76	Positive	2.67**
Residence (rural)[b]	0.11	−0.23	Negative	−5.73***
Obj. GM knowledge (high)[c]	0.78°	0.16	Positive + negative	0.27
GM acceptance (yes)[b]	1.01**	3.36*	Negative + positive	−2.96**
Sigma		3.122**	Objective	−3.79***
Log likelihood	−102.162	−348.515	All	−3.73***

GM, genetic modification. *Note*: °, *, **, *** denote statistical significance at 10%, 5% and 1% and 0.1%, respectively. Significance at 10% is only applicable to the double hurdle model. Categories or levels in between brackets refer to the direction of the effect. Education (<, ≥ college degree); Age (<, ≥40 years); Target group (student, non-student sample); Auction type (1 product 'FBR' versus 2 products 'FBR + non-GM alternative'); Farmer family (no, yes), Residence (urban, rural); and Acceptance (no, yes).

[a] Based on multinomial logistic regression analysis (De Steur *et al.*, 2010b).

[b] Based on De Steur *et al.* (2013). The percentage reduction refers to the initial acceptance rate is 62.2%.

[c] Based on double hurdle regression analysis (De Steur, Gellynck, Feng, *et al.*, 2012). Whilst the 1st hurdle examines the determinants of being willing to pay for FBR or not (i.e. WTP choice; $n = 251$), the 2nd hurdle analyzes the effects on the amount someone is willing to pay (i.e. WTP level; $n = 207$).

[d] Based on 'random effects' panel data regression analysis (De Steur, Buysse, *et al.*, 2013). Effects refer to the impact of an information treatment on the initial WTP, i.e. when only information about folate content is provided.

these differences, this may be attributable to hypothetical bias (De Steur, Vanhonacker, *et al.*, 2014).

WTP for FBR is largely determined by objective GM food knowledge and acceptance (De Steur, Gellynck, Feng, *et al.*, 2012). Besides, the target group variable indicates significant differences between the student and non-student subsample, by which the latter is typically in favor of GM technology and FBR. While this may call for tailored folate interventions, e.g. promoting folic acid supplementation for young people, another study specifically confirmed the unattractiveness of such supplements in relation to FBR (De Steur, Feng *et al.*, 2014). This is also shown in the insignificant effect of auctioning FBR alone or together with supplements as a non-GM alternative. When the latter is available, the majority still prefers FBR.

A closer look at the role of information demonstrates that learning about the folate benefits of FBR increases consumers' WTP (De Steur, Buysse, Feng, & Gellynck, 2013). Surprisingly, awareness of the application of GM technology did not necessarily affected WTP for FBR. Even if this information lowered WTP, knowledge about the folate benefits was generally effective enough to compensate for this reduction. As such, the consumer benefits of FBR seem to be the decisive factor that outweighs potential negative perceptions that might be associated with the GM technology. Nevertheless, the premium for FBR is lower than if it would have been based on conventional breeding techniques (De Steur, Feng *et al.*, 2014). Another interesting finding relates to the impact of specific GM information and conflicting information in particular. While Shanxi women are most susceptible to one-sided positive or negative GM information, and evaluate objective information rather as a negative treatment, conflicting information resulted in a significant reduction of WTP, which confirms previous research (Fox, Hayes, & Shogren, 2002; Parkhurst *et al.*, 2004; Rousu *et al.*, 2004). However, as the downward adjustment of WTP is less pronounced when positive information is presented first, a primacy effect is expected to occur.

Regarding the effect of design characteristics, we did not found significant differences in bidding behavior when the auctions were held on a different time (morning, afternoon or evening; weekday versus weekend), or with smaller or larger panel sizes.

Macro-level analysis: potential health impacts and cost-effectiveness

The results of the macro-level analysis of FBR in China are presented in Table 5. Here, the DALY concept is selected as the health measure of CEA. Besides reviewing the findings from key studies on FBR in China (De Steur *et al.*, 2010a) and Shanxi Province (De Steur, Blancquaert, Gellynck, Lambert, & Van Der Straeten, 2012), reference is also made to a cost-effectiveness study on multi-biofortified rice, in which also zinc, iron and provitamin A levels are enhanced (De Steur, Gellynck, Blancquaert, *et al.*, 2012).

The burden analysis shows that a total number of 314 180 DALYs are lost due to folate deficiency in China, of which 72.2% is caused by fatal outcomes, namely Neural-Tube Defects that result in abortions or stillbirths due to inadequate maternal folate intake. Regarding non-fatal outcomes, spina bifida accounts for the highest number of years lived with disability.

By focusing only on women of childbearing age, the size of this burden is largely underestimated, by which currently only 3% of China's burden of micronutrient malnutrition is attributable to folate deficiency (De Steur, Gellynck, Blancquaert, *et al.*, 2012). A regional health analysis demonstrates that more than 80% of the folate burden affects Northern China (De Steur *et al.*, 2010a). As expected, the situation in Shanxi Province is particularly problematic. According to the most recent analysis, this region obtains a share of 36.4% (De Steur, Blancquaert, *et al.*, 2012).

Due to the relatively high folate content of biofortified rice, i.e. about 40 times higher than in regular rice, implementing FBR would substantially reduce the annual number of DALYs lost. Under the assumption that current rice patterns are maintained, 22 871–68 614 DALYs (Shanxi) and 62 836–188 508 DALYs (China) could be saved each year. Even though the burden of folate deficiency is smaller than for other micronutrient deficiencies, comparison of the potential health impacts of conventional biofortified crops (Meenakshi *et al.*, 2010) and GM Golden Rice (Zimmermann & Qaim, 2004) shows that the FBR has relatively one of the highest effectiveness rates (De Steur, Blancquaert, *et al.*, 2012).

When taken into account the intervention costs, i.e. US$ 19.9 million (Shanxi) versus US$ 32.3 million (China) (De Steur, Blancquaert, *et al.*, 2012; De Steur, Gellynck, Blancquaert, *et al.*, 2012), both the regional and country-wide introduction of FBR are considered to be highly cost-effective micronutrient strategies. Depending on the impact scenario and geographical scope, saving a DALY with FBR would cost between US$ 21.4 and US$ 120.3. Because of the targeted nature of the intervention, by which health benefits solely refer to prevention of maternal folate deficiency, the cost to save a DALY is higher than in the case of Golden Rice (US$ 3.1–19.4) (Stein *et al.*, 2006). Nevertheless, inserting both transgenic traits – folate and pro-vitamin A – into a so-called multi-biofortified crop would result in the largest cost-effectiveness, i.e. US$ 2.3–9.6 per DALY saved (De Steur, Blancquaert, *et al.*, 2012).

Discussion

In this review article, we have presented a socio-economic research framework for evaluating GM foods with health benefits. Through the combination of both micro- and macro-level analysis it addresses key knowledge gaps in four key research domains: acceptance, willingness-to-pay, health impacts and cost-effectiveness. Thereby, the focus is

Table 5. Review of three macro-level evaluation studies on FBR in China and Shanxi Province. Key findings on the current burden of folate deficiency, and potential health impacts and cost-effectiveness of FBR.

Current burden[a]	Folate deficiency		Health impacts[e]	FBR[d]		Cost-effectiveness[e]	FBR[d]	
(DALYs lost/year)	Shanxi Province[b]	China[c]	(DALYs saved/year)	Shanxi Province[b]	China[c]	(US$/DALY saved)	Shanxi Province[b]	China[c]
YLD (i.e. NTD live births)	31 710	87 500	Pessimistic scenario	22 871	62 836	Pessimistic scenario	120.3	64.2
YLL (i.e. fatal NTDs)	82 645	226 680	Optimistic scenario	68 614	188 508	Optimistic scenario	40.1	21.4
Total (YLD + YLL)	114 355	314 180						

DALY, disability-adjusted life year; FBR, folate biofortified rice; NTD, neural-tube defect; YLD, years lived in disability; YLL years of life lost.

[a] The annual burden of folate deficiency focuses on NTDs as the main adverse health outcome of folate deficiency.

[b] Shanxi figures derived from De Steur *et al.* (2012).

[c] Based on a health impact study on folate biofortified rice (De Steur *et al.*, 2010a) and cost-effectiveness analysis on multi-biofortified rice (De Steur, Gellynck, Blancquaert, *et al.*, 2012).

[d] The application of the DALY framework on FBR is based on the HarvestPlus Technical Monograph on vitamin A, zinc and iron enriched crops (Stein *et al.*, 2005).

[e] In line with previous research, two impact scenarios were used according to the applied coverage rate, i.e. pessimistic (20%) versus optimistic (60%) (Stein *et al.*, 2006; Zimmermann & Qaim, 2004). These estimates are based on consumers' acceptance of (micro-level data, see "Micro-level analysis of FBR"), and access to FBR (farmers' acceptance).

primarily on GM biofortified foods as one of the most advanced examples of using GM technology to develop foods with consumer/health benefits. This relatively new and growing area in agriculture biotechnology is highly relevant from a policy and societal perspective because its product innovations are both controversial and beneficial to humans. As such, this article highlights the importance of proactive market analysis in order to valorize GM foods with health benefits and to provide policy makers, decision makers and health planners with information about the potential demand and impacts. Furthermore, it may assist researchers in (better) predicting the market potential of such foods, as well as allow them to go beyond the current state of literature. Moreover, this framework might also be adapted to other research fields dealing with healthy, but controversial products, for which socio-economic evidence is lacking at different analytical levels. This calls for systematic reviews or meta-analyses on a specific socio-economic research level, applied to agricultural biotechnology and its GM foods with other improved health traits (Martin, 2013), health care biotechnology and its biopharming applications like antibodies or vaccines (Ahmad *et al*., 2012), or the broad spectrum of functional foods (Hasler, 2002; Siro, Kapolna, Kapolna, & Lugasi, 2008). After all, (GM) biofortified crops are not panacea and the only tool to reduce micronutrient malnutrition. Furthermore, it will be also key to adapt this framework to evaluate GM technologies targeted at the improvement of non-health related quality traits, such as an extended shelf life or an improved taste (Engel *et al*., 2002).

Even though this framework provides a scientifically sound basis for further research in this field, it is not intended to be perceived as an all-inclusive model. Instead, it builds upon existing and comparable research on GM foods and health interventions, and encompasses well-established or highly relevant concepts in socio-economic literature, while being specifically targeted towards the consumer. Although the perceptions of, and impacts on consumers can be perceived as precursors of other stakeholders' decision to support, adopt or implement GM foods with health benefits, future research could further extend this framework. At micro-level, for instance, one could conduct a stakeholder analysis and incorporate it into the micro or macro-level analysis. Thereby, it would be interesting to confront key stakeholders, such as producers, decision-makers and health planners, with the findings at consumer level. But also macro-level analysis could contribute to micro-level research, e.g. by including the potential health benefits as an information treatment in order to examine the effect of health related messages on the acceptance of GM foods with health benefits.

Furthermore, our framework did not reflect upon international trade issues for adopting such GM foods. When looking at trade models on GM rice (Demont & Stein, 2013), and Golden Rice (Anderson & Jackson, 2005; Anderson, Jackson, & Nielsen, 2005) in particular, very large welfare gains with small trade effects have been reported. Still, one may need to consider the possible role of (perceptions on) trade barriers on the introduction of future GM foods with health benefits.

Besides the empirical focus, we also make methodological choices, which are scientifically underpinned in this review. However, these choices do not aim to restrict future research. For example, despite the relevance of current GM food valuation research to agribusiness stakeholders and policy makers, there are still concerns on the artificial, one-time measurement of WTP and its determinants, like information (Colson & Rousu, 2013; Lusk, 2011). CEA, for instance, has as much advantages and disadvantages as CBA, while both methods provide only one indicator of the decision process of policy makers or program planners. One could also take into the account the irreversibility and uncertainty of introducing GM crops by adopting a real option approach (Andoseh, Bahn, & Gu, 2014) for evaluating (the timing of) decisions on GM crops (Furtan, Gray, & Holzman, 2003), and, as Kikulwe, Wesseler, and Falck-Zepeda (2008) suggested, combine it with WTP analysis to justify (a delay in) release.

The relevance of this framework is further illustrated by reviewing the case of FBR in China. When analyzing *ex-ante* the potential of this GM crop with health benefits, different studies at micro-level lend support for a substantial market in high-risk regions. Consumers generally accept it and are even prepared to pay 34% more than for regular rice. The health impact studies further support FBR as a valuable micronutrient intervention, which could reduce 20%–60% of China's burden of folate deficiency. Moreover, as it would cost between US$ 21.4 and US$ 64.2 to save a DALY, FBR is also considered a highly cost-effective health strategy. However, despite the market potential of such GM foods with health benefits at both micro and macro level, it is important to notice that their specific characteristics, especially the linkage between nutrition and agriculture, require additional conditions to be met in order to ensure a successful commercialization. Nevertheless, through its combined approach, the present review article has provided a valuable, easily adaptable and applicable conceptual framework to measure key socio-economic aspects of GM foods with health benefits.

References

Ahmad, P., Ashraf, M., Younis, M., Hu, X., Kumar, A., Akram, N. A., et al. (2012). Role of transgenic plants in agriculture and biopharming. *Biotechnology Advances, 30*, 524–540.

Anand, A., Mittelhammer, R., & McCluskey, J. (2007). Consumer response to information and second-generation genetically modified food in India. *Journal of Agricultural & Food Industrial Organization, 5*, 1–18.

Anderson, K., & Jackson, L. A. (2005). Some implications of GM food technology policies for Sub-Saharan Africa. *Journal of African Economies, 14*, 385–410.

Anderson, K., Jackson, L. A., & Nielsen, C. P. (2005). Genetically modified rice adoption: implications for welfare and poverty alleviation. *Journal of Economic Integration, 20*, 771–788.

Andoseh, S., Bahn, R., & Gu, J. (2014). The case for a real options approach to ex-ante cost-benefit analyses of agricultural research projects. *Food Policy, 44*, 218−226.

Anthony, V. M., & Ferroni, M. (2012). Agricultural biotechnology and smallholder farmers in developing countries. *Current Opinion in Biotechnology, 23*, 278−285.

Arioldi, M. (2007). *Gains in QALYs vs. DALYs averted. The troubling implications of using residual life expectancy*. LSE Health working paper. No 8. London: London School of Economics and Political Science.

Arnesen, T., & Kapiriri, L. (2004). Can the value choices in DALYs influence global priority-setting? *Health Policy and Education, 70*, 137−149.

Arvanitoyannis, I., & Krystallis, A. (2005). Consumers' beliefs, attitudes and intentions towards genetically modified foods, based on the 'perceived safety vs. benefits' perspective. *International Journal of Food Science and Technology, 40*, 343−360.

Baker, G., & Burnham, T. (2001). Consumer response to genetically modified foods: market segment analysis and implications for producers and policy makers. *Journal of Agricultural and Resource Economics, 26*, 387−403.

Balistreri, E., McClelland, G., Poe, G., & Schulze, W. (2001). Can hypothetical questions reveal true values? A laboratory comparison of dichotomous choice and open-ended contingent values with auction values. *Environmental and Resource Economics, 18*, 275−292.

Bateman, I. J., Carson, R. T., Day, B., Hanemann, M., Hanley, N., Hett, T., et al. (2002). *Economic valuation with stated preference techniques: A manual*. Cheltenham, UK: Edward Elgar Publishing.

Bishop, R. C., & Heberlein, T. A. (1979). Measuring values of extra-market goods: are indirect measures biased? *American Journal of Agricultural Economics, 61*, 926−930.

Blamires, C. (1997). Pricing research techniques: a review and a new approach. *Journal of Market Research Society, 39*, 85−107.

Bouis, H. E. (2002). Plant breeding: a new tool for fighting micronutrient malnutrition. *Journal of Nutrition, 132*, S491−S494.

Bredahl, L. (2001). Determinants of consumer attitudes and purchase intentions with regards to genetically modified foods − results of a cross-national survey. *Journal of Consumer Policy, 24*, 23−61.

Bredahl, L., Grunert, K., & Frewer, L. (1998). Consumer attitudes and decision-making with regard to genetically engineered food products - a review of the literature and a presentation of models for future research. *Journal of Consumer Policy, 21*, 251−277.

Breidert, C., Hahsler, M., & Reutterer, R. (2006). A review of methods for measuring willingness-to-pay. *Innovative Marketing, 4*.

Brookes, G., Elobeid, A., Tokgoz, S., & Yu, T.-H. E. (2010). *The production and price impact of biotech crops*. Center for Agricultural and Rural Development, Iowa State University.

Brown, T. C. (2005). Loss aversion without the endowment effect, and other explanations for the WTA-WTP disparity. *Journal of Economic Behavior & Organization, 57*, 367−379.

Campos-Bowers, M., & Wittenmyer, B. (2007). Biofortification in China: policy and practice. *Health Research Policy and Systems, 5*, 1−7.

Canavari, M., & Nayga, R. M., Jr. (2009). On consumers' willingness to purchase nutritionally enhanced genetically modified food. *Applied Economics, 41*, 125−137.

CDC. (2011). *Economic evaluation*. Glossary of terms. Atlanta, GA: Centers for Disease Control and Prevention.

Chen, M., & Li, H. (2007). The consumer's attitude toward genetically modified foods in Taiwan. *Food Quality and Preference, 18*, 662−674.

Chow, J., Klein, E. Y., & Laxminarayan, R. (2010). Cost-effectiveness of "Golden Mustard" for treating vitamin a deficiency in India. *PloS One, 5*.

Chowdhury, S., Meenakshi, J. V., Tomlins, K., & Owori, C. (2009). Are consumers willing to pay more for biofortified foods? Evidence from a field Experiment in Uganda. In *HarvestPlus Working Paper No. 3*. Washington, D.C: International Food Policy Research Institute.

Christophe, I., Bruhn, M., & Roosen, J. (2008). Knowledge, attitudes towards and acceptability of genetic modification in Germany. *Appetite, 51*, 58−68.

Coast, J. (2004). Is economic evaluation in touch with society's health values? *British Medical Journal, 329*, 1233−1236.

Colson, G., & Huffman, W. (2009). Consumers' willingness to pay for new genetically modified food products: evidence from experimental auctions of intragenics and transgenic foods. In *International Association of Agricultural Economists 2009 Conference*. Beijing, China: IAAE.

Colson, G., & Rousu, M. C. (2013). What do consumer surveys and experiments reveal and conceal about consumer preferences for genetically modified foods? *GM Crops & Food, 4*, 158−165.

Colson, G. J., Huffman, W. E., & Rousu, M. C. (2011). Improving the nutrient content of food through genetic modification: evidence from experimental auctions on consumer acceptance. *Journal of Agricultural and Resource Economics, 36*, 343.

Corrigan, J. R., Depositario, D. P. T., Nayga, R. M., Wu, X., & Laude, T. P. (2009). Comparing open-ended choice experiments and experimental auctions: an application to Golden Rice. *American Journal of Agricultural Economics, 91*, 837−853.

Corrigan, J. R., & Rousu, M. C. (2006). The effect of initial endowments in experimental auctions. *American Journal of Agricultural Economics, 88*.

Costa-Font, M., & Gil, J. (2009). Structural equation modelling of consumer acceptance of genetically modified (GM) food in the Mediterranean Europe: a cross country study. *Food Quality and Preference, 20*, 399−409.

Costa-Font, M., Gil, J., & Traill, W. (2008). Consumer acceptance, valuation of and attitudes towards genetically modified food: review and implications for food policy. *Food Policy, 33*, 99−111.

Costa-Font, M., & Mossialos, E. (2007). Are perceptions of risks and benefits of genetically modified food (in)dependent? *Food Quality and Preference, 18*, 173−182.

Costa-Font, M., Tranter, R. B., & Gil, J. M. (2012). *Consumers' opinions and attitudes towards co-existence of GM and non-GM food products*. West Sussex, UK: John Wiley & Sons.

Cox, D., Evans, G., & Lease, H. (2008). Australian consumers' preferences for conventional and novel sources of long chain omega-3 fatty acids: a conjoint study. *Food Quality and Preference, 19*, 306−314.

Dai, L., Zhu, J., Zhou, G., Wang, Y., Wu, Y., Miao, L., et al. (2002). Dynamic monitoring of neural tube defects in China during 1996 to 2000 (Article in Chinese). *Zhonghua Yu Fang Yi Xue Za Zhi, 36*, 402−405.

Dannenberg, A. (2009). The dispersion and development of consumer preferences for genetically modified food − a meta-analysis. *Ecological Economics, 68*, 2182−2192.

De Groote, H., & Kimenju, S. (2008). 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, 33*, 362−370.

De Steur, H., Blancquaert, D., Gellynck, X., Lambert, W., & Van Der Straeten, D. (2012a). Ex-ante evaluation of biotechnology innovations: the case of folate biofortified rice in China. *Current Pharmaceutical Biotechnology, 13*, 2751−2760.

De Steur, H., Blancquaert, D., Gellynck, X., Storozhenko, S., Liqun, G., Lambert, W., et al. (2013a). How negative product attributes alter consumer perceptions of folate biofortified rice in a high risk region of China. *International Journal of Biotechnology, 12*, 269−287.

De Steur, H., Buysse, J., Feng, S., & Gellynck, X. (2013b). The role of information on consumers' willingness-to-pay for GM rice with health benefits. An application to China. *Asian Economic Journal, 27*, 391−408.

De Steur, H., Feng, S., Xiaoping, S., & Gellynck, X. (2014a). Consumer preferences for micronutrient strategies in China. A comparison between folic acid supplementation and folate biofortification. *Public Health Nutrition, 17*, 1410–1420.

De Steur, H., Gellynck, X., Blancquaert, D., Lambert, W., Van Der Straeten, D., & Qaim, M. (2012b). Potential impact and cost-effectiveness of multi-biofortified rice in China. *New Biotechnology, 29*, 432–442.

De Steur, H., Gellynck, X., Feng, S., Rutsaert, P., & Verbeke, W. (2012c). 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 Quality and Preference, 25*, 87–94.

De Steur, H., Gellynck, X., Storozhenko, S., Liqun, G., Lambert, W., Van Der Straeten, D., et al. (2010a). The health benefits of folate biofortified rice in China. *Nature Biotechnology, 28*, 554–556.

De Steur, H., Gellynck, X., Storozhenko, S., Liqun, G., Lambert, W., Van Der Straeten, D., et al. (2010b). Willingness to accept and Purchase genetically modified Rice with high folate content in Shanxi province, China. *Appetite, 54*, 118–125.

De Steur, H., Liqun, G., Van Der Straeten, D., Lambert, W., & Gellynck, X. (2014b). The potential market for GM rice with health benefits in a Chinese high-risk region. *Journal of Food Products Marketing*, in press.

De Steur, H., Vanhonacker, F., Feng, S., Xiaoping, S., Verbeke, W., & Gellynck, X. (2014c). Cognitive biases and design effects in experimental auctions: an application to GM rice with health benefits. *China Agricultural Economic Review*, in press, accepted in February 2014.

Demont, M., & Stein, A. J. (2013). Global value of GM rice: a review of expected agronomic and consumer benefits. *New Biotechnology, 30*, 426–436.

Depositario, D. P. T., Nayga, R. M., Wu, X., & Laude, T. P. (2009). Effects of information on consumers' willingness to pay for Golden Rice. *Asian Economic Journal, 23*, 457–476.

Drichoutis, A., Nayga, R. M., & Lazaridis, P. (2011). The role of training in experimental auctions. *American Journal of Agricultural Economics, 93*, 521–527.

Drummond, M. F., Sculpher, M. J., Torrance, G. W., O'Brien, B., & Stoddart, G. L. (2005). *Methods for the economic evaluation of health care programmes* (3 ed.). New York: Oxford University Press.

Engel, K.-H., Frenzel, T., & Miller, A. (2002). Current and future benefits from the use of GM technology in food production. *Toxicology Letters, 127*, 329–336.

Evans, D. B., Tan-Torres Edejer, T., Adam, T., & Lim, S. S. (2005). Methods to assess the costs and health effects of interventions for improving health in developing countries. *British Medical Journal, 331*, 1137–1140.

Fishbein, M. (1963). An investigation of the relationships between beliefs about an object and attitude towards that object. *Human Relations, 16*, 233–240.

Fox, J. A., Hayes, D. J., & Shogren, J. F. (2002). Consumer preferences for food irradiation: how favorable and unfavorable descriptions affect preferences for irradiated pork in experimental auctions. *The Journal of Risk and Uncertainty, 24*, 75–95.

Frewer, L. J., Howard, C., Hedderley, D., & Shepherd, R. (1997). Consumer attitudes towards different food-processing technologies used in cheese production – the influence of consumer benefit. *Food Quality and Preference, 8*, 271–280.

Frewer, L. J., & Shepherd, R. (1995). Ethical concerns and risk perceptions associated with different applications of genetic engineering: interrelationships with the perceived need for regulation of the technology. *Agriculture and Human Values, 12*, 48–57.

Frewer, L. J., van der Lans, I. A., Fischer, A. R. H., Reinders, M. J., Menozzi, D., Zhang, X. Y., et al. (2013). Public perceptions of agri-food applications of genetic modification – a systematic review and meta-analysis. *Trends in Food Science & Technology, 30*, 142–152.

Furtan, W. H., Gray, R. S., & Holzman, J. J. (2003). The optimal time to license a biotech "lemon". *Contemporary Economic Policy, 21*, 433–444.

Gamble, J., Muggleston, S., Hedderley, D., Parminter, T., & Richardson-Harman, N. (2000). *Genetic engineering: The public's point of view*. HortResearch Client Report No. 2000/249. Auckland: HortResearch.

Ganiere, P., Chern, W., & Hahn, D. (2006). A continuum of consumer attitudes toward genetically modified foods in the United States. *Journal of Agricultural and Resource Economics, 31*, 129–149.

Gaskell, G., Allum, N., & Stares, S. (2003). *Europeans and Biotechnology in 2002*. Eurobarometer 58.0.

Gaskell, G., Allum, N., Wagner, W., Kronberger, N., Torgersen, H., Hampel, J., et al. (2004). GM foods and the misperception of risk perception. *Risk Analysis, 24*, 185–194.

Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Castro, P., Esmer, Y., et al. (2010). *Europeans and Biotechnology in 2010. Winds of change?*. Eurobarometer 73.1.

Gaskell, G., Stares, S., Allansdottir, A., Allum, N., Corchero, C., Fischler, C., et al. (2006). *Europeans and biotechnology in 2005: Patterns and trends*. Eurobarometer 64.3.

Gold, M. R., Stevenson, D., & Fryback, D. G. (2002). HALYS and QALYS and DALYS, Oh My: similarities and differences in summary measures of population health. *Annual Review of Public Health, 23*, 115–134.

Gonzalez, C., Johnson, N., & Qaim, M. (2009). Consumer acceptance of second-generation GM foods: the case of biofortified Cassava in the North-East of Brazil. *Journal of Agricultural Economics, 60*, 604–624.

Grosse, S. D., Teutsch, S. M., & Haddix, A. C. (2007). Lessons from cost-effectiveness research for United States public health policy. *Annual Review of Public Health, 28*, 365–391.

Hall, C., Moran, D., & Allcroft, D. (2006). Valuing perceived risk of genetically modified food: a meta-analysis. In D. Pearce (Ed.), *Environmental valuation in developed countries: Case studies* (pp. 97–131). Cheltenham, UK: Edward Elgar Publishing.

Han, J. H., & Harrison, R. W. (2006). Consumer valuation of the second generation of genetically modified (GM) foods with benefits disclosure. In *Southern Agricultural Economics Association Annual Meeting. Orlando, Florida, February 5–8, 2006*.

Hanemann, W. M. (1984). Welfare evaluations in contingent valuation experiments with discrete responses. *American Journal of Agricultural Economics, 66*, 332–341.

Hanemann, W. M., & Kanninen, B. J. (1999). The statistical analysis of discrete-response data. In I. Bateman, & K. Willis (Eds.), *Valuing environmental preferences: Theory and practice of the contingent valuation method in the U.S., E.C. and developing countries*. New York: Oxford University Press.

Hanley, N., Shogren, J., & White, B. (2006). *Introduction to environmental economics*. Oxford: Oxford University Press.

Hasler, C. M. (2002). Functional foods: benefits, concerns and challenges—a position paper from the American Council on Science and Health. *The Journal of Nutrition, 132*, 3772–3781.

Ho, P., Vermeer, E., & Zhao, J. (2006). Biotechnology and food safety in China: consumer's acceptance or resistance? *Development and Change, 37*, 227–254.

Hoban, T. (1998). Trends in consumer attitudes about agricultural biotechnology. *AgBioForum, 1*, 3–7.

Hoffman, E., Menkhaus, D., Chakravarti, D., Field, R., & Whipple, G. (1993). Using laboratory experimental auctions in marketing research: a case study of new packaging for fresh beef. *Marketing Science, 12*, 318–338.

Horowitz, J. K., & McConnell, K. E. (2002). A review of WTA/WTP studies. *Journal of Environmental Economics and Management, 44*, 426–447.
Hossain, F., Onyango, B., Schilling, B., Hallman, W., & Adelaja, A. (2003). Product attributes consumer benefits and public approval of genetically modified foods. *International Journal of Consumer Studies, 27*, 353–365.
House, L. O., Lusk, J. L., Jaeger, S. R., Traill, W. B., Moore, M., Valli, C., et al. (2004). Objective and subjective Knowledge: impacts on consumer demand for genetically modified foods in the United States and the European Union. *AgBioForum, 7*.
Huang, J., Qiu, H., Bai, J., & Pray, C. (2006). Awareness, acceptance of and willingness to buy genetically modified foods in Urban China. *Appetite, 46*, 144–151.
Huffman, W., Rousu, M., Shogren, J., & Tegene, A. (2007). The effects of prior beliefs and learning on consumers' acceptance of genetically modified foods. *Journal of Economic Behavior & Organization, 63*, 193–206.
James, C. (2012). *Global status of commercialized Biotech/GM crops: 2012*. ISAAA Brief No. 44. Ithaca, NY: ISAAA.
Jan, M.-S., Fu, T.-T., & Huang, C. (2007). A Conjoint/Logit analysis of consumers' responses to genetically modified Tofu in Taiwan. *Journal of Agricultural Economics, 58*, 330–347.
Johannesson, M. (1995). The relationship between cost-effectiveness analysis and cost-benefit analysis. *Social Science and Medicine, 41*, 483–489.
Kassardjian, E., Gamble, J., & Gunson, A. (2005). New approach to Elicit consumers' willingness to purchase genetically modified apples. *British Food Journal, 107*, 541–555.
Kaye-Blake, W., O'Connell, A., & Lamb, C. (2007). Potential market segments for genetically modified food: results from cluster analysis. *Agribusiness, 23*, 567–582.
Kikulwe, E., Wesseler, J., & Falck-Zepeda, J. (2008). *Introducing a genetically modified banana in Uganda: Social benefits, costs, and consumer perceptions*. Washington, DC: International Food Policy Research Institute (IFPRI).
Kontoleon, A., & Yabe, M. (2006). Market segmentation analysis of preferences for GM derived animal foods in the UK. *Journal of Agricultural & Food Industrial Organization, 4*, 1–36.
Lähteenmäki, L., Grunert, K., Ueland, Ø., Astrom, A., Arvola, A., & Bech-Larsen, T. (2002). Acceptability of genetically modified cheese presented as real product alternative. *Food Quality and Preference, 13*, 523–533.
Lancaster, K. (1966). A new approach to consumer theory. *Journal of Political Economy, 74*, 132–157.
Langford, I. H., & Bateman, I. J. (1993). *Welfare measures for contingent valuation studies: Estimation and reliability*. Global Environmental Change Working Paper 93–04. Centre for Social and Economic Research on the Global Environment: University College London.
Laxminarayan, R., Chow, J., & Shahid-Salles, S. A. (2006). Intervention cost-effectiveness: overview of main messages. In D. T. Jamison, J. G. Breman, A. R. Measham, G. Alleyne, M. Claeson, D. B. J. Evans, et al. (Eds.), *Disease control priorities in developing countries* (2nd ed.). (pp. 35–86). New York: Oxford University Press.
Li, Q., Curtis, K., McCluskey, J., & Wahl, T. (2002). Consumer attitudes toward genetically modified foods in Beijing, China. *AgBioForum, 5*, 145–152.
Li, Q., Wahl, T., & McCluskey, J. (2003). Segmenting consumer preferences toward GM Foods: implications for China's food culture. In *WCC-101 Annual Meeting 'Agribusiness & Food Marketing in China' Proceedings. Portland, OR: WCC-101*.
List, J. A. (2002). Preference reversals of a different kind: the 'More is less' phenomenon. *American Economic Review, 92*, 1636–1643.
List, J. A., & Gallet, C. A. (2001). What experimental protocol influence disparities between actual and hypothetical stated values? Evidence from a meta-analysis. *Environmental and Resource Economics, 20*, 241–254.
List, J. A., & Shogren, J. F. (1999). Price information and bidding behavior in repeated second-price auctions. *American Journal of Agricultural Economics, 81*, 942–949.
Loomis, J. (2011). What's to know about hypothetical bias in stated preference valuation studies? *Journal of Economic Surveys, 25*, 363–370.
Loureiro, M., Umberger, W. J., & Hine, S. (2003). Testing the initial endowment effect in experimental auctions. *Applied Economics Letters, 10*, 271–275.
Lusk, J. L. (2003). Effects of cheap talk on consumer willingness-to-pay for Golden Rice. *American Journal of Agricultural Economics, 85*, 840–856.
Lusk, J. L. (2011). Consumer preferences for genetically modified food. *Frontiers of Economics and Globalization, 10*, 243–262.
Lusk, J. L., Feldkamp, T., & Schroeder, T. C. (2004). Experimental auction procedure: impact on valuation of quality differentiated goods. *American Journal of Agricultural Economics*, 389–405.
Lusk, J. L., Fox, J. A., Schroeder, T. C., Mintert, J., & Koohmaraie, M. (2001). In-store valuation of steak tenderness. *American Journal of Agricultural Economics, 83*, 539–550.
Lusk, J. L., & Hudson, D. (2004). Willingness-to-pay estimates and their relevance to agribusiness decision making. *Review of Agricultural Economics, 26*, 152–169.
Lusk, J. L., Jamal, M., Kurlander, L., Roucan, M., & Taulman, L. (2005). A meta-analysis of genetically modified food valuation studies. *Journal of Agricultural and Resource Economics, 30*, 28–44.
Lusk, J. L., & Shogren, J. F. (2007). *Experimental auctions: Methods and applications in economic and marketing research*. Cambridge: Cambridge University Press.
Martin, C. (2013). The interface between plant metabolic engineering and human health. *Current Opinion in Biotechnology, 24*, 344–353.
Meenakshi, J. V., Johnson, N., Manyong, V., De Groote, H., Javelosa, J., Yanggen, D., et al. (2010). How cost-effective is biofortification in combating micronutrient malnutrition? An ex-ante assessment. *World Development, 38*, 64–75.
Moerbeek, H., & Casimir, G. (2005). Gender differences in consumers' acceptance of genetically modified foods. *International Journal of Consumer Studies, 29*, 308–318.
Murray, C., & Lopez, A. (1996). *The global burden of disease*. Cambridge: Harvard University.
Musgrove, P., & Fox-Rushby, J. (2006). Cost-effectiveness analysis for priority setting. In D. T. Jamison, J. G. Breman, A. R. Measham, G. Alleyne, M. Claeson, D. B. J. Evans, et al. (Eds.), *Disease control priorities in developing countries* (2nd ed.). (pp. 271–285). New York: Oxford University Press.
Naqvi, S., Zhu, C., Farre, G., Ramessar, K., Bassie, L., Breitenbach, J., et al. (2009). Transgenic multivitamin corn through biofortification of endosperm with three vitamins representing three distinct metabolic pathways. *Proceedings of the National Academy of Sciences of the United States of America, 106, 7762–7767*.
Ngorsuraches, S. (2008). Defining types of economic evaluation. *Journal of the Medical Association of Thailand, 91*, 21–27.
O'Conner, E., Cowan, C., Williams, G., O'Connell, J., & Boland, M. (2005). Acceptance by Irish consumers of a hypothetical GM dairy spread that reduces cholesterol. *British Food Journal, 107*, 361–380.
Onyango, B. M., Govindasamy, R., Hallman, W., Jang, H. M., & Puduri, V. S. (2006). Consumer acceptance of genetically modified foods in South Korea: factor and cluster analysis. *Journal of Agribusiness, 1*, 61–78.

Paine, J. A., Shipton, C. A., Chaggar, S., Howells, R. M., Kennedy, M. J., Vernon, G., et al. (2005). Improving the nutritional value of Golden Rice through increased pro-vitamin A content. *Nature Biotechnology, 23*, 482–487.
Parkhurst, G., Shogren, J., & Dickinson, D. (2004). Negative values in Vickrey auctions. *Journal of Agricultural Economics, 86*, 222–235.
Pearce, D., & Özdemiroglu, E. (2002). *Economic valuation with stated preference techniques: Summary guide*. London: Department for Transport, Local Government and the Regions.
Plott, C. R., & Zeiler, K. (2005). The willingness to pay – willingness to accept Gap, the 'Endowment effect', subject misconceptions and experimental procedures for eliciting valuations. *American Economic Review, 95*, 530–545.
Pope, N., Voges, K., Brown, M., & Forrest, E. (2004). Consumer attitudes towards genetically modified foods: development of a multidimensional scale. In *ANZMAC 2004. Wellington, New Zealand*.
Pray, C. E., & Huang, J. (2007). Biofortification for China: political responses to food fortification and GM technology, interest groups, and possible strategies. *AgBioForum, 10*, 161–169.
Qaim, M. (2009). The economics of genetically modified crops. *Annual Review of Resource Economics, 1*, 665–693.
Radas, S., Teisl, M. F., & Roe, B. (2008). An open mind wants more: opinion strength and the desire for genetically modified food labeling policy. *Journal of Consumer Affairs, 42*, 335–361.
Raney, T. (2006). Economic impact of transgenic crops in developing countries. *Current Opinion in Biotechnology, 17*, 174–178.
Ren, A., Zhang, L., Hao, L., Li, Z., Tian, Y., & Li, Z. (2007). Comparison of blood folate levels among pregnant Chinese women in areas with high and low prevalence of neural tube defects. *Public Health Nutrition, 10*, 762–768.
Rimal, A., Moon, W., & Balasubramanian, S. K. (2007). Labelling genetically modified food products: consumers' concern in the United Kingdom. *International Journal of Consumer Studies, 31*.
Rodríguez-Entrena, M., & Salazar-Ordóñez, M. (2013). Influence of scientific–technical literacy on consumers' behavioural intentions regarding new food. *Appetite, 60*, 193–202.
Roosen, J., Thiele, S., & Hansen, K. (2005). Food risk perceptions by different consumer groups in Germany. *Acta Agriculturae Scandinavica Section C-economy*, 13–26.
Rousu, M. C., Huffman, W. E., Shogren, J. F., & Tegene, A. (2004). Estimating the public value of conflicting information: the case of genetically modified foods. *Land Economics, 80*, 125–135.
Saher, M., Lindeman, M., & Hursti, U.-K. K. (2006). Attitudes towards genetically modified and organic foods. *Appetite, 46*, 324–331.
Sassi, F. (2006). Calculating QALYs, comparing QALY and DALY calculations. *Health Policy and Planning, 21*, 402–408.
Schnettler, B., Sepulveda, O., & Ruiz, D. (2008). Differentiated acceptance of transgenic foods of animal and vegetable origin in the region of La Araucania, Chile. *Ciencia e investigación agraria, 35*, 169–180.
Shogren, J. F., Cho, S., Koo, C., List, J. A., Park, C., Polo, P., et al. (2001). Auction mechanisms and the measurement of WTP and WTA. *Resource and Energy Economics, 23*, 97–100.
Siegrist, M. (2008). Factors influencing public acceptance of innovative food technologies and products. *Trends in Food Science & Technology, 19*, 603–608.
Siegrist, M., Cvetkovich, G., & Roth, C. (2000). Salient value similarity, social trust, and risk/benefit perception. *Risk Analysis, 20*, 353–362.
Silk, K. J., Weiner, J., & Parrott, R. L. (2005). Gene cuisine or frankenfood? The theory of reasoned action as an audience segmentation strategy for messages about genetically modified foods. *Journal of Health Communication, 10*, 751–767.
Siro, I., Kapolna, E., Kapolna, B., & Lugasi, A. (2008). Functional food. Product development, marketing and consumer acceptance—a review. *Appetite, 51*, 456–467.
Stein, A. J., Meenakshi, J. V., Quinlivan, E., Nestel, P., Sachdev, H. P. S., & Bhutta, Z. A. (2005). Analyzing the health benefits of biofortified staple crops by means of the disability-adjusted life years approach: a handbook focusing on iron, zinc and Vitamin A. HarvestPlus Technical Monograph 4 *HarvestPlus technical monograph 4* (pp. 32). Washington, D.C: International Food Policy Research Institute.
Stein, A. J., Sachdev, H. P. S., & Qaim, M. (2006). Potential impact and cost-effectiveness of Golden Rice. *Nature Biotechnology, 24*, 1200–1201.
Stevens, R., & Winter-Nelson, A. (2008). Consumer acceptance of provitamin A-biofortified maize in Maputo, Mozambique. *Food Policy, 33*, 341–351.
Storozhenko, S., De Brouwer, V., Volckaert, M., Navarrete, O., Blancquaert, D., Zhang, G.-F., et al. (2007). Folate fortification of rice by metabolic engineering. *Nature Biotechnology, 25*, 1277–1279.
Tan-Torres Edejer, T., Baltussen, R., Adam, T., Hutubessy, R., Acharya, A., Evans, D. B., et al. (2003). In *Making choices in health: WHO guide to cost-effectiveness analysis*. Geneva: World Health Organization.
Tenbült, P., De Vries, N., Dreezens, E., & Martijn, C. (2005). Perceived naturalness and acceptance of genetically modified food. *Appetite, 45*, 47–50.
Traill, W. B., Jaeger, S. R., Yee, W. M. S., Valli, C., House, L. O., Lusk, J. L., et al. (2004). Categories of GM risk-benefit perceptions and their antecedents. *AgBioForum, 7*, 176–186.
Umberger, W. J., & Feuz, D. M. (2004). The usefulness of experimental auctions in determining consumers' willingness to pay for quality differentiated products. *Review of Agricultural Economics, 26*, 170–185.
UN, EC, IMF, OECD, & World Bank. (2005). *Handbook of National Accounting: Integrated environmental and economic accounting 2003, studies in methods*. Series F, No.61, Rev.1, Glossary. New York: United Nations.
Venkatachalam, L. (2004). The contingent valuation method: a review. *Environmental Impact Assessment Review, 24*, 89–124.
Verdurme, A., Gellynck, X., & Viaene, J. (2003a). Consumers and new technologies: the case of GM food. *International Journal of Biotechnology, 5*, 439–453.
Verdurme, A., & Viaene, J. (2001). Consumer attitudes towards GM food: literature review and recommendations for effective communication. *Journal of International Food & Agribusiness Marketing, 13*, 77–98.
Verdurme, A., & Viaene, J. (2003). Consumer beliefs and attitude towards genetically modified food: basis for segmentation and implications for communication. *Agribusiness, 19*, 91–113.
Verdurme, A., Viaene, J., & Gellynck, X. (2003b). Consumer acceptance of GM food: a basis for segmentation. *International Journal of Biotechnology, 5*, 58–75.
Vermeulen, H., Kirsten, J., Doyer, T., & Schönfeldt, H. (2005). Attitudes and acceptance of South African urban consumers towards genetically modified white maize. *Agrekon, 44*, 118–137.
Wang, Y., & Johnston, S. (2007). The status of GM rice R&D in China. *Nature Biotechnology, 25*, 717–718.
WHO. (2000). *Considerations in evaluating the cost-effectiveness of environmental health interventions*. Geneva: WHO.
WHO. (2001). *Macroeconomics and health: Investing in health for economic development*. Report of the Commission on Macroeconomics and Health. Geneva: World Health Organization.
Willan, A. R., O'Brien, B. J., & Leyva, R. A. (2001). Cost-effectiveness analysis when the WTA is greater than the WTP. *Statistics in Medicine, 20*, 3251–3259.

World Bank. (1993). *World Development Report 1993*. New York: Oxford University Press.
World Bank. (1994). *Enriching lives: Overcoming vitamin and Mineral malnutrition in developing countries*. Washington, DC: World Bank.
Yee, W., Traill, W., Lusk, J., Jaeger, S., House, L., & Moore, M. (2008). Determinants of consumer's willingness to accept GM foods. *International Journal of Biotechnology, 10*, 240–259.
Zhang, X., Huang, J., Qiu, H., & Huang, Z. (2010). A consumer segmentation study with regards to genetically modified food in urban China. *Food Policy, 35*, 456–462.
Zimmermann, R., & Qaim, M. (2004). Potential health benefits of Golden Rice: a Philippine case study. *Food Policy, 29*, 147–168.