Food Policy 79 (2018) 132–140

Contents lists available at ScienceDirect

Food Policy

journal homepage: www.elsevier.com/locate/foodpol

Farmers' valuation of transgenic biofortified sorghum for nutritional improvement in Burkina Faso: A latent class approach

Obi Chinedu[a,b], Edouard Sanou[b], Juan Tur-Cardona[b], Fabio Bartolini[a], Godelieve Gheysen[c], Stijn Speelman[b,*]

[a] Department of Food, Agriculture and Environment, University of Pisa, Via S. Michele degli Scalzi, 2, 56124 Pisa, PI, Italy
[b] Department of Agricultural Economics, Ghent University, Coupure links 653, 9000 Gent, Belgium
[c] Department of Biotechnology, Ghent University, Coupure links 653, 9000 Gent, Belgium

ARTICLE INFO

Keywords:
Farmers
Transgenic biofortified sorghum
Micronutrient malnutrition
Choice experiment
Latent class model

ABSTRACT

Micronutrient malnutrition has been a challenge in Burkina Faso for many years, where it has led to worsening food security situation. Vitamin, iron and zinc deficiencies affects 1 in 4 persons in the country and is responsible for early child nutritional disorder. The high prevalence of micronutrient malnutrition may be attributed to the dominant role in the diet of local sorghum varieties, deficient in essential micronutrients. To address this issue Africa Harvest is developing a biofortified sorghum variety. However the success of this innovation with farmers will depend on numerous factors such as product attributes, previous experience and socioeconomic factors. In this study, we applied a choice experiment to investigate the farmers' valuation of various sorghum seed attributes as well as to identify the factors that influence the farmers valuation. Our results show that there is a market for transgenic biofortified food in the country and thus that it could be a veritable instrument for reducing micronutrient malnutrition problems. We found that farmers are willing to pay more for biofortified sorghum, particularly if it also scores better on other attributes than the local varieties. Furthermore, we showed that those that have experience with the first-generation genetic modified crop (Bt cotton), are more likely to adopt the second-generation crop (biofortified sorghum). Given the importance of the other attributes and the heterogeneous preferences it is key to involve farmers in the development of the new product.

1. Introduction

Micronutrient malnutrition (MNM) is an important contributor to the global burden of diseases (International Food Policy Research Institute, IFPRI, 2016). It has been a challenge in Burkina Faso for many years, where it has led to worsening food security situation (World Food Programme, 2017). MNM in form of vitamin, iron and zinc deficiencies affects 1 in 4 persons in the country (FAO, 2014). A UNICEF report showed that while 34% of the country's population are chronically malnourished, above 10% suffers from acute malnutrition (UNICEF, 2013). Furthermore, another report showed that Burkina Faso has a very high level of infant mortality rate, averaging at 129 per 1000 livebirth, with 34.6% of children being stunted and 25.7% underweight (IFPRI, 2015).

The high prevalence of MNM in Burkina Faso may be attributed to its location in an arid region where the climatic and soil conditions are unfavourable for sustainable cultivation of highly nutritious food (Li et al., 2012; Miller and Welch, 2013; Obi et al., 2017). For instance, it was found that the local sorghum cultivar, the most important staple crop, is deficient in essential micronutrients (da Silva et al., 2011; Paiva et al., 2017; Traore and Stroosnijder, 2005). Therefore, by continuously consuming this starchy crop, the nutritional needs of the rural poor are not met.

The initiative to improve the nutritive content of the local sorghum cultivar through biotechnology was taken by Africa Harvest International (AHI) in 2001. The project was funded under the Grand Challenges in Global Health initiative by the Bill and Melinda Gates Foundation. The resulting African Biofortified Sorghum (ABS) would contain increased levels of vitamin A, Iron, and Zinc (AHBFI, 2007).

Nevertheless, for a new biofortified crop to achieve success in reducing the problem of MNM in the country, it must be highly valued by the rural poor. This can only be possible, however, if the dissuading factors are eliminated. First, transgenic biofortification as the second generation of genetic modification (GM) projects is still in its early stage of development (De Steur et al., 2017), yet it is mired with strong controversies. These controversies may play an important role in the

* Corresponding author.
E-mail address: stijn.speelman@ugent.be (S. Speelman).

https://doi.org/10.1016/j.foodpol.2018.06.006
Received 24 October 2017; Received in revised form 25 May 2018; Accepted 21 June 2018
Available online 28 June 2018
0306-9192/

adoption decision of farmers (Adenle et al., 2013). Second, biofortification in general tends to alter the sensory attributes of crops such as taste, fragrance and colour (De Groote et al., 2014). These changes have been found to deter the acceptance of non-transgenic biofortified crops in many developing countries (Banerji et al., 2016; De Steur et al., 2012).

In Burkina Faso, aside from the GM controversies and the possible changes in product attributes, the local food culture is another factor that can play a role in the farmers' adoption. In earlier attempts to introduce improved sorghum varieties with better agronomic attributes, studies have shown that the farmers kept preferring their local sorghum cultivar (Adesina and Baidu-Forson, 1995; Olembo et al., 2010). Issues relating to perceived superiority of the attributes of local cultivars, penchant to seed saving culture, and transaction costs were identified. Although a noticeable adoption level was later reported, thanks to the introduction of the participatory sorghum breeding project. Nonetheless, the recorded improvement is only pronounced in the project areas whereas adoption of improved varieties at the national level is still as low as 3–5% (CIRAD, 2016).

The new transgenic biofortified variety is being produced to provide an additional nutritive attribute that is not available in either the improved variety nor the local varieties. Following Saltzman et al. (2013), we hypothesize that farmers will not only consider the nutritive value of the biofortified variety, but also the agronomic and economic attributes when making adoption decision. Therefore, the objective of this research is to determine the market potential of the transgenic biofortified sorghum in the country. To achieve this, we estimated the farmers' valuation, or rather the welfare drawn from hypothetical attributes of the biofortified variety. Furthermore, we examined how their socioeconomic characteristics, experiences, local practices, and motivations influence their valuation of the new variety, and calculated the farmers willingness to pay for attribute changes.

The study contributes to the existing literature in market potential of transgenic biofortified crop in twofold. First, the Discrete Choice Experiment (DCE) methodology used in the study is quite unique. Most ex ante studies conducted on farmers' choice for transgenic crops use contingent valuation presenting a dichotomous choice between a transgenic variety and a non-transgenic variety (Hubbell et al., 2002; Krishna and Qaim, 2007; Qaim and de Janvry, 2003). This method has been subjected to criticisms in terms of its ability to deliver reliable and accurate estimates (Mogas et al., 2006). For instance, Hanley et al. (2001) observed that the approach is not suitable to deal with cases where attributes valuations are multidimensional. Furthermore, compared to other related DCE studies which used multinomial logit model (Birol et al., 2007; Breustedt et al., 2008; Schreiner, 2014), our study is different because it accounts for farmers' preference heterogeneity.

Different models of DCE that can account for unobserved heterogeneity as well as potential source of variabilities in decision makers' preference have been contrasted by Greene and Hensher (2003). Considering the three possible alternatives (parametric mixed logit model, random parameter latent class model, and the semi-parametric latent class model), Kikulwe et al. (2011) posited that when the objective is to segment a population based on the welfare derived from a new technology, a semi-parametric latent class model (LCM) is most relevant from a policy perspective. Therefore, by using this LCM, we were able integrate a wide spectrum of product alternatives and covariate parameters that segmented our respondents based on homogeneous characteristics within, and heterogeneous across. Segmentation is a very useful marketing strategy to identify different categories of farmers and how they value a product.

Secondly, the addition of the seed source attribute to the DCE is innovative. Arguments have been put forward on how the source of transgenic seeds and their distribution conditions influence farmers' adoption. For example, while Mabaya et al. (2015) stated that the potential of transgenic crops to improve nutritional security in Sub-Saharan Africa (SSA) depends to a large extent on the farmers' access to the seed, Andekelile and Leon (2016) added that the conditions on which seeds are distributed are vital, and should harmonise with farmers' experience and practices. Seed saving practice might lead to low adoption of new transgenic crop varieties, specifically if new seeds are protected by intellectual property rights and seed reuse restriction conditions applies (Black et al., 2010). Furthermore, when the rural poor farmers are obliged to purchase the transgenic seeds every planting season, the traditional seed exchange behaviours may be disturbed, thereby greatly affecting the market of transgenic seeds (Azadi et al., 2015; Garcia-Yi et al., 2014). While these arguments have always resurfaced in many GM debates, the degree to which the seed source and distribution conditions influences farmer's preference for transgenic biofortified seeds was never captured in a DCE.

The rest of the paper is structured as follow: in Section 2, the Choice experiment method is presented, starting with the theoretical framework. This is followed by the description of the choice experiment design and data sampling method. The results and discussions come afterwards in Section 3, then the conclusion and recommendations follow in Section 4.

2. Choice experiment method

2.1. Theoretical framework

Choice models are based on the theory of individual choice behaviour which captures the farmers' preference for attributes that make up a product (Louviere et al., 2008). It has its theoretical origin in Lancaster's' model of consumer choice (Lancaster, 1966), and the theory of Random Utility. Lancaster stated that satisfaction will be obtained from the attributes of a product rather from the product itself, while Random utility observed people to be rational and as such, when presented with two or more options, they would likely decide in favour of the one providing them with higher utility. To elicit the preference of an individual from a set of alternatives, a DCE is often applied. As a stated preference elicitation method, DCE is appropriate when a product is new and/or not yet commercially available (Louviere et al., 2000; Lindsay et al., 2009). Unlike the revealed preference method, stated preference methods give the researcher the room to include hypothetical attributes which might not be available in alternative products that are already in the market.

The LCM is one of the econometric models that can be used to analyse DCE data The LCM simultaneously identifies subgroups having homogenous preferences for an attribute and the characteristics which these groups have in common. It assumes that individuals reside in 'latent' classes which are unknown to the analyst, with each class having a homogenous preference structure. Classes, otherwise referred as segments in this article, are often determined by the socio-economic characteristics of the respondents and choice of product attribute. In related literature on transgenic crop market research, a LCM was applied by Birol et al. (2011), Kikulwe et al. (2011) and Birol et al. (2007). In the latter two studies, motivational questions concerning farmers' knowledge, perception and attitude towards the transgenic food were included to segment membership structure. It was observed in all the studies that a significant heterogeneity exists in respondents' preference for transgenic foods. The result is particularly important in market segregation and targeting. For instance, in Uganda, Kikulwe et al. (2011) observed that the biofortified banana should be a pro-poor programme targeting rural farmers. Therefore, by applying LCM in our study, we can provide relevant information to policy makers and product developers for product development and marketing strategy.

Following the econometric model specification proposed by Greene and Hensher (2003), before the LCM, a Conditional Logit (CL) may first be specified. While the CL presents a holistic preference of all respondents, the LCM gives a segmented preference structure. The general econometric model consists of parameterized utility functions $U_{nij/s}$ in terms of observable independent variables $\beta_s X_{nij}$ and unknown parameters or Error components $\varepsilon_{nij/s}$ as shown below.

$$U_{nij/s} = \beta_s X_{nij} + \varepsilon_{nij/s} \quad (1)$$

Simply put, $U_{nij/s}$ is the utility that a farmer *n,* who belongs to a segment *s* derives from the selection of alternative *i* in the choice set *j*. The β is the segment-specific parameter vector which encompasses first, the choice parameter, and second the socio-economic and motivational parameter vectors. While *X* is the vector of attributes, ε is the error component. The inclusion of the error component implies that researchers can only predict with some level of uncertainty the choice of the respondent; therefore, it is assumed that choices made among the alternatives will be a function of the probability that the satisfaction associated with the selected option is higher than that of the alternatives not selected. Nevertheless, for this probability function to be accurate, the error term must be identical, independently distributed and follow a Type 1 or Gumbel distribution (Rungie et al., 2011). If this is the case, the conditional probability that the farmer *n*, belonging to segment *s*, selects the alternative *i* in the choice set *j* is given as

$$P_{nit/s} = \frac{\exp(\beta_s X_{nij})}{\sum_{i=1}^{I} \exp(\beta_s X_{nij})} \quad (2)$$

And the probability that the farmer belongs to the segment is expressed as:

$$P_{ns} = \frac{\exp(\alpha_s \theta_n)}{\sum_{s=1}^{S} \exp(\alpha_s \theta_n)} \quad (3)$$

where α_s is the segment-specific parameter vector to be estimated (i.e. the characteristics of the farmer that contributes to the membership of a segment) and θ_n is the individual specific variable (attributes of the product). Therefore, the probability that the farmer chooses an alternative is the conditional joint probability from Eqs. (2) and (3), as specified below as

$$P_{ni} = \sum_{s=1}^{S} \left(\frac{\exp(\alpha_s \theta_n)}{\sum_{s=1}^{S} \exp(\alpha_s \theta_n)} \right) \prod_{j=1}^{J} \left(\frac{\exp(\beta_s X_{nij})}{\sum_{i=1}^{I} \exp(\beta_s X_{nij})} \right) \quad (4)$$

By including the seed cost attribute, it is possible to calculate the farmers' valuation or willingness to pay (WTP) for product attribute changes. This is done by dividing the non-price attribute with the seed price attribute, as specified below

$$WTP = \frac{\beta_k}{(-)\beta_c} \quad (5)$$

where β_k is the coefficient of a non-seed price attribute, and β_c is the coefficient of the seed price attribute. In determining the farmers' valuation or welfare measure, attributes presented in quantitative form are compared with another quantitative attribute. A similar process is used for qualitative attributes. By so doing, the valuation that farmers attach to the attributes can be compared between the segments identified in the LCM.

2.2. The choice experiment design

The different stages in the design of the choice experiment are well-elaborated by various researchers (Hanley et al., 2001; Hoyos, 2010; Lindsay et al., 2009). The first stage of DCE is to select the relevant attributes of the product. Relevant attributes for transgenic biofortified sorghum were identified by combining literature review with experts' opinion. Literature includes previous studies on the adoption of high yielding traditional bred sorghum in Burkina Faso, as well as studies on farmers' perception and adoption decision of transgenic crops in Sub-Saharan Africa (SSA) (Adesina and Baidu-Forson, 1995; Kuwornu et al., 2011; Lacy et al., 2006; Olembo et al., 2010; vom Brocke et al., 2010; Zakaria et al., 2014). The engaged experts include researchers from the AHI consortium, the *Institut National de l'Environnement et de la Recherche Agricole* (INERA) and the Ministry of Agriculture and Food Security in Burkina Faso. The experts were selected based on their knowledge of the ABS project and farming system in Burkina Faso.

During the expert consultation, five attributes were selected reflecting important sorghum characteristics. These include micronutrient, seed price, seed source, yield and maturity date. The use of a limited set of attributes is a fair standard assumption in DCE model as it helps to improve the respondents cognitive ability to complete the experiment (Lindsay et al., 2009). Often, focus groups are organized to define an appropriate set of attributes (Alpizar et al., 2001), but because of the security situation in the country at the time of the design, it was opted to go for individual expert consultations. Finally, pretesting of the CE with some farmers confirmed that the attributes included were relevant.

The second stage is assigning attribute levels. There is no agreed optimal number of level, but the levels assigned must reflect the range of situations that the respondents might expect to experience, and they should be feasible and realistic (Lindsay et al., 2009; Hanley et al., 2001). Literature review, expert consultation, and market surveys were used in the selection. Where quantitative values were used for example in seed price, yield and maturity attributes, the status quo represents the current (or estimated) average value of such attribute. Additional levels were added to this base level as shown in Table 1, and further explained below.

The first attribute "increased micronutrients" refers to the extra micronutrients that could be added to the existing varieties. This attribute is the most important feature of the biofortified sorghum programme, and the major difference from the normal improved varieties. Two levels were suggested: Yes, indicating the presence or No indicating the absence of extra micronutrients. As the transgenic biofortified sorghum has not yet been commercialized, the exact type and level of nutrients to be added is undefined, thereby making qualitative levels the preferred option. More so, although Vitamin A is the target nutrient, the AHI experts that were consulted hinted that other micronutrients are also considered.

The "seed price" attribute is the price of sorghum seed per kg. It is a monetary variable that is relevant in the estimation of the utility derived from the other attributes of the product. Three levels were proposed. The first level 4000 CFA is the current average price of one Kg of the improved sorghum variety in the country. The other levels 5000 CFA and 3000 CFA are relevant estimates proposed by the consulted experts from the Ministry of Agriculture and Food Security. The rational for adding a higher and lower price level is that the AHI may decide to sell the ABS seed for a higher price than the improved variety because of its extra nutrient. A lower price may equally be decided as a market penetration strategy since the farmers are not used to buying seeds in the market.

The "Seed source" attribute describes the sector that manufactures and provides the seed to the farmers. This attribute is added from the backdrop of the argument that farmers in SSA might be less willing to

Table 1
Attributes and levels of attribute for choice experiment.

Attributes	Definitions	Levels
Increased Micronutrients	Whether or not an additional micronutrient is present	Yes, No*
Seed price (CFA)	The amount paid for the purchase of seed per kg	5000, 4000*, 3000
Seed source	The sector responsible for the production and marketing of seed	Private, public*, public-private partnership
Yield (kg)	The expected yield per hectare (kg)	650, 750*, 850, 1000
Days to maturity (days)	Number of days taken for the crop to mature	70, 80*, 95, 110

[*] Represent the baseline level, \$1 = 592 CFA.

	Alt 1	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Micronutrient	Yes	No	No	Yes	I prefer the local sorghum seed	I will totally abandon sorghum production
Seed cost	3000	5000	4000	4000		
Seed Provider	PP	Public	PP	Private		
Yield	650	850	1000	750		
Maturity date	110	80	70	95		

Fig. 1. Example of choice Set. *If an improved Sorghum variety would be introduced, which alternative would you prefer?.*

adopt transgenic crop seeds whose seed provider and conditions are alien to local experience (Andekelile and Leon, 2016; Mabaya et al., 2015; Virgin et al., 2007). Three "seed source" levels (public, public-private partnership and private) were considered in the choice experiment. The public seed sector represents the baseline level, because most improved varieties are developed and marketed by this sector (Azadi et al., 2015). In Burkina Faso, new varieties of sorghum seeds (produced by INERA and other regional public research institutions) are often distributed publicly by the state run seed distribution agency, the certified seed producers, and the local farmers' organization (CIRAD, 2016). The second level, public-private partnership is a development and distribution approach that is jointly organized by public institutions and private seed manufacturing companies. An example of such partnership in Burkina Faso can be observed in the Cotton sector (Sanou et al., 2018). The third level is private. Current involvement of the private sector in development and distribution of sorghum seeds is very low, and the fact sorghum is a subsistence crop and that most of the farmers are poor smallholders makes greater private sector engagement difficult (Smale et al., 2018). Nevertheless private seed companies are active for other field crops and vegetables in Burkina Faso (Diallo, 2018).

The "Yield" attribute is the anticipated yield of the product per hectare. The baseline yield 750 kg/ha was obtained through the consultation with experts in the Ministry of Agriculture and Food security. The study of Lacy et al. (2006) on farmer choice of sorghum varieties in southern Mali gave an insight on the other levels. The yield attribute is important to evaluate the findings of previous research by Adesina and Baidu-Forson (1995) who opined that the yield attribute of sorghum is "barely significant" in farmers adoption of modern sorghum varieties.

The final attribute "Days to Maturity" refers to the number of days taken for the crop to mature. In an arid country, a crop with a shorter maturity period means a higher ability to resist the climatic variations, and it is often preferred. Again, the study of Lacy et al. (2006) was vital in the identification of levels. Four levels were specified with 80 days being the average of sorghum maturity date in the study area.

The third stage in the DCE is designing the choice set. A choice set is a group of hypothetical alternatives constructed through experimental design. Among available alternatives, a fractional factorial design was used for the study. The fractional factorial design generates a sample of the full design in such that the most important effects can be estimated (Lindsay et al., 2009; Alpizar et al., 2001). One advantage of fractional factorial design is that the reduction in the number of choice sets does not lead to a concomitant loss in estimation power (Hanley et al., 2001). The D – efficiency approach of fractional factorial was used to design the experiment with the help of SAS software (Kuhfeld et al., 1994). A D-efficient design tends to greatly reduce the predicted standard errors of the parameter estimate and produce even stronger statistical results (Hoyos, 2010; Rose et al., 2008). The alternatives were not labelled, because it could make the respondents ignore the attributes and concentrate on the labels (Saldias et al., 2016; Doherty et al., 2011). This is particularly a problem in sensitive market research like transgenic food, where a strong attitude exists due to controversies and external influences.

In the choice set, two opt-out alternatives were included. One describing the desire to continue with current sorghum seed, and the other, the intention to abandon sorghum production if a transgenic variety is introduced. The addition of these opt-out alternatives is used to determine the farmers' penchant to the local sorghum cultivar and their attitude towards transgenic crops. The respondents were also asked during the interview about their current yield and their frequency of seed purchase, in a way that their current values for the status quo could be used in the analysis. To avoid that the survey would become too long, the design was blocked into 2 partitions. Blocking helps to promote response efficiency by reducing cognitive effort for each respondent (Johnson et al., 2013). Respondents were randomly assigned to one of the blocks, facing 6 choice sets or situations. A total of 5400 individual choices were obtained for the study (6 alternatives × 6 choice sets × 150 farmers). Fig. 1 presents an example of one of the choice sets.

2.3. Sampling and data collection

The respondents for the research were a subsample of the sample of cotton farmers collected for the project *SOCBIOAfri- Addressing Societal Challenges of Biotechnology in Africa, Towards Balanced Innovation.* This larger dataset contained 324 cotton producing households spread across cotton producer's groups, *Groupement de Producteurs de Coton*, (GPC) in 3 districts of Burkina Faso (Dedougou, Bobo, and Diebougou). Sanou et al. (2018) fully described the sampling method. In summary, the data was collected in the 2015–2016 agricultural season and in the cotton producing area of Western Burkina Faso.

Since it is the tradition in Burkina Faso that most cotton farmers also cultivate sorghum and maize (Sanders, 2016), our sample-frame is a sub-set of the cotton farmers who produce sorghum. The process of selecting these farmers followed a stratified random sampling procedure. We first selected GPCs with at least two sorghum producing member, this is followed by random selection of 2 or 3 sorghum farmers per GPC. Ensuring that a balanced number of respondents were selected per district, and in consideration of the budget constraints, we selected and interviewed only 150 farming households (50 per district) for this research. Farmer' characteristics of this subsample are similar to those of the larger sample of 324 farmers. By being members of cotton producers organization, our respondents are believed to be reasonably informed, have good networks, and possibly among the first groups to adopt the biofortified seeds if released (Zongo et al., 2015).

Although we acknowledge that our sample size is small and may prevent the detection of small effects, it is sufficient to deliver a reliable estimate (de Bekker-Grob et al., 2015). More so, we adopted some techniques to improve the statistical power of our sample size. First, we adopted the D-efficient (optimal) design procedure which is effective in producing a reliable estimate when sample size is small (Hoyos, 2010; Johnson et al., 2013; Rose and Bliemer, 2013). Second, we used unlabelled alternatives as labelling would require a larger sample (Hensher et al., 2005). Thirdly, our sample size is within the range adopted by 41% of DCE studies reviewed by de Bekker-Grob et al. (2015). Finally, it is by far higher than the minimum sample sizes recommended by some researchers. For instance, the 50 by Rose and Bliemer (2013) and the 20 respondents per version in a block experiment by Lancsar and Louviere (2008).

Data was collected from the household head using a structured questionnaire by a trained survey team. The survey was conducted face to face. The individual assessment was adopted due to the sensitivity of the subject matter. In each interview session, the respondents received information on transgenic biofortification and were notified of the ABS project. This was followed with a short description of the experimental setting, clear definitions of the product attributes, how to respond to questions, and assurance of the confidentiality of their response. The survey usually took 30 min per session, covering 3 parts. 1. Information regarding their socio-economic and farm characteristics, 2. A set of motivational questions to ascertain their nutritional knowledge and attitude towards GM crops, and 3. the application of the choice experiment.

2.4. Data analysis

The socio-economic and farm characteristics were evaluated using descriptive statistics like mean and Analysis of Variance (ANOVA). The 17 motivational questions were structured into 5 points Likert scale which ranged from Strongly disagree (1) to Strongly agree (5). To group farmers based on their response to the motivational questions, a principal component analysis (PCA) was conducted. The PCA was used to remove correlation, reduce complexities, and synthetize more relevant factors (or classify variables). The criteria for accepting factor solutions (number of components) were set on a minimum eigenvalue of 1 and factor loadings above 0.30. However, other conditions such as the information on the scree plot, number of variables loaded in each factor, and the theoretical sense of the loadings were also considered. The factor score was used to assign individuals to different components. A positive coefficient indicates a likelihood of possessing the feature explained by the associated component. The coefficient of the factors was obtained using the factor score command in the STATA 13 software.

Finally, the factors obtained from PCA and the explanatory variables included in the socio-economic characteristics were used as class membership parameters in the LCM of the choice experiment.

3. Results and discussions

3.1. Socioeconomic and farm characteristics

Table 2 presents the socioeconomic characteristics of the respondents. From the 150 farm household heads interviewed, 140 (93.3%) were males, and the average age was 44.6 years. The level of education was low, with only 32% having any form of formal education. The mean farm size per household was 8.25 ha from which on average 1.57 ha (19%) was allocated to sorghum production. The average sorghum produced by the respondents was 790 kg/ha per season. Sorghum was the most important food staple reported by 72.7% of the respondents, and most of them (84.7%) cultivate it every season. Sorghum is cultivated mainly for household consumption (91.3%). Most farmers (92.7%) still practice seed saving, but about 60% indicated that the source of their seed did not matter to them. Although, the seed saving practice is a constraint to adoption of new sorghum varieties also reported in previous studies (Adesina & Baidu-Forson, 1995; CIRAD, 2016; Olembo et al., 2010), our study show evidence that this practice can be broken since 60% of the respondents may not be influenced by the source of the seed.

The means of the socioeconomic and farm characteristics of the respondents in the 3 districts were compared using ANOVA. The result shows that there were no significant differences in any of the variables across the three districts.

3.2. Motivational factors

Three components were obtained from the PCA which satisfied the criteria set for selection (Table 3). The first component was labelled 'Knowledgeable farmers'. These consist of the group of farmers (56%) that recorded a high score on questions relating to nutritional knowledge. They showed great understanding of the micronutrient deficiency in the local sorghum cultivars and were aware of the transgenic crops. The second component is labelled 'Risk-averse farmers'. They scored high on questions relating to the risk associated to adopting transgenic biofortified sorghum. They demand more information, affordable price and government approval before they would adopt the new product. About 63.3% of the farmers are risk averse. Finally, the third component is called 'Negative experience'. This factor has high loading on the questions regarding previous experience. The farmers in this group (about 36%) are regularly informed of research on improved sorghum varieties but due to previous bad experience with hybrid varieties introduced to them, are most likely to continue with their local cultivars.

3.3. Result of the latent class model

The LCM was estimated using NLOGIT 5.0. We first specified the product attributes that influence the farmers' choice for biofortified sorghum. Secondly, we specified the socioeconomic characteristics and motivational factors that could determine the class membership. In a first estimation, the CL model was used to assess the overall preference structure of the farmers without considering their personal characteristics. The result of the CL is presented in Table 4. It reveals that all the product attributes included in the model are significant utility

Table 2
Socio-economic and farm characteristics of farmers.

Parameters	Total sample (150)	Bobo (N = 50)	Dedougou (N = 50)	Diebougou (N = 50)
Socioeconomic characteristics				
Gender (% of males)	93.3	94	92	94
Age (average years)	44.6	45.20	44.26	44.44
Education level (% literacy)	32	36	38	42
Sorghum acreage (hectare)	1.59	1.60	1.41	1.77
Total acreage (hectare)	8.25	9.88	8.81	6.07
Total annual yield (kg/ha)	790	801	761	807
Farm characteristics (% of yes)				
Importance of sorghum				
Sorghum as household staple	72.7	74	68	76
Grows sorghum every season	84.7	92	82	80
Purpose of sorghum production				
Consumption only	91.3	94	92	88
Sales only	8.7	6	8	12
Sorghum seed provision				
Save seed for next season	92.7	94	92	92
Sometimes purchase seed from market	6.7	6	10	4
Seed source does not matter	59.3	68	60	50

Table 3
Principal component analysis result (N = 150).

	Motivational statements	Rotated factor loading (Varimax)		
		Knowledgeable (56%)	Risk averse** (63.3%)	Negative experience** (36%)
1	Do you know that the public health studies in Burkina revealed deficiencies in vitamin A, iron and zinc for children under 5 and women?	**0.36**	0.18	−0.06
2	Do you know that these deficiencies can be the cause of certain diseases?	**0.36**	0.18	−0.06
3	Have you (or your family members) already suffered from any deficiency due to a lack of these elements?	0.17	0.14	−0.01
4	Do you know that these nutrients can be enhanced in sorghum?	**0.56**	−0.01	0.03
5	Have you ever heard about bio-fortified sorghum?	**0.44**	−0.11	0.06
6	Do you know that Burkina Faso has subscribed to a local sorghum enrichment programme to fortify sorghum with vitamin A, zinc and iron?	**0.40**	−0.07	0.05
7	Do you think the bio-fortified sorghum programme is welcome?	−0.17	0.14	0.05
8	Do you think it's appropriate to improve the micronutrients in sorghum?	-no loadings		
9	Would you like to learn more about this bio-fortified sorghum programme?	−0.01	−0.26	0.01
10	I am regularly informed of the research on improved varieties	−0.05	0.26	**0.37**
11	I regularly participate in exhibition fairs of research findings	−0.07	0.07	**0.37**
12	I believe bio-fortified sorghum should be better explained to the producers by the relevant authorities	0.01	**0.49**	−0.11
13	The bio-fortified sorghum seed should be available at the same price as the local variety	−0.01	**0.50**	−0.14
14	I prefer to continue with the local variety	0.04	−0.10	**0.56**
15	I will produce bio-fortified sorghum provided the government agrees	−0.08	**0.33**	0.17
16	I have a bad experience with previously improved varieties of sorghum	0.05	−0.09	**0.53**
17	I will produce bio-fortified sorghum if the price is affordable	0.001	**0.35**	0.21
	Eigenvalues	2.92	2.75	2.20
	Accepted factor loadings	> 0.3		

Statements 1: Strongly disagree; 2 Disagree; 3 Neutral; 4 Agree; 5 Strongly agree.
***, **, * = significant at 1%, 5%, 10% level.
Note that the percentage of farmers do not add to 100 because of possibilities of intersection.
Factor loadings above the threshold of 0.30 are indicated in bold.

Table 4
Conditional logit representing utility derived from sorghum attribute.

Utility parameter	Coefficient	Standard error
Increased Micronutrients	3.3835***	0.1685
Seed price	−0.0008***	0.0006
Public seed source[1]	0.7164***	0.1088
Private seed source[1]	−0.6964***	0.1419
Yield	0.0069***	0.0004
Days to maturity	−0.0333***	0.0032
Probability of selecting an opt out alternative		
Alt 5: Preference for local seed	27%	
Alt 6: Abandon (GM) sorghum	0%	

[1] Compared to public-private partnership.
***, **, * = significant at 1%, 5%, 10% level.

parameters considered by the farmers in their choice decision. This, therefore, suggests that the farmers consider many attributes and often compare them before making decisions. For instance, compared to the seed source, the addition of micronutrients returns a higher utility for the farmers. It has a positive and very high significant effect on farmers' utility. Preference for the seed providers shows that farmers will favour in the first instance a public-sector seed source, before public-private partnerships, and a private sector. This is in line with earlier studies that the seed sector matters for transgenic crop adoption in SSA (Mabaya et al., 2015; Mabaya, 2015).

Farmers also made valuation on the maturity period, yield and seed cost. The expected days of maturity of sorghum have a negative and significant relationship with the farmers' choice. The negative coefficient is in line with the expectation that farmers would likely adopt a sorghum cultivar that is early maturing. Drought is arguable the major environmental challenge facing sorghum farmers in Burkina Faso, therefore, an early maturing attribute would be a high incentive to adopt the new biofortified seeds. The utility parameter of yield is positive and highly significant, indicating that the farmers have a clear preference for high yielding seeds. A positive but barely significant preference for yield has been reported for Burkina sorghum farmers by Adesina and Baidu-Forson (1995). Ascribing a higher utility for sorghum yield is expected. This is because the demand of food generally has increased, because of the increased population. While the poverty level is high with the poorest farmers not being able to purchase cereals, it is, therefore, plausible for farmers to prefer high yielding sorghum seed. Finally, the seed price attribute is negative and significant, indicating a preference for seed varieties with a lower cost. This is in line with economic theory and is expected because the majority of farmers in the study area practice seed saving, and those that purchase seed accessed it mostly from government agencies at lower price. Nevertheless, we can infer that the new biofortified variety may be able to compete with the local and improved variety if it is provided through a market penetration pricing strategy.

The second part of Table 4 shows the probabilities of selecting the opt-out alternatives. The result shows that on average, 27% of the farmers would prefer the local seed against the new variety. More so, with a 0% preference for alternative 6, we can assert that on average, 73% of the farmers sampled in our study may be willing to adopt a biofortified variety. CIRAD (2016) equally reported a 75% adoption for improved sorghum varieties in villages selected for the participatory sorghum breeding project in Burkina Faso. When we combine this result with our previous finding that 60% of farmers are indifferent to the source of their seed, we can confidently argue in line with Grabowski et al. (2016) that small scale farmers in Burkina Faso are not stuck in traditions, but compare the value of new technology with existing alternatives before making adoption decision.

3.4. Socio-economic and motivational factors influencing farmers valuation

Although the result from the CL model is useful in determining the farmers' valuation of the new sorghum attributes, it does not however reflect the heterogeneity of preferences among respondents. The CL assumption that the utility is homogenous across all the farmers might

Table 5
Information criteria for determining the optimal number of class.

No. of segment	Parameters	Log likelihood	P^2	AIC	BIC
1	6	−878.8	0.3772	1769	1798
2	17	−795.3	0.5068	1617	1679
3	26	−742.9	0.5393	1537	1663
4	27	−764.1	0.5262	1582	1712

not be true in our study. The LCM provides evidence for systematic heterogeneity in the preference structure of the sorghum farmers. To estimate this heterogeneity, the LCM was run several times with increasing number of segments and different combinations of segment membership variables. To identify the optimal number of segments, a balanced assessment of the Log-likelihood function, Akaike Information Criteria (AIC), Bayesian Information Criteria (BIC), and the Mcfadden pseudo squared (P^2) were considered following Kikulwe et al. (2011) and Birol et al. (2007).

Considering the information criteria in Table 5, the log-likelihood improved and P^2 increased as more parameters were added until they maximized in a model with 3 segments. This implied an optimization at this number of segments. To confirm this, the AIC and BIC decreased from the first segment but were minimized at 3. Therefore, a three-segment model was selected. The best fitting LCM included the following variables in the membership function: the farmers' attitude towards risk, the sorghum yield of farmers; and whether farmers save seed or not. Finally, a comparative summary statistic of the features of the segments was obtained. The segment probabilities of individual respondents were used to assign farmers to a given segment. A respondent is assigned to the segment where he scores the highest probability.

In the 3 segments model presented in Table 6, 31.2% of the respondents belong to segment 1, 14.1% to segment 2 and 54.7% belong to segment 3. The segment 3 is the reference, so the coefficients are normalized to zero to allow a comparative interpretation. The first part of the table presents the coefficients for the seed attributes, while the second part shows the class membership function. The third part is the description of individuals in the segment.

For segment 1, the utility coefficients reveal that farmers belonging to this segment have preference for sorghum seed with more micronutrients, lower price and higher yields. In terms of seed source, a higher preference is found for public seed providers compared to either a private or public-private partnership. Maturity period does not seem to be a significant determinant of choice for the farmers. Furthermore, the estimates from the segment membership function reveal that farmers who are more risk averse but produce relatively higher quantities of sorghum are more likely to belong to the segment. We label this segment "Micronutrient Preference Group" due to three reasons. First, the coefficient of the increased micronutrient attribute for this segment is much higher than that of the other segments. Second, when we normalized the utility parameters in this segment by price attribute, we observed that the segment members derive the highest utility from the increased micronutrient attribute. Third, the farmers in the group produce significantly higher quantity of sorghum than other groups. With proper information and awareness of its nutritive quality, this segment could be encouraged to adopt the new biofortified variety.

Segment 2 differs from 1 in many ways. For instance, in contrast to 1, the absolute value for the coefficient of the increased micronutrient attribute was quite small. The respondents show more preference for public seed sources and shorter day of maturity than for increased micronutrient. Furthermore, in the segment membership, we observe that farmers who practice seed saving culture and those that produce smaller quantities of sorghum are more likely to belong to this group. We label this group "Small Sorghum Producers Group" because of the following factors. First, the private seed source is not an important determinant factor in their choice. Second, they focus on the early maturing attribute, indicating possibility for subsistence cultivation. Finally, the seed saving culture and production of smaller quantity of sorghum are obvious characteristics of these farmers. A distribution agreement allowing seeds to be reused may influence this group to adopt the biofortified sorghum.

Finally, when normalized with the seed price attribute, farmers in segment 3 relative to those in segment 2, value increased micronutrient more and days to maturity less. The peculiar feature of segment 3 is that they attach higher utility to sorghum seed provided by a public-private partnership than other segments. Following Birol et al. (2011), the segment membership coefficients of the group can be interpreted as long as the other segments have the same signs. Consequently, farmers who take more risk are likely to belong to this group. Following the characteristics of risk averse farmers identified in PCA, this group of risk takers would likely be producing Bt cotton, and are less likely to be influenced by price or seed source. We labelled this group "Risk

Table 6
The LCM estimate for transgenic sorghum seed attribute.

	Segment 1 (31.2%) Micronutrient preference	Segment 2 (14.1%) Small sorghum producers	Segment 3 (54.7%) Risk takers
Utility parameter: Biofortified sorghum seed attributes			
Higher Micronutrient levels	23.283*** (5.47)	2.5576** (1.082)	3.2506*** (0.2879)
Seed price	−0.0047*** (0.001)	−0.0018*** (0.0004)	−0.0010*** (0.00012)
Public seed source[1]	5.1014*** (1.453)	2.0309*** (0.5474)	0.2016 (0.16577)
Private seed source[1]	2.4205*** (0.9192)	−2.7152 (3.0654)	−1.0117*** (0.2131)
Seed yield	0.0385*** (0.0079)	0.0121***(0.0028)	0.0081*** (0.00069)
Days to maturity	−0.0036 (0.0256)	−0.0459***(0.01614)	−0.0391*** (0.00493)
Segment membership: Farmers characteristics			
Constant	30.719(0.118D + 08)	4.0378 (3.5584)	–
Risk averse-attitude	0.5025*** (0.1909)	0.43557 (0.6989)	–
Annual sorghum production	0.00668** (0.0028)	−0.0165** (0.0069)	–
Seed saving practice	−36.641(0.118D + 08)	5.8351** (2.284)	–
Individual features			
Total annual yield (kg/ha)***	846	676	783
Sorghum acreage (hectare)	1.61	1.58	1.58
Total acreage (hectare)	6.89	9.63	8.76
Age (average years)	44.6	43.8	43.8
Number of farmers	47	21	82

[1] Compared to public-private partnership.
***, **, * = significant at 1%, 5%, 10% level.

Table 7
Farmers willingness to pay for a change in attribute.

WTP for	Class 1 Micronutrient preference	Class 2 Small scale farmers	Class 3 Risk takers
Extra Micronutrient	4953	1421	3251
Public seed source	1085	1128	–
Private seed source	515	–	1012
Higher seed yield	8	7	8
Early maturing seed	–	26	39

Parameters in CFA per kg; Blank spaces are due to insignificant coefficient in LCM.

Takers". They may show positive attitude towards transgenic sorghum variety, and would most likely be among the early adopters. They constitute a little above half of the farmers sampled (54.7%).

3.5. Farmers willingness to pay for attribute changes

This section estimates the welfare measure for going from the current seed used by the farmers to the new biofortified variety. The welfare measure is the premium they are willing to pay for a change in attribute levels. The WTP reported in Table 7 was estimated from the utility parameter in the LCM. The WTP for changes in some product attributes whose coefficients are insignificant in the LCM were not reported in the table. Although the table showed the mean WTP for changes in different product attributes included in the choice set, in line with the objective of the research, we concentrate more on the farmers WTP for our attribute of interest, which is increased micronutrients.

The results show that generally, the farmers may pay premium for the new sorghum seed with extra micronutrients. However, the extra amount to be paid varies among the segments. For the Micronutrient Preference farmers, the mean WTP to go from a local sorghum variety to the biofortified variety is 4953CFA per kg. This implies that the farmers in this class would likely pay on average an additional 4953CFA per kg to get the new biofortified sorghum seed with higher micronutrient. The Risk Takers are willing to pay on average an extra 3251CFA per kg for biofortified seed with increased micronutrients. Finally, the Small Sorghum producers are willing to pay less than the two groups. Their WTP for a biofortified sorghum seed with increased micronutrients is estimated at 1421CFA per kg. This is however expected as most farmers in this class do not buy their seeds from the market but use saved seeds from previous planting seasons.

4. Conclusion and recommendations

Transgenic biofortification is emerging as an alternative public health intervention project for the improvement of the nutritional status of people. However, none of such crops have been released to the farmers due to the controversies surrounding the process. In Burkina Faso, where transgenic biofortified foods may have important health benefits given the high frequency of MNM, biofortified seeds need to possess desirable attributes to be able to contend with the highly valued local variety. Far to provide an exhaustive answer at the dilemmas, our work focuses on investigating in ex-ante the market potential of the proposed transgenic biofortified sorghum by AHI. We employed a DCE to investigate the farmers' valuation of various attributes that could make up the biofortified seed as well identified the factors that influence the farmers valuation.

The results show that there is a promising market for transgenic biofortified sorghum in Burkina Faso, and the biofortified variety may be used as a veritable tool for reduction of MNM in the country. The findings from the DCE suggest that local farmers in Burkina Faso can change from traditional seed saving practices and are able to conduct a proper valuation of the attributes of the new products before making adoption decision. We showed that aside from the farmers that may still maintain a high penchant to the local seed variety, about 73% of farmers in the sample would be willing to cultivate the proposed transgenic sorghum variety. Nevertheless, the attributes of the new product should be significantly more appealing than the local variety for this market size to be achieved. Specifically, early maturation, higher yields, and lower prices would make these seeds more attractive.

Secondly, the LCM shows that there was heterogeneity in the preference structure of the farmers. The study identified three distinct classes of farmers based on their preference structure, the Micronutrient Preference Farmers, the Small Sorghum and the Risk Takers group. By segmenting our respondents into these 3 groups, we showed that those that have experience with first generation transgenic crops in the country (Bt cotton), are more likely to adopt the second-generation product. This segment otherwise known as the Risk Takers constitute a majority of the sample (55%), so we propose that they become the first market targeting group.

Finally, as a general implication for the development of the biofortified sorghum, we recommend that farmers should be carried along in the further development of the product. Adequate information should be provided to farmers, and if possible, the sorghum farmers' organizations should partner with AHI in the development of the new biofortified sorghum. Despite showing that farmers are willing to pay premium for the new biofortified seed, we hold that a market penetration strategy (subsidized price) is necessary to introduce the crop to farmers. We also recommend a strong government involvement in the development of the new product. The role of the government should among other things create awareness of the nutritional values of the new product, subsidize the product as well as participate in the eventual distribution of the transgenic seed.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.foodpol.2018.06.006.

References

Adenle, A.A., Morris, E.J., Parayil, G., 2013. Status of development, regulation and adoption of GM agriculture in Africa: views and positions of stakeholder groups. Food Policy 43, 159–166. http://dx.doi.org/10.1016/j.foodpol.2013.09.006.

Adesina, A.A., Baidu-Forson, J., 1995. Farmers' perceptions and adoption of new agricultural technology: evidence from analysis in Burkina Faso and Guinea, West Africa. Agric. Econ. 13 (1), 1–9. http://dx.doi.org/10.1016/0169-5150(95)01142-8.

AHBFI, 2007. A global vision with an African focus to fight poor nutrition with nutrient-rich crops. The Africa Biofortified Sorghum Project. Mid-Term Report December 2007. Nairobi, Kenya; Johannesburg, South Africa; Washington DC, USA.

Alpizar, F., Carlsson, F., Martinsson, P., 2001. Using choice experiments for non-market valuation. Econ. Issues 8, 83–110.

Andekelile, M., Leon, M., 2016. Prospects of genetic modified maize crop in Africa. Afr. J. Biotechnol. 15 (15), 571–579. http://dx.doi.org/10.5897/AJB2015.15098.

Azadi, H., Ghanian, M., Ghoochani, O.M., Khachak, P.R., Taning, C.N.T., Hajivand, R.Y., Dogot, T., 2015. Genetically modified crops: towards agricultural growth, agricultural development or agricultural sustainability? Food Rev. Int. 9129 (September). http://dx.doi.org/10.1080/87559129.2014.994816. 150211124031008.

Birol, E., Asare-marfo, D., Karandikar, B., Roy, D., 2011. A Latent Class Approach to Investigating Farmer Demand for Biofortified Staple Food Crops in Developing Countries: The Case of High-Iron Pearl Millet in Maharashtra, India. HarvestPlus Working Paper, vol. 7.

Birol, E., Villalba, E.R., Smale, M., 2007. Farmer preferences for milpa diversity and genetically modified maize in Mexico: a latent class approach. IFPRI Discussion Paper 00726. https://doi.org/10.1017/S1355770X08004944.

Black, R., Fava, F., Mattei, N., Robert, V., Seal, S., Verdier, V., 2010. Case studies on the use of biotechnologies and on biosafety provisions in four African countries. J. Biotechnol. 156 (4), 370–381. http://dx.doi.org/10.1016/j.jbiotec.2011.06.036.

Breustedt, G., Müller-scheeßel, J., Latacs-Lohman, U., 2008. Forecasting the adoption of GM oilseed rape: Evidence from a discrete choice experiment in Germany. J. Agric. Econ. 59 (2), 237–256. http://dx.doi.org/10.1111/j.1477-9552.2007.00147.x.

CIRAD, 2016. Fifteen years of participatory sorghum breeding in Burkina Faso : addressing farmers ' needs through collaboration. Retrieved April 10, 2017, from < http://www.cirad.fr/en/our-research/research-results > .

da Silva, L.S., Jung, R., Zhao, Z.yo., Glassman, K., Taylor, J., Taylor, J.R.N., 2011. Effect of suppressing the synthesis of different kafirin sub-classes on grain endosperm texture, protein body structure and protein nutritional quality in improved sorghum lines. J. Cereal Sci. 54 (1), 160–167. http://dx.doi.org/10.1016/j.jcs.2011.04.009.

de Bekker-Grob, E.W., Donkers, B., Jonker, M.F., Stolk, E.A., 2015. Sample size requirements for discrete-choice experiments in healthcare: a practical guide. Patient 8 (5), 373–384. http://dx.doi.org/10.1007/s40271-015-0118-z.

De Steur, H., Demont, M., Gellynck, X., Stein, A.J., 2017. The social and economic impact of biofortification through genetic modification. Curr. Opin. Biotechnol. 44, 161–168. http://dx.doi.org/10.1016/j.copbio.2017.01.012.

Diallo, Y., 2018. Identifying Leading Seed Companies in Western and Central Africa: Landscaping study for the Regional Access to Seeds Index for Western & Central Africa. Access to Seeds Foundation. < https://www.accesstoseeds.org/app/uploads/2018/05/Leading-Seed-Companies-in-Western-and-Central-Africa.pdf > .

Doherty, E., Campbell, D., Hynes, S., Rensburg, T. Van, 2011. The effect of using labelled alternatives in stated choice experiments : an exploration focusing on farmland walking trails in Ireland. In: Second International Choice Modelling Conference Annual Conference, (April).

FAO, 2014. Country Fact Sheet on Food and Agriculture Policy Trends - Burkina Faso, vol. 25, Rome.

Garcia-Yi, J., Lapikanonth, T., Vionita, H., Vu, H., Yang, S., Zhong, Y., Li, Y., Nagelschneider, V., Schlindwein, B., Wesseler, J., 2014. What are the socio-economic impacts of genetically modified crops worldwide? A systematic map protocol. Environ. Evidence 3 (1), 24. http://dx.doi.org/10.1186/2047-2382-3-24.

Grabowski, P.P., Kerr, J.M., Haggblade, S., Kabwe, S., 2016. Determinants of adoption and disadoption of minimum tillage by cotton farmers in eastern Zambia. Agric. Ecosyst. Environ. 231, 54–67. http://dx.doi.org/10.1016/j.agee.2016.06.027.

Greene, W.H., Hensher, D.A., 2003. A latent class model for discrete choice analysis: contrasts with mixed logit. Transp. Res. Part B 37 (8), 681–698. http://dx.doi.org/10.1016/S0191-2615(02)00046-2.

Hanley, N., Mourato, S., Wright, R.E., 2001. Choice modelling approaches: a superior alternative for environmental valuation? J. Econ. Surv. 15 (3), 435–462. http://dx.doi.org/10.1111/1467-6419.00145.

Hensher, D.A., Rose, J.M., Greene, W.H., 2005. Applied Choice Analysis, A Primer. Cambridge University Press. https://doi.org/10.1007/9781316136232.

Hoyos, D., 2010. The state of the art of environmental valuation with discrete choice experiments. Ecol. Econ. 69 (8), 1595–1603. http://dx.doi.org/10.1016/j.ecolecon.2010.04.011.

Hubbell, B., Marra, M., Carlson, G., 2002. Estimating the demand for a new technology: Bt cotton and insecticide policies. Am. J. Agric. Econ. 5 (4), 118–132.

IFPRI, 2015. 2015 Nutrition Country Profile: Burkina Faso. Global Nutrition Report.

International Food Policy Research Institute, 2016. Global Nutrition Report - From promise to Impact: Ending Malnutrition by 2030. Washington, DC. https://doi.org/10.2499/9780896295841.

Johnson, F.R., Lancsar, E., Marshall, D., Kilambi, V., Mühlbacher, A., Regier, D.A., Bresnahan, B.W., Kanninen, B., Bridges, J.F.P., 2013. Constructing experimental designs for discrete-choice experiments: Report of the ISPOR conjoint analysis experimental design good research practices task force. Value Health 16 (1), 3–13. http://dx.doi.org/10.1016/j.jval.2012.08.2223.

Kikulwe, E.M., Birol, E., Wesseler, J., Falck-Zepeda, J., 2011. A latent class approach to investigating demand for genetically modified banana in Uganda. Agric. Econ. 42 (5), 547–560. http://dx.doi.org/10.1111/j.1574-0862.2010.00529.x.

Krishna, V.V., Qaim, M., 2007. Estimating the adoption of Bt eggplant in India: who benefits from public-private partnership? Food Policy 32 (5–6), 523–543. http://dx.doi.org/10.1016/j.foodpol.2006.11.002.

Kuhfeld, W.F., Tobias, R.D., Garratt, M., 1994. Efficient experimental design with marketing research applications. J. Mark. Res. 31 (4), 545–557. http://dx.doi.org/10.2307/3151882.

Kuwornu, J.K.M., Sarpong, D.B., Osei, W.K., 2011. Farmers' willingness to adopt genetically modified maize seeds in Ghana. Insights Changing World J.(3).

Lacy, S.M., Cleveland, D.A., Soleri, D., 2006. Farmer choice of sorghum varieties in southern Mali. Hum. Ecol. 34 (3), 331–353. http://dx.doi.org/10.1007/s10745-006-9021-5.

Lancaster, K., 1966. A new approach to consumer theory. Retrieved from. J. Political Econ. 74 (2), 132–157. http://www.jstor.org/stable/1828835.

Lancsar, E., Louviere, J., 2008. Conducting discrete choice experiments to inform health care decision making: a user â€™ s guide, experiments to inform healthcare a user ' s guide. PharmacoEconomics 26, 661–677. http://dx.doi.org/10.2165/00019053-200826080-00004. December 2015.

Li, S.L., Zhang, Y.B., Rui, Y.K., Chen, X.F., 2012. Nutrient content in maize kernels grown on different types of soil. Phyton 81 (2), 41–43.

Lindsay, M.J., Hanson, K., McPake, B., 2009. How to do (or not to do)...Designing a discrete choice experiment for application in a low-income country. Health Policy Plan. 24 (2), 151–158. http://dx.doi.org/10.1093/heapol/czn047.

Louviere, J.J., Hensher, D.A., Swait, J.D., 2000. Stated Choice Methods: Analysis and Application. Cambridge University Press. http://dx.doi.org/10.1002/jae.701.

Louviere, J.J., Street, D., Burgess, L., Wasi, N., Islam, T., Marley, A.A.J., 2008. Modeling the choices of individual decision-makers by combining efficient choice experiment designs with extra preference information. J. Choice Model. 1 (1), 128–164. http://dx.doi.org/10.1016/S1755-5345(13)70025-3.

Mabaya, E., 2015. Adoption of GM crops in Africa: why the seed sector matters. In: Mitton, P., Bennett, D. (Eds.). Analyses: Africa's Future Can Biosciences Contribute? Banson/B4FA, pp. 36–46.

Mabaya, E., Fulton, J., Simiyu-Wafukho, S., Nang'ayo, F., 2015. Factors influencing adoption of genetically modified crops in Africa. Dev. Southern Africa 32 (5), 577–591. http://dx.doi.org/10.1080/0376835X.2015.1044078.

Miller, B.D.D., Welch, R.M., 2013. Food system strategies for preventing micronutrient malnutrition. Food Policy 42, 115–128. http://dx.doi.org/10.1016/j.foodpol.2013.06.008.

Mogas, J., Riera, P., Bennett, J., 2006. A comparison of contingent valuation and choice modelling with second-order interactions. J. For. Econ. 12 (1), 5–30. http://dx.doi.org/10.1016/j.jfe.2005.11.001.

Obi, C.T., Ejiogu, A.O., Sanou, E.I.R., 2017. The role of transgenic biofortified food in the reduction of hidden hunger in Nigeria. In: First International Conference of Food Security and Hidden Hunger. Federal University Ndufu-Aliku, Eboyi State, Nigeria.

Olembo, K., M'mboyi, F., Kiplagat, S., Sitiney, J., Oyugi, F., 2010. Sorghum breeding in sub-Saharan Africa: the success stories. African Biotechnology Stakeholders Forum, 37p. Retrieved from < http://absfafrica.org/downloads/Sorghum Book Series.pdf > .

Paiva, C.L., Queiroz, V.A.V., Simeone, M.L.F., Schaffert, R.E., de Oliveira, A.C., da Silva, C.S., 2017. Mineral content of sorghum genotypes and the influence of water stress. Food Chem. 214, 400–405. http://dx.doi.org/10.1016/j.foodchem.2016.07.067.

Qaim, M., de Janvry, A., 2003. Genetically modified crops, corporate pricing strategies, and farmers' adoption: the case of Bt cotton in Argentina. Am. J. Agric. Econ. 85 (4), 814–828. http://dx.doi.org/10.1111/1467-8276.00490.

Rose, J.M., Bliemer, M.C.J., 2013. Sample size requirements for stated choice experiments. Transportation 40 (5), 1021–1041. http://dx.doi.org/10.1007/s11116-013-9451-z.

Rose, J.M., Bliemer, M.C.J., Hensher, D.A., Collins, A.T., 2008. Designing efficient stated choice experiments in the presence of reference alternatives. Transport. Res. Part B: Methodological 42 (4), 395–406. http://dx.doi.org/10.1016/j.trb.2007.09.002.

Rungie, C.M., Coote, L.V., Louviere, J.J., 2011. Structural choice modelling: theory and applications to combining choice experiments. J. Choice Model. 4 (3), 1–29. http://dx.doi.org/10.1016/S1755-5345(13)70040-X.

Saldias, C., Speelman, S., Drechsel, P., van Huylenbroeck, G., 2016. A livelihood in a risky environment: Farmers' preferences for irrigation with wastewater in Hyderabad, India. R. Swedish Acad. Sci. 1–14. http://dx.doi.org/10.1007/s13280-016-0824-3.

Saltzman, A., Birol, E., Bouis, H.E., Boy, E., De Moura, F.F., Islam, Y., Pfeiffer, W.H., 2013. Biofortification: progress toward a more nourishing future. Global Food Security 2 (1), 9–17. http://dx.doi.org/10.1016/j.gfs.2012.12.003.

Sanders, J., 2016. A new sorghum production system in Burkina Faso. Purdue Agric. 1–14.

Sanou, E.I.R., Gheysen, G., Koulibaly, B., Roelofs, C., Speelman, S., 2018. Farmers' knowledge and opinions towards Bollgard II ® implementation in cotton production in Western Burkina Faso. New Biotechnol. 42, 33–41.

Smale, M., Assima, A., Kergna, A., Thériault, V., Weltzien, E., 2018. Farm family effects of adopting improved and hybrid sorghum seed in the Sudan Savanna of West Africa. Food Policy 74, 162–171.

Schreiner, J., 2014. Farmers' valuation of incentives to produce GMO-free milk: a discrete choice experiment. Syst. Dyn. Innovation Food Networks 2, 312–323. http://dx.doi.org/10.1108/bfj.2009.070111haa.001.

Traore, K., Stroosnijder, L., 2005. Sorghum quality, organic matter amendments, and health: farmers' perception in Burkina Faso, West Africa. Ecol. Food Nutr. 44, 225–245. http://dx.doi.org/10.1080/03670240590953421. July 2014.

UNICEF, 2013. Unicef Humanitarian action for Children - Burkina Faso. Retrieved from < https://www.unicef.org/appeals/files/Burkina_Faso_HAC_2013_28_dec.pdf > .

Virgin, I., Bhagavan, M., Komen, J., Kullaya, A., Louwaars, N., Morris, E.J., Okori, P., Persley, G., 2007. Agricultural biotechnology and small-scale farmers in Eastern and Southern Africa. Biotechnology. Retrieved from < http://www.sei-international.org/mediamanager/documents/Publications/Risk-livelihoods/agricultural_biotech_smallscale_east_south_africa.pdf > .

vom Brocke, K., Trouche, G., Weltzien, E., Barro-Kondombo, C.P., Gozé, E., Chantereau, J., 2010. Participatory variety development for sorghum in Burkina Faso: Farmers' selection and farmers' criteria. Field Crops Res. 119 (1), 183–194. http://dx.doi.org/10.1016/j.fcr.2010.07.005.

World Food Programme, 2017. Burkina Faso: Country Brief. Retrieved January 18, 2018, from < http://documents.wfp.org/stellent/groups/public/documents/ep/wfp272247.pdf?_ga=1.94460636.1799879439.1481286284 > .

Zakaria, H., Adam, H., Abujaja, A.M., 2014. Knowledge and perception of farmers towards genetically modified crops : the perspective of farmer based organizations in northern region of Ghana. Am. Int. J. Contemp. Sci. Res. www.americanij.com, 1 2014(2 June–July).

Zongo, B., Diarra, A., Barbier, B., Zorom, M., Yacouba, H., Dogot, T., 2015. Farmers' practices and willingness to adopt supplemental irrigation in Burkina Faso. Int. J. Food Agric. Econ. 3 (1), 101–117.