Revisiting strategies to incorporate gender-responsiveness into maize breeding in southern Africa

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Abstract
In sub-Saharan Africa there is increasing focus on identifying women’s trait preferences within crop breeding to enable gender-responsive product development. In the case of maize, breeding programs are ready to incorporate specific traits to increase gender-responsiveness but lack guidance on what these specific traits might be. We propose an inductive approach to determine a pathway towards increasing gender-responsiveness within maize breeding. A survey of 306 farmers was conducted to determine gender differences in maize varieties used together with key agronomic practices. Variety was a significant predictor of the gender of the plot manager and of the household head in contrast to previous surveys conducted in researcher-led on-farm trials. On-farm trials are conducted using pre-defined agronomic management practices and preferences identified at harvest are likely to centre around yield. This study highlighted significant differences in several agronomic practices used by female plot managers and female household heads. Although further studies are required to understand preferences associated with varietal choice, our results suggest that current researcher-led on-farm trials may not identify gender-specific trait preferences driving varietal choice. Furthermore, a trait-specific approach is not the only avenue towards increasing gender-responsiveness in maize breeding in southern Africa. The scope for increasing gender-intentionality in maize breeding could be expanded to incorporate selection environments more relevant to agronomic management practices used by female plot managers and households at advanced stages of the breeding pipeline. This approach could provide an immediate entry point to increase gender-intentional maize breeding in southern Africa.

Keywords
Zea mays, smallholder farmers, women’s preferences, logit model

Introduction
Understanding trait preferences of farmers, processors and end-users is the first step in demand-driven breeding (Marimo et al., 2020). Production goals and access to resources vary across farmers groups, with gender differences often being significant (Weltzien et al., 2020). Neglecting women’s preferences risks the development of new varieties that are rejected or that harm women by increasing gender inequality (Ashby and Polar, 2021). For this reason, incorporating gender-responsiveness into crop breeding has been the recent focus of intense interest in sub-Saharan Africa (SSA) (Ashby and Polar, 2019; Christinck et al., 2017; Dufour et al., 2021; Mukankusi et al., 2018; Newilah et al., 2021; Tegbaru et al., 2020; Thiele et al., 2020; Weltzien et al., 2020; Voss submitted). The CGIAR (Consultative Group for International Agricultural Research) Gender and Breeding Initiative (http://www.rtb.cgiar.org/gender-breeding-initiative/) is leading in the development of tools, supporting methodologies and practices to support gender-responsive breeding. Maize has limited end-uses in comparison to cassava and banana (Ekpa et al., 2018) where significant gender-specific trait preferences have been identified (Thiele et al., 2020). Except for maize grain texture in Malawi (Lunduka et al., 2012; Smale and Heisey, 1994),

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there are currently no breeding traits in southern Africa intentionally incorporated to specifically target female maize farmers (Cairns et al., 2021; Voss et al., submitted). This lack of gender-specific traits does not reflect the willingness of maize breeding programs to incorporate relevant gender-based trait preferences, but rather a lack of knowledge around what specific traits, if any, are required by women or men. In theory, any heritable trait can be incorporated into a product profile, however, the more traits that are used in selection the more the overall genetic gain is reduced. There is also a significant cost associated with adding new traits to a product profile, through the development of phenotypic assays and, increasingly, molecular breeding strategies. Although there has been a significant reduction in breeding cycle time and product life cycles (Cairns and Prasanna, 2018; Prasanna et al., 2021), the time taken to add a new trait into a product profile until the delivery of new varieties, incorporating this trait, into the hands of farmers is significant. A robust business case is therefore required for the addition of any new trait.

A clear entry point to discern gender-based trait preferences in maize are on-farm trials used by breeding programs at the final stage of varietal development. These trials are used to confirm the performance of pre-commercial varieties in the target environment prior to release (Setimela et al., 2017). Farmer surveys within these trials can capture preferred traits and varieties, and the willingness of farmers to pay for specific traits (Kassie et al., 2017; Setimela et al., 2017; Worku et al., 2020). The benefit of using on-farm trials as a platform to elucidate gender-specific trait preferences is, in theory, they provide a direct feedback loop to breeders. However, on-farm variety trials are fit-for-purpose, simplifying farm heterogeneity to provide robust estimates of varietal performance in the target environment. While the research space around technology testing on-farm is currently an area of intense debate and innovation (De Roo et al., 2017; Laajaj et al., 2020; Moyo et al., 2021; van Etten et al., 2019), on-farm trials in maize varietal development were previously largely researcher-led and conducted at a specific plant population using conventional agricultural practices, with inputs (seed, fertiliser and pesticides) supplied at optimum rates (Setimela et al., 2017). Thus, they do not reflect the range of agronomic management practices used by farmers nor capture post-harvest information including storage, preparation and consumption. This deductive approach also does not reflect the real-life choices made by farmers when choosing seed (Almekinders et al., 2019). Seed choices are “balanced with trade-offs with other livelihood activities that make demands on labor, such as time, cash, and exposure to risk” (McEwan et al., 2021), thus what farmers like does not necessarily translate to what farmers use (Syngenta Foundation, 2021).

An alternative, inductive approach would be to understand if there are differences in maize varieties currently grown by male and female plot managers within male and female headed households, learning from how the system currently works. Similar approaches have previously been used to understand traits associated with maize varieties used by farmers, but these studies have not used a gender-disaggregated approach (Dao et al., 2015; Sibiya et al., 2013). To investigate this approach, we surveyed maize plots from 306 farms randomly selected in two wards of Murehwa District, Zimbabwe and recorded for each the gender of the head of the corresponding household, the gender of the plot manager, maize varieties and all the main agronomic practices used. The primary aim of this study was to assess whether maize varieties (and agronomic practices) were associated with (1) the gender of the plot manager, and (2) the gender of the head of the household.

Methodology

The survey was conducted in Murehwa District, Mashona land East, Zimbabwe (-17.6432, 31.7840, 1400 masl). This district was chosen as maize is the predominant crop and malnutrition remains high. Maize is grown by 87% of households in this district, with average household production estimated at 279 kg/household (ZimVAC, 2020). Average maize yields in Murehwa district were estimated at 0.67 t ha$^{-1}$ in 2019/2020 (ZimVAC, 2020). Over the past ten years Zimbabwe has made significant progress in the reduction of stunting in all districts, except for Murehwa, where stunting increased by 6% (ZimVAC, 2020). Murehwa frequently experiences drought (Frischen et al., 2020), and the season 2019/2020 was predicted to have below seasonal rainfall (https://www.herald.co.zw/experts-warn-of-another-drought/), the fourth drought in five years (Frischen et al., 2020). Murehwa District is subdivided into 29 wards. Two wards (4 and 27) were selected based on soil type, elevation, distance to the main road and, finally, prior experience working with extension agents in each ward. Five wards (7, 8, 11, 12 and 16) are along the main road to Mozambique and were excluded as they were considered not representative of the district. Uniform soil texture and elevation was used to reduce variability in drought risk within a ward. Soil texture data was derived from the Africa SoilGrids 250 m data soil data base (https://www.isric.org/projects/soil-property-maps-africa-250-m-resolution). Soil texture is related to water holding capacity and nutrient availability, thus only wards with uniform soil texture were selected. Elevation data was obtained from the SRTM30 dataset (https://srtm.csi.cgiar.org/) through DIVA-GIS (https://www.diva-gis.org). Based on these factors, wards 4 and 27 were selected for inclusion in the subsequent survey.

A total of 306 farmers were randomly sampled in Ward 4 and Ward 27 of Murehwa, and heads of households interviewed by a team of 10 trained enumerators using a systematic questionnaire. The primary aim of the survey was to assess farming household heterogeneity (in particular through the delineation of a typology) in order to select representative farms for detailed research (including on-farm trials). In Zimbabwe farmers have several fields on which they grow maize and other crops (Manzeke et al., 2019). Homefields are fields close the homestead. Due to the proximity of homefields to the homestead, these fields are less at risk from grazing by roaming livestock. Manure, organic
amendments and mineral fertiliser and labour are preferentially invested in homefields (Zingore et al., 2007). Fields further away from the homestead are referred to as outfields. Over time the concentration of nutrient resources in homefields and the nutrient depletion in outfields results in a marked gradient of soil fertility with distance from the homestead (Rusinamhodzi et al., 2015). If farmers had planted maize on their homefields, farmers were asked to list the maize varieties they planted on that part of the farm, as well as all major agronomic operations: land preparation, planting, application of fertilizers and organic amendments, intercropping, weeding etc. Farmers were also asked to estimate the area under maize production and their yields. The same questions were used for maize planted on the outfields. Farmers participating in the survey used a range of different varieties (Table 1). The company Seed Co produces several hybrids within each different maturity group. Each maturity group is easily identifiable by an animal displayed on the label. Extra-early maturity (monkey) maize is called the 400 series and contains two white hybrids. The 500 series, early maturity group (zebra), has five white hybrids. The 600 series, medium maturity (lion), includes five white hybrids. And the 700 series, late maturity (elephant), has two white hybrids. Recycled seed is saved hybrid seed from the previous year. Open pollinated varieties (OPV) included amongst others - the improved variety ZM521 and Hickory King. ZM521 is still marketed by one seed company in Zimbabwe, although it is likely the seed has been retained by each household. Hickory King is a popular OPV that the formal sector stopped supporting almost 40 years ago (Machida et al., 2014).

The survey yielded a dataset for 558 maize plots. Based on the quantity of fertilizer used, the composition of the fertilizers used, and the estimated size of the plot, we calculated the rate of mineral nitrogen (N) and mineral phosphorus (P₂O₅) applied. Quantity of manure and quantity of compost used were converted into qualitative variables (i.e. used or not). The number of weeding operations was converted into a categorical variable of weeding frequency with 3 levels: low (0 or 1 operation), medium (2 operations) and high (more than 2 operations). Maize varieties with less than 15 entries were relabelled as ‘Other’. Land preparation using draught animal and land preparation using tractor (very few entries) were grouped as a land preparation category ‘ploughing’. Nine plots for which the plot manager was declared as ‘children’ were removed from the analysis. Plot area, N rate, P₂O₅ rate and planting dates were scaled. Finally, the variables ‘gender of the plot manager’ and ‘gender of the head of the household’ were assigned the value 1 for ‘female’ and 0 otherwise.

To assess if particular maize varieties and agronomic practices were associated with the gender of the plot manager on one hand and the gender of the head of the household on the other, two logit models were used, one with the response variable ‘manager of the plot female’ (0/1) and the other with the response variable ‘head of the household female’ (0/1). As a farm could cultivate more than one plot, explanatory variables were aggregated to the farm level. In total this gave 295 independent farms. Continuous variables; N rate, P rate and planting date were calculated as a weighted average (weighted by plot area) over the whole farm. The area dedicated to maize was calculated as the sum of all individual plots. Categorical variables were aggregated over a farm by first converting each into a set of binary variables and then recording a presence or absence for each of these new binary variables across the whole farm. In this way, levels of a categorical factor were no longer mutually exclusive as a farm may have multiple varieties present across the farm, for example. The complete set of categorical variables considered were: open pollinated varieties, recycled seeds, K2 PGS61, PAN 413, PAN 53, PHB 30G19, SC400 series, SC500 series, SC600 series, SC700 series, ZAP 55, ZAP 61, other varieties, gentle slope, flat land, steep slope, land preparation with hand hoe, land preparation through ploughing (animal traction or tractor), conservation agriculture (defined as the combination of no-tillage and retention of some crop residues as mulch), intercropping, manure applied (yes, no), compost applied (yes, no), low weeding frequency, medium weeding frequency, high weeding frequency, and pesticide applied (yes, no). All variables were included in initial models. Models were then reduced to obtain the lowest Akaike information criterion (AIC) using a stepwise backwards elimination algorithm. These models were confirmed through an exhaustive search using the genetic algorithm of glmulti (Calcagno, 2020). All analyses were carried out using R (Version 4.1.0). Codes are provided in the supplemental data.

**Results**

Household characteristics of surveyed participants are presented in Table 2. Forty-three percent of households were female headed. The average age of the household head was 53.0 years old for female headed households and 54.3 years old for male headed households. Over 90% of male headed households were married compared to 43.5%
of female headed households. In female headed households, the highest level of education was primary for almost 60% of household heads, and secondary for 40%. In male headed households, the highest level of education was secondary for almost 65% of household heads. Average family size was 5.3 and 5.7 for female headed and male headed households, respectively. The total area under crop production in 2018/2019 was almost 40% larger in male headed households compared to female headed households. In average, female headed households estimated they had 1.9 ha under crop production in homefields and 1.0 ha in outfields, while male headed households estimated they had 4.0 ha under crop production in homefields and 2.5 ha in outfields. The total area under maize production in female and male headed households was similar, with a mean of 1.5 ha in female headed households and 1.6 ha in male headed households. Almost 80% of the area under maize production in both female and male headed households was on homefields. Mean total maize production in the 2018/2019 season was estimated at 411.4 kg in female headed households and 520.8 kg in male headed households. Female headed households also owned less cattle than male headed households.

The distribution of maize fields managed by men, women or the family was almost equally split, with 34% being managed by women. A summary of plots managed by women or men is presented in Table 3. Each farm planted multiple plots of maize, although not all farms planted maize on outfields. A small proportion of plots (9%) within female headed households, were managed by male (unmarried) sons.

The results of the logit models showed variety choice to be significantly associated with the plot manager being female (Figure 1A) and with the head of the household being female (Figure 1B). The maize variety PHB 30G19 was unlikely to be grown by female plot managers, while maize varieties from the SC400 and SC500 series, open pollinated varieties, ZAP61, ‘other varieties’, and PAN 413 tended to be associated with female plot managers (Figure 1A). In addition, female headed households were found to be less likely to grow the SC700 series and PAN 53, but more likely to plant recycled seeds and PAN 413 (Figure 1B).

Discussion

These results differ to a previous study on gender-disaggregated varietal preferences in the same region of Zimbabwe. Setimela et al. (2017) found very limited differences in variety preferences between male and female participants when researcher-led on-farm trials were evaluated at harvest. Interestingly both genders showed no preference towards the SC400 and SC500 series, with the SC600 series and Pan53 identified as popular varieties. Our study suggests strong gender use in maize varieties grown in this

| Table 2. Household characteristics of female and male headed households. |
|--------------------------|--------------------------|
| **Gender of household head** | Female | Male |
| Number | 132 | 174 |
| Age of the household head (years) | 53.0 | 54.3 |
| Marital status of the household head | | |
| Divorced (%) | 3.8 | 1.7 |
| Married (%) | 45.5 | 92.5 |
| Single (%) | 3 | 1.7 |
| Widow or widower (%) | 47.7 | 3 |
| Education of the household head | | |
| Primary level (%) | 57.6 | 31 |
| Secondary level (%) | 40.9 | 64.4 |
| Tertiary level (%) | 1.5 | 4.6 |
| Family size (n) | 5.28 | 5.7 |
| Total cropped area (ha) | 2.9 | 4.0 |
| Homefield (ha) | 1.9 | 2.5 |
| Outfield (ha) | 1.0 | 1.5 |
| Total maize area (ha) | 1.5 | 1.6 |
| Homefield (ha) | 1.2 | 1.3 |
| Outfield (ha) | 0.3 | 0.3 |
| Total maize production in 2020 (kg) | 411.4 | 520.8 |

| Livestock | | |
| Cattle (n) | 1.9 | 3 |
| Donkeys (n) | 0 | 0.10 |
| Goats and sheep (n) | 2.08 | 2.08 |

| Agricultural assets | | |
| Ploughs (% of households owning) | 43 | 58 |
| Cultivators (% of households owning) | 17 | 36 |
| Scotch carts (% of households owning) | 27 | 36 |
| Wheel barrows (% of households owning) | 55 | 64 |
| Knapsacks (% of households owning) | 30 | 48 |

| Table 3. Maize plot managers in homefields and outfields within female and male headed households. |
|--------------------------|--------------------------|
| **Female headed households** | Number | Percentage (%) |
| Male plot manager | 22 | 9.4 |
| Homefield | 17 | 7.2 |
| Outfield | 5 | 2.1 |
| Whole family | 81 | 34.5 |
| Homefield | 63 | 26.8 |
| Outfield | 18 | 7.7 |
| Female plot manager | 132 | 56.2 |
| Homefield | 118 | 50.2 |
| Outfield | 14 | 7.7 |

| **Male headed households** | | |
| Male plot manager | 174 | 55.4 |
| Homefield | 151 | 48.9 |
| Outfield | 23 | 7.3 |
| Whole family | 84 | 26.8 |
| Homefield | 66 | 21.0 |
| Outfield | 18 | 5.7 |
| Female plot manager | 56 | 17.8 |
| Homefield | 48 | 15.3 |
| Outfield | 8 | 2.6 |
Yield is a key trait for most farmers, thus in on-farm trial evaluations hybrids with the highest yield are likely to be preferred in this specific context. However eliciting farmer preferences in researcher-led on-farm trials does not necessarily reflect real-life decisions made by farmers when choosing to grow varieties (Almekinders et al., 2019; Syngenta Foundation, 2021). Our results confirm this hypothesis; preferences identified female participants within a researcher-managed on-farm trial did not translate to decisions made when selecting varieties to plant. These results suggest that understanding the rationale of current decisions made by plot managers and household heads when selecting varieties and the trade-offs farmers make between traits when selecting varieties could be important pathways towards identifying gender-specific traits for incorporation into breeding pipelines. Maize varieties in the SC700 series were the only late maturity hybrids included in this survey and hybrids from this series were unlikely to be grown by female headed households. Early maturing varieties cut short the lean season (Voss et al., 2021) and reduce the risk of drought exposure (Tegbaru et al., 2020; Weltzien et al., 2020). Late maturing varieties in Zimbabwe are more expensive. Female headed households are generally more resource constrained with limited disposal income and livestock ownership, as confirmed in this survey, and therefore may be more likely to purchase cheaper, earlier maturing maize varieties. In CIMMYT’s southern Africa maize breeding pipeline, the intermediate to late maturity product profile accounts for almost 60% of regional investment, with approximately 35% for the early maturity product profile and 5% for pro-vitamin A maize (Nicholas Davis pers. comm.). If confirmed, re-aligning investment to reflect female plot managers and female household heads preference could help increase gender-responsiveness within maize breeding in southern Africa.

Interestingly, using intercropping, and not using manure were predictive of maize plots with female plot managers or household heads. Prevalent intercrops in this study were pumpkin and cowpea. Intercropping is often associated with female farmers who have less land. Intercropping increases dietary diversity, increasing system caloric yield (Madembo et al., 2020; Mhlanga et al., 2021) whilst reducing inputs and maximizing yield per unit area and labour utilization efficiency (Ndiritu et al., 2014; Tufa et al., 2019). Legumes are considered as a women’s crop in Zimbabwe and generally grown as part of a maize intercropping system (Foti et al., 2020; Mapfumo et al., 2001). Intercropping increases interspecific competition for resources (nutrients, water and light) between crops in time and space and can result in a maize yield penalty (Mhlanga et al., 2021). Currently selection and advancement within breeding programs is conducted under conventional agronomy (i.e. standard plant density without intercropping). The distinct gendered use of agronomic management practices implies that selection at advanced stages of the breeding pipeline could be expanded to include practices widely used by female plot managers and female household heads to remove advanced hybrids that do not perform under these conditions from the

Figure 1. Dot-whisker plots of the estimates and confidence intervals for logit models run after model reduction with (A) gender of the manager of the plot as the response variable (1 if female, 0 otherwise), and (B) gender of the head of the household as response variable (1 if female, 0 otherwise). Whiskers crossing the y-axis (grey dotted line) indicate non-significance for the corresponding factor.
breeding pipeline. Intercropping maize with cowpea has also been associated with suppressing fall armyworm incidence (Baudron et al., 2019). However, growing pumpkin has also been associated with increased fall armyworm incidence in maize (Baudron et al., 2019), thus increased tolerance to fall armyworm could potentially reduce yield loss associated with this pest in female managed plots or headed households. Oxen are used to plough fields and women have less control over oxen than men (Djurfeldt et al., 2019). In this study female headed households had significantly less cattle than male headed households and hence use less manure than their male headed counterparts. At the same time, competing demands on women’s time with domestic chores prevents women with little time to apply manure during the growing season (Hove and Gweme, 2018). Both constraints together could, in part, explain why female plot managers or household heads were unlikely to use manure in maize production. Interestingly a higher nitrogen application rate was predictive of female plot managers, yet nitrogen application rate was not a significant predictor of the gender of the household head. Previous studies in southern Africa have found female headed households apply one-third less fertilizer than male headed households (Burke et al., 2018), and 9% fewer female farmers than male farmers apply fertilizer at all (Djurfeldt et al., 2019). Steeper slopes in female managed plots are likely to result in greater fertility gradients than nitrogen stress may still be prevalent for this group. Conservation agriculture has implication for labour requirements particularly in manual systems with limited access to herbicides (Farnworth et al., 2015). In Zimbabwe, women found preparation of basins for conservation agriculture and weeding strenuous, citing labour constraints as the main reason for dis-adoption (Hove and Gweme, 2018). This may explain why conservation agriculture (using manual hoe-prepared basins) was unlikely to be practised in female headed households due to the labour demands (Nyagumbo et al. 2017).

There is a growing literature base around the presence of gendered differences in the perception of intra-household decision making processes (Acosta et al., 2020; Annan et al., 2021; Campenhout et al., 2021) and the mis-reporting of assets (Ambler et al., 2017). Similarly, information related to production and area is subjective and sensitive to recall bias (Kosmowski et al., 2021). The primary aim of our survey was to ensure that farm diversity was captured during the selection of farms for on-farm trials related to genetic and agronomic biofortification. Information in this survey was therefore provided by household heads and not individual plot managers. Thus, further confirmation is required to ensure the information around varietal use and agronomic management practices by plot managers is correct.

Conclusions

The findings of this study suggest differences between experimental evidence and farmer’s practices. Surveys conducted in on-farm trials are an important method to identify potential constraints to adoption of hybrids prior to commercialisation, however, they only provide a snap-shot of preferences at the time of the survey and do not reflect the real-life choices farmers make at the point of sale. Further quantitative work is required to understand why female plot managers and household heads chose to grow certain varieties. The strong focus on improving yield and agronomic traits in maize breeding in southern Africa has resulted in notable genetic gain in grain yield under a range of climatic conditions (Masuka et al., 2017a, and 2017b; Prasanna et al., 2021). However, there is a growing recognition that end-user preferences need to inform traits within product profiles (Syngenta Foundation, 2021). While there has been extensive work in end-user traits crops, such as cassava, banana and yams, particularly related to gender specific traits (Thiele et al., 2020), processing and organoleptic traits are currently not measured within maize breeding programs in southern Africa and varietal differences in key traits related to these properties are largely unknown. Understanding current genetic variability between commercial varieties for traits related to greenmealies, storage, processing and organoleptic properties will be essential to elucidating specific characteristics favoured or rejected by female plot managers. These results highlight significant differences in management practices used by male and female maize farmers. An immediate step towards increasing gender-responsiveness within maize breeding programs in Zimbabwe would be to incorporate the screening of maize varieties at stage four (regional trials) of the breeding pipeline under management systems used by female plot managers or household heads, specifically intercropping with pumpkins and/or cowpeas. As on-farm trials move towards a tricot-based approach (van Etten et al., 2019), if female headed households and female plot managers are adequately targeted, managements systems used by these groups would be organically incorporated into testing at this stage. While the geographic area used in this study was not large enough to adequately cover a product profile to redirect breeding strategies, this approach could provide relatively simple steps towards increasing gender-responsiveness within maize breeding pipelines in southern Africa. These steps would not have been identified using farmer trait preference surveys undertaken in researcher-led on-farm trials where trials are conducted under pre-defined agronomic conditions and end at harvest. Livestock breeding programs have used internet-based tools for choice experiments, such as 1000minds, and applied economic weights to ascertain the relative importance of target traits (Byrne et al., 2016). While this approach could be important to ultimately discern gender-responsive traits and provide the appropriate economic weights for selection, our approach may provide a simple and cost-effective way to immediately increase gender-responsiveness within maize breeding programs in southern Africa.

Acknowledgements

We thank Connie Madembo and enumerators in Ward 4 (Kudzai Charevambo, Memory Chipangura, Joseph Jokwiro, Wadzanai Mvundura, and Precious Ngairo) and Ward 27 (Rosemary...
Chikosha, Jonathan Chingorivo, Taimbovere Makoni, Loveness Mudarikwa, and Sandra Ndambakuwa) for their assistance with fieldwork. We are grateful to Mike Olsen and Rachel Voss for helpful discussions and the anonymous reviewers for their valuable comments.

Declaration of conflicting interests
The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding
This study was supported through the UK Global Challenges Research Fund administered by the Biotechnology and Biological Sciences Research Council for the project “Addressing malnutrition with biofortified maize in Zimbabwe: from crop management to policy and consumers” (LATI Identifier: GB-GOV-13-FUND–GCRF-BB_T009047_1), the Bill & Melinda Gates Foundation funded project “Seed Production Technology for Africa” (INV-018951) and the CGIAR Research Program on Maize (MAIZE). The CGIAR Research Program MAIZE receives W1&W2 support from the Governments of Australia, Belgium, Canada, China, France, India, Japan, Korea, Mexico, Netherlands, New Zealand, Norway, Sweden, Switzerland, UK, U.S., and the World Bank.

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the Biotechnology and Biological Sciences Research Council (grant number GB-GOV-13-FUND–GCRF-BB_T009047_1, INV-018951).

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Supplemental material
Supplemental material for this article is available online.

Notes
1. Product profiles allow plant breeders to focus their activities on the development of products that will replace established varieties on the market. A product profile is based on the needs of farmers and end-users, serving as a guideline for variety development (Ragot et al., 2018), allowing breeders to concentrate on key traits (Cobb et al., 2019).
2. Genetic gain is the amount of increase in performance achieved per unit time through artificial selection.

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