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Perspective

Maize seed choice and perceptions of climate variability among smallholder farmers

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ABSTRACT

Despite decades of research and interventions, crop yields for smallholder farmers across sub-Saharan Africa are dramatically lower than in developed countries. Attempts to address low yields of staple crops in Africa since the Green Revolution through policies and investments in advanced seed cultivars have had mixed results. Numerous countries have heartily embraced and promoted hybrid cultivars through government subsidy programs and investments in research and seed multiplication. One possible explanation for why these programs have not resulted in more significant yield improvements is the challenge faced by farmers to select cultivars that are suited to their local environmental conditions. The question of what seeds farmers choose is exceptionally complex as it is often affected by local seed availability, the availability of information on seed performance, and the transfer of that information to farmers. At the foundation of this choice are farmers' perceptions of different seed varieties coupled with their perceptions of climate variability. We examine seed choice in Zambia, a country with decades of hybrid maize seed development and supporting policies. We demonstrate how input subsidy programs and seed market liberalization have led to choice overload and a discontinuity in information exchange between farmers and seed companies. The decision making environment is further complicated by the heterogeneity in growing conditions and its variable impact on seed performance, which complicates characterization of seed duration at the farm level. Perceptions and biases related to climate variability effect seed choice, and potentially lead farmers to make risk averse decisions, which ultimately depress maize yields.

1. Introduction: hybrid maize, input subsidies, and climate variability in Africa

The Green Revolution in Asia during the 1960s was based on the development of high-yielding varieties of staple crops (Evenson and Golin, 2003). During this period, average yields of rice and wheat doubled as a result of the improved germplasm and widespread use of fertilizer, particularly in areas with high rainfall or irrigation access. In sub-Saharan Africa (SSA), where maize is grown by the vast majority of households on rainfed agricultural land, the story is somewhat different (McCann, 2009). Despite the proliferation of hybrid varieties of maize and fertilizer across SSA, African farmers are still struggling to achieve a revolution in grain production similar to other parts of the world (Smale and Jayne, 2003). While many SSA countries like Kenya and Zimbabwe experienced significant gains in maize production since the 1960's, a substantial gap remains between actual and potential maize yields (van Ittersum et al., 2016).

Numerous countries in SSA including Ethiopia, Ghana, Kenya, Malawi, Nigeria, Tanzania, and Zambia have all implemented input subsidy programs at substantial cost to government and donor budgets (Mason and Ricker-Gilbert, 2013). The majority of these programs focus on providing inorganic fertilizer to small farmers at subsidized prices and increasingly on providing subsidized seeds, particularly hybrid maize seeds. These costly and ambitious hybrid crop and fertilizer subsidy programs have been met with limited success (Denning et al., 2009; Mason et al., 2013). While the majority of countries experienced a decrease in absolute maize production during the 1990s, others (such as Malawi) experienced an increase due to input support programs (Smale and Jayne, 2003). There are however, limits to solving the pervasive SSA yield gap through inputs, given the biophysical limitations posed by poor soil fertility and the constraints this places on improvements in crop genetics (Tittonell and Giller, 2013).

Another reason crop yields remain low is changing weather patterns and increasing frequency and intensity of weather events in SSA (Kotir, 2011; Field and Intergovernmental Panel on Climate Change, 2012; Campbell et al., 2016). Climate variability disproportionately impacts

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poorer nations and poorer, agrarian households within those nations who rely on rainfall for agriculture (Jarvis et al., 2011). The impact of climate variability on crop production is expected to constitute a significant threat to food security, particularly with crops like maize in more marginal parts of SSA in this century (Lobell et al., 2008; Rippke et al., 2016). Approximately 40% of Africa's maize growing area faces occasional drought stress resulting in yield losses of 10–25% and one quarter of the maize crop is impacted by drought with losses up to 50% of the harvest (CIMMYT, 2013).

The development of crops that are adaptable to changing weather patterns has the potential to improve food security in rainfed agricultural areas of Africa. In addition to doubling or tripling the yield of local open pollinating varieties (OPVs), some hybrid maize varieties are more adaptable to climate variability (Cairns et al., 2013). One major advance in SSA are varieties that can reach physiological maturity in three to four months as opposed to six months which is more common with OPVs. Hybrid varieties with different maturation periods have the potential to mitigate the effects of increasingly erratic growing seasons and facilitate adaptation to climate variability by maximizing the growing period (Tambo and Abdoulaye, 2012). Early maturity hybrids are more appropriate for areas with either a short rainy season (about three months) or that frequently experience dryspells or drought (Cooper et al., 2008). Additionally, early maturing varieties, can be planted later in any region if the rains begin later and still reach physiological maturity by the end of the growing season (Smale et al., 2015). Medium maturing varieties are appropriate for zones that reliably get four to five months of rains and late maturing varieties are most advantageous in higher rainfall zones that can support a six to seven month growing season. There is a tradeoff with maturity though since generally speaking, a longer maturation period translates into higher potential yield.

There is a growing literature documenting that farmers in developing countries are aware of trends in precipitation variability and employ a range of coping and adaptation strategies (Thomas et al., 2007; Mertz et al., 2008). A number of studies document various ex-ante agricultural strategies smallholder farmers use to cope with the effects of climatic variability including selecting new seed varieties (for example: Eakin, 2000; Smit and Skinner, 2002; Jarvis et al., 2011; Mercer et al., 2012). Most of the literature concerning climate adaptation focuses on demographic and economic explanations (for example: Below et al., 2012; Bryan et al., 2009; Deressa et al., 2009), and to a much lesser extent psychological and behavioral factors (for example, Jain et al., 2015). There is a growing literature regarding the importance of smallholder perceptions of climate change (Grothmann and Patt 2005; Mertz et al., 2008; Nyanga et al., 2011).

There are a number of cognitive factors that can influence farmer's perceptions of climate variability and adaptation. People rely on heuristics for judging probabilities and this can cause them to assign greater weight to more recent or extreme events (Tversky and Kahneman, 1973), which has been found to be true with farmers experiencing shocks and disturbances (Morton, 2007; Marx et al., 2007; Hertwig and Todd, 2003). There is also evidence that historical preferences or "path dependency" can influence perceptions and hinder adoption of climate adaptation technologies (Wise et al., 2014). The efficacy of one's beliefs about coping with drought is also an important predictor of an individual's propensity to adopt and maintain new behaviors (Truelove et al., 2015).

Another factor which may impact an adaptation activity such as a farmer's seed choice is their ability to evaluate multiple competing varieties of seeds. Farmers need to process many factors related to seed selection as well as to navigate the decision landscape under conditions of environmental uncertainty. Past research has found that poverty, common among smallholder farmers in SSA, impedes cognitive function (Mani et al., 2013). The choice of what seed to plant is cognitively challenging given the vast array of seed attributes and varieties a farmer must both understand and evaluate. Each farmer has unique experiences with seed varieties, unique farm conditions, and faces a different set of choices constrained by local seed availability, all of which dictate what variety they seek in a given year. In other words, farmers make seed choices based on many factors and it is unclear how important climate-related factors are relative to other factors.

With a generally weak presence of agricultural extension in SSA and an influx of seed varieties from private seed companies and non-governmental agencies, farmers are inundated with numerous yet similar choices of cultivars. Previous research has investigated farmer perceptions of seed cultivars (Gibson, 2009) and adoption of maize varieties (Fisher et al., 2015) but not unpacked the behavioral complexity inherent in the selection of hybrid maize seed cultivars by farmers given the diversity in farmers' perceptions of climate variability. We explore seed choice and misinformation by examining the following research questions: (1) How do farmers' perceptions of hybrid maize seed attributes differ from information provided by seed companies? (2) Is there a mismatch between farmers' seed choices and the timing of planting within the context of inter-annual climate variability? (3) What factors drive the choice of maize cultivars and to what extent do farmers' perceptions of climate variability matter?

We explore these research question in the context of southern Zambia, a region with relatively low rainfall conditions in a country where maize cultivation is prevalent, and hybrid maize adoption is high. While we explore these research questions in a specific context, the decision-making is similar across maize producing areas of SSA despite the high physiological and socioeconomic variability. In countries where maize production dominates, there are diverse seed types available, generally low information exchange about different cultivars, and heterogeneity of farmers' perceptions of weather events and climate trends even within a small geographic area.

2. Introduction of hybrid maize seed in Zambia

The maize seed industry in Zambia was formalized with the establishment of the parastatal Zambian Seed Company (Zamseed) in 1981 (Morris, 1998; Smale et al., 2015). Zamseed was largely organized to replicate maize seed varieties, developed by the National Agricultural Research Service (NARS), which was responsible for the establishment of shorter-season hybrid varieties. The government of Zambia also provided farmers with subsidized fertilizer and seed on credit and purchased their harvest through the parastatal National Agricultural Marketing Board (NAMBOARD) (Smale and Jayne, 2003). These new varieties combined with subsidized credit for seed and fertilizer led to a doubling of maize area in Zambia during the 1970s and 1980s (Smale et al., 2015). The establishment of similar institutions and similar investments made during the colonial period in various African countries had similar benefits for small farmers post-independence (Smale and Jayne, 2003).

As a result of pressure from the International Monetary Fund and the World Bank through the Structural Adjustment Program, the government of Zambia liberalized the seed market in the 1990s. During this process, Zamseed was privatized, and new regional and international seed companies entered the market. The number of hybrids and improved OPVs doubled between 1992 and 1996 (Howard and Mungoma, 1997). Since then, hundreds of new varieties have been released in Zambia by 14 different companies and research institutions, and the rights of almost all these varieties are held by private seed companies (Smale et al., 2015). The International Maize and Wheat Improvement Center alone released 160 drought tolerant maize varieties between 2007 and 2013 in 13 African countries (Fisher et al., 2015). Many of these new hybrid varieties were released by multinational companies on a regional scale and so many of the varieties are the same across SSA countries.

After liberalization the government abandoned NAMBOARD due to its high operational costs but found it politically infeasible to stop subsidies (Smale and Jayne, 2003). The Fertilizer Credit Program (FCP), started in 1997, was an input loan until the end of the season but loan default was high and the FCP morphed into the Fertilizer Support Program (FSP) in 2002 (Mason et al., 2013). The name of the program was changed to the Farmer Input Support program (FISP) in 2009 but the goal remained the same. Since independence, there was only a brief period in the early 1990s where there were no agricultural subsidies in Zambia (Mason et al., 2013). In other countries where adoption of climate adaptable varieties is high, such as Malawi and Uganda, input subsidy programs and dissemination efforts are believed to be the reason for adoption (Fisher et al., 2015).

Originally FISP allocated maize varieties to farmers in various regions based loosely on agroecological suitability. The seed and fertilizer was delivered directly to farmers through their agricultural cooperatives based on FISP assessments leaving farmers no choice about the variety. Over time FISP allowed farmers to choose between more varieties of hybrid maize and gradually offered more seed variety choice to farmers each year. With the introduction of the electronic voucher program in the 2015–2016 growing season (implemented in thirteen districts across the country) farmers are able to use vouchers to redeem inputs from agricultural suppliers, thus giving them a choice of any hybrid maize seeds available from their preferred dealer. Redemption of coupons to purchase seeds is also used in other countries, although in some cases, such as Malawi, farmers are able to choose between OPVs and hybrids (Dorward et al., 2008).

The process of hybrid seed development in Zambia involves numerous national, regional, and international private seed companies (see Fig. 1). Seed companies submit newly developed varieties to the Seed Certification and Control Institute (SCCI) who evaluate the seeds at seven research stations across Zambia for two years. The Variety Release Committee (VRC), comprised of various government and non-government stakeholders, decides which seeds to certify. Once certified, the new varieties are released to farmers. Varieties historically reached farmers through the FISP (orange pathway in Fig. 1) but with the introduction of the electronic voucher ("e-voucher") component to FISP piloted in the 2015–2016 season, farmers are able to choose any seed available on the market directly through agricultural input suppliers (blue pathway in Fig. 1).

Through investment, market liberalization, and subsidies, the Government of Zambia effectively institutionalized hybrid maize production among small-scale farmers over the last few decades, a trend that is similar across SSA. In the process, farmers who were accustomed to very few choices of maize cultivars are increasingly faced with an abundance of choice and varying degrees of information about these new seed alternatives. We address the pervasive and complex seed choice issue in the context of smallholder agriculture in southern Zambia, a country that has one of the highest rates of adoption of hybrid seeds in a relatively low rainfall region where drought and dryspells are commonplace.

3. Study area

Zambia is a dryland ecosystem and the majority of farming is rainfed agricultural production. There is a unimodal rainy season that runs roughly from November until April. This study took place in Choma and Pemba districts, two of the 13 districts that comprise Southern Province. Our study area is similar to other arid regions of SSA characterized by high frequency of dryspells and drought events (Fisher et al., 2015). There are three agroecological zones in Zambia and average annual rainfall ranges from 800 to 1200 mm per year. The southeast portion of Choma and Pemba fall within agro ecological Zone I, covering one of the hottest and driest region of the country while the remainder of Choma and Pemba fall within Zone II, a medium rainfall belt.

In our study area, the texture, structure, and physical properties of the soil vary but generally have poor physical properties that make it difficult to till and difficult to access nutrients. Topographical constraints on crop production in this area include soil erosion and low soil depth in hilly and escarpment areas (Aregheore, 2017).

Hybrid maize adoption is very high and increasing in Zambia, similar to other SSA countries (including Kenya and Zimbabwe) that have developed hybrid seed systems (Smale et al., 2013). Almost all smallholder farmers in the study area rely solely on rain for maize production and more than 80 percent of farmed land is allocated to maize. See Fig. 2 for map of sample area and participant locations.

3.1. Sample

Household-level surveys were conducted between October 14 and November 10, 2016 prior to the arrival of the rainy season. Survey questions covered basic socioeconomic data, production data from the 2014–2015 season, farmers' perceptions of rainfall, and rainfall events and their previous experiences with extreme weather events. The maize

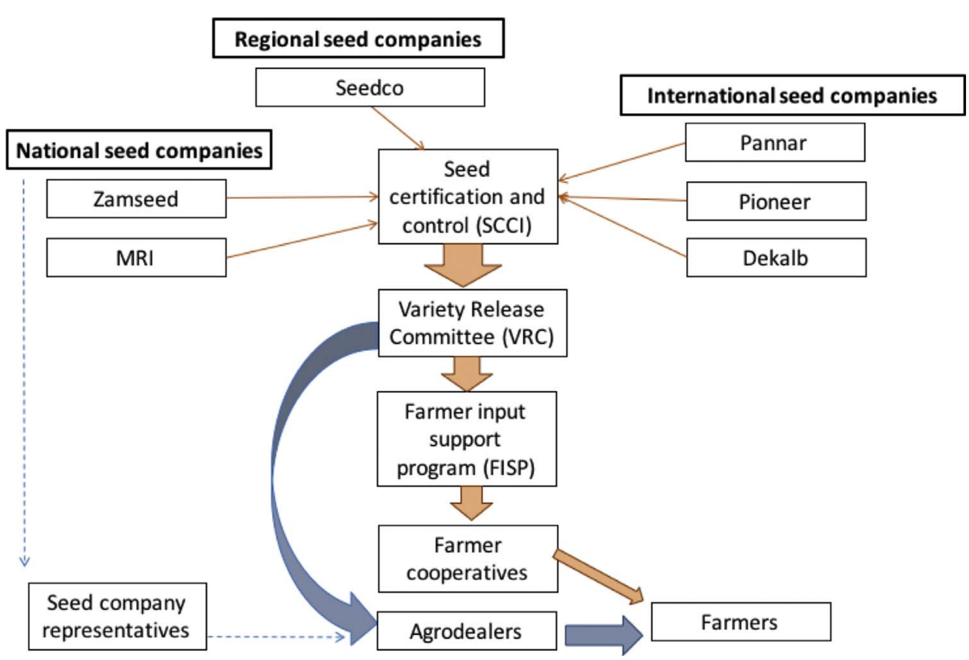

Fig. 1. Schematic of seed choice filtering in Zambia. *Note: the orange pathway illustrates the filtering of seed choice prior to the 2016 growing season and the blue pathway illustrates the abundance of seed choice after the introduction of the e-voucher system, rolled out in the 2015/6 season.

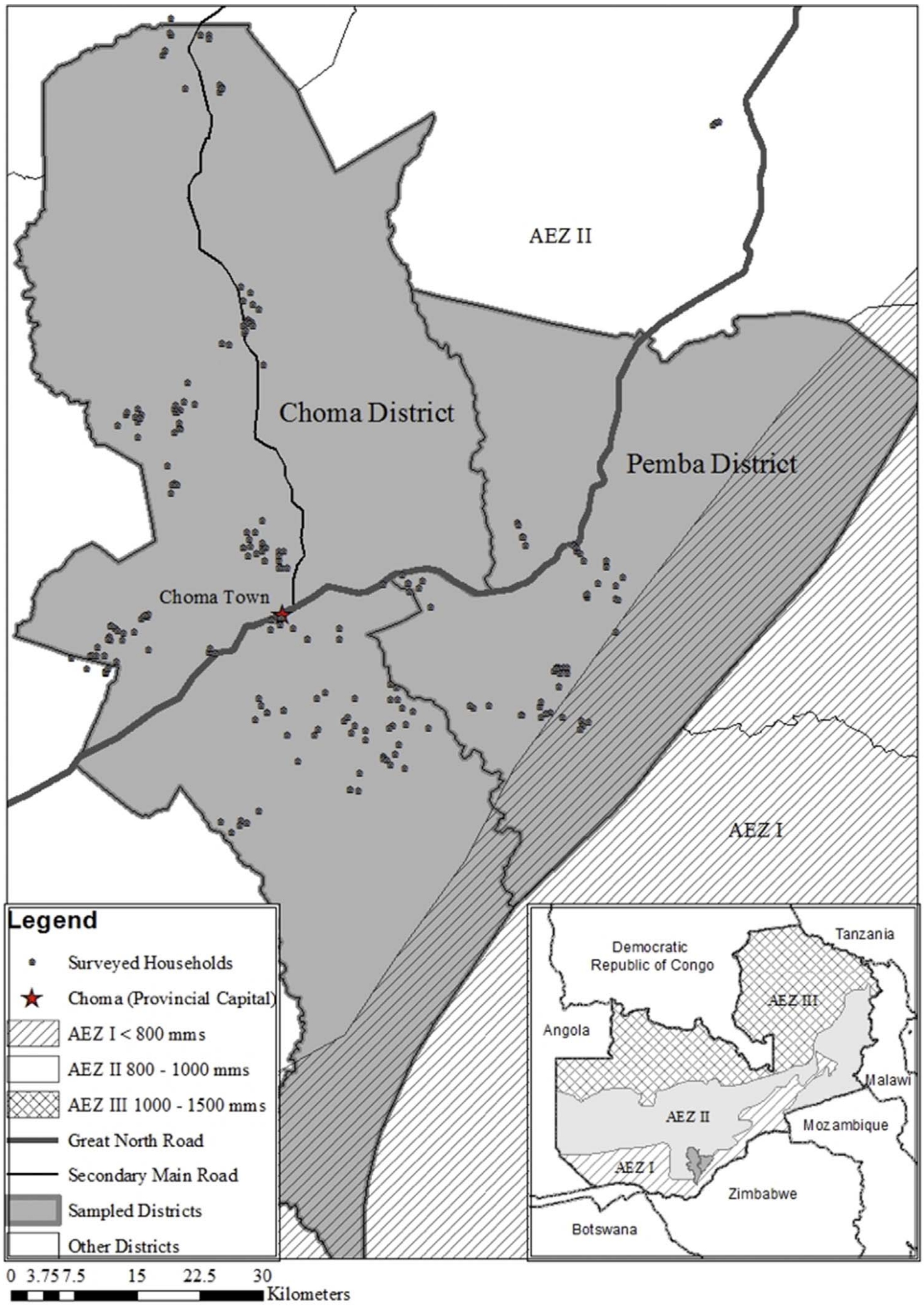

Fig. 2. Map of study area, showing surveyed households and agroecozones.

yield data covered each maize "planting", or each time a farmer planted a different maize variety or planted maize on a different date. The environmental perceptions variables are described in more detail below. We sampled households from all 12 camps (the administrative unit below district) within Choma and Pemba districts.

We contacted camp officers (similar to agriculture extension agents) and asked them to contact three community chairpersons who were each asked to invite 20 farmers to participate. We asked the chairpersons to select participants from community rosters to attend a group meeting at a central location, ensuring representation from "vulnerable and female headed households" We then randomly selected roughly one-third of each group to participate in the survey for a total of 244 farmers.

Table 1 provides descriptive statistics of the sample population. Sixty-two percent of the sampled respondents were male with an average age of 46. There were 8 household members on average, 3.7 of which were children, 2.7 were young adults, and 0.3 were over 65. The average respondent completed some secondary school and the highest average education level in the household was completing secondary school. Eighty-eight percent of respondents were members of agricultural cooperatives, 83% participated in FISP, 17% held titled land. The average time it takes to walk from a respondent's household to an improved road was 75 min.

3.2. Precipitation and planting dates

In Zambia there is a distinct growing season from roughly November to April. Fig. 3 depicts daily precipitation over the growing season from a weather station in Mochipapa, outside of the district town of Choma. The planting dates for farmers' primary plantings

Table 1
Descriptive statistics of farmers (N = 244).

Variable	Mean	Std. Dev.	Min	Max
Age (years)	45.85	12.15	21	81
Asset Index (PCA quintiles)	2.81	1.43	1	5
Education level (categories)[a]	4.26	1.33	0	7
Total household labor (people)	5.81	2.53	0	13
Off farm income (Kwacha)[b]	2970	5008	0	43,900
Cooperative member (1 = yes)	0.88	0.33	0	1
Participated in FISP (2014–2015)	0.83	0.38	0	1
Distance to improved road (minutes walking)	75.90	135.14	1	1000
Hold land title (1 = yes)	0.17	0.38	0	1
Earliest planting date (weeks after Oct 1)	4.94	1.78	1	10
Number of fields planted (fields)	1.99	0.95	1	5

[a] Educational categories are as follows: None (1), Some Primary (2), Completed Primary (3), Some Secondary (4), Completed Secondary (5), Some Post-Secondary (6), Completed Post-Secondary (7).
[b] One Zambian kwacha (ZMW) = $0.10 at the time of survey.

varied from early November until the end of December. Nearly one-third of farmers planted some maize field during the week of December 1.

Intermittent periods of no or low rain are common—such as the dryspell that occurred during the first three weeks of March in the 2014–2015 season. Most farmers reported that dryspells lasted between 14 and 30 days. There was heterogeneity in the duration of dryspells by farmers within close proximity demonstrating the microclimatic variation common in this area. Dryspells can be particularly damaging during the flowering and early grain filling stages and can sometimes result in total crop loss or require replanting.

3.3. FISP and seed choice

We asked farmers to identify specific plantings of maize given that many farmers may plant multiple cultivars in a single growing season or distribute plantings of a single cultivar across different planting dates. We define a planting as any variety or combination of varieties in a given field on a given sowing date. Data used in this paper were collected from the 2014–2015 growing season, prior to the rollout of the electronic voucher program, so seed choice was still somewhat constrained. In the 2014–2015 growing season farmers cultivated a total of 37 different varieties of maize. Of these, 22 varieties were reported as acquired through the FISP and seven "local" (OPV) maize varieties reported. Of the eight seed companies currently producing hybrid maize in Zambia, farmers in the sample planted varieties from six: Dekalb (DK), MRI Seed Zambia (MRI), Pannar Seed (PAN), Pioneer (PBB),

Table 2
Seed varieties cultivated and relevant attributes.[a]

Variety	Obs	Classification	Days to maturity	Price (ZMW/ 10 kg)[b]	Price (ZMW/ 25 kg)[b]	Potential (mt/ha)
DK 8031	8	Very early	105	155	–	6.5
DK 8033	49	Early	110–115	157	–	10
DK 8053	1	Medium	120–130	157	–	10
DK 9089	1	Early/Medium	115–120	170	–	10
MRI 594	1	Medium	130	150	340	10
MRI 614	13	Medium	130	150	340	10
MRI 624	53	Medium	135	175	400	11
MRI 634	5	Medium	135	150	340	10
MRI 694	2	Medium	145	300	650	13
PAN 413	44	Very early	110–115	240	600	9
PAN 4M-19	1	Early	100–110	–	–	8
PAN 53	55	Medium	135–140	160	400	9
PIO 30G19-6	64	Early	128	220	550	–
PIO P2859W	2	Medium to Late	135–145	247	618	–
SC 403	6	Very early	121–125	150	360	5
SC 411	2	Very early	121–125	150	360	8
SC 507	1	Early	–	–	–	–
SC 513	58	Early	127–130	180	425	8
SC 525	3	Early	127–130	180	425	10
SC 608	2	Medium	130–136	345	760	14
SC 621	3	Medium	130–136	190	445	9.5
SC 627	7	Medium	130–136	190	445	10
SC 637	5	Medium	130–136	235	540	13
SC 701	1	Late	140–148	345	760	13
SC 719	1	Late	140–148	320	750	14
ZMS 402	3	Very early	100–105	200	485	6.5
ZMS 520	2	Early	–	–	–	–
ZMS 606	50	Medium	125–130	230	570	9
ZMS 608	6	Medium	–	–	–	–
ZMS 638	1	Medium	125–130	265	640	9.5
Total	450			208.16	509.23	9.84

[a] The data in this table comes from seed company publications. Missing data reflects instances where we could not find any documentation.
[b] One Zambian kwacha (ZMW) = $0.10 at the time of survey.

SeedCo (SC), and Zamseed (ZMS). No single seed company dominated in Southern province and of the seven most popular varieties, six were from different seed companies.

Seed companies use different terminology to characterize the maturity periods of varieties they produce. Seed companies initially characterized the maturity categories as "early", "medium", or "late" maturing but more recently some seed companies have started using finer terms like "very early" and "early to medium". Seed Co recently released an "ultra early" variety, which matures even earlier than "very early".

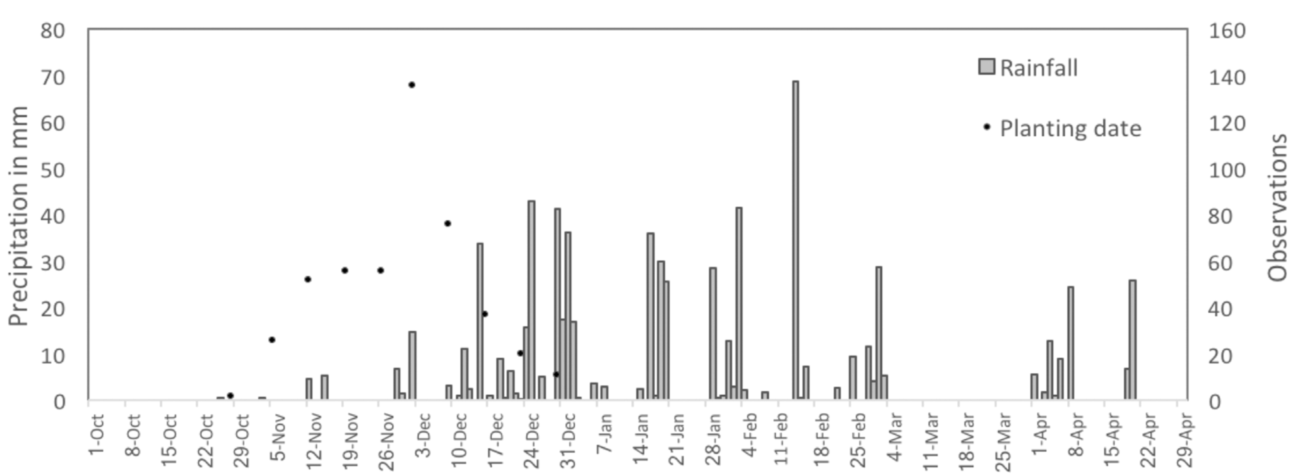

Fig. 3. Precipitation and planting dates in Choma District, Zambia during the 2014–2015 season[a].
Note: [a] Precipitation data comes from the Mochipapa research station in Choma Province. Planting dates frequencies are from the household surveys from Choma and Pemba Provinces.

Table 2 illustrates the 30 hybrid varieties cultivated by farmers in the study area. There is an overlapping range in classification and the number of days to maturity according to published manuals of seed companies for the varieties reported by farmers: Very early: 105–125; early: 110–130; medium: 120–136; and late:140-148. Very early to early are only five days different on either end with 15 days of overlap. Early and medium also overlap by 10 days.

The majority of farmers planted early or medium maturing varieties. There were only two plantings of late maturing hybrid varieties out of the entire sample of 450 plantings. Thirty-eight plantings of local maize were reported (not included in the table). We can also see in the table that according to seed companies categorization there is a positive relationship between the yield potential of a seed variety and the duration. Generally speaking, the longer the plant spends in the field, the higher the yield is expected to be. It is also clear from the table that the seed price increases with the duration and thus yield potential of the variety.

4. Results

The following section describes the seeds chosen by the sample of farmers in Southern district and their attributes as defined by farmers and seed companies. We then look at farmers' planting dates and the impact of planting dates on maize yield by seed maturity class. The final portion of the results section examines the determinants of maize seed choice.

4.1. Perceptions of seed attributes

Table 3 presents farmer's assessments of the attributes associated with the hybrid varieties they are most familiar with. Each attribute has a value of 1 if the farmer stated that the given attribute was a positive characteristic of the crop, and 0 otherwise. The mean value presented is the percentage of farmers whom associate each attribute with the seed variety they chose. These percentages can be roughly interpreted as the marginal utility of choosing a variety because of that attribute.

The most common attribute associated with any variety was whether the seed was easily available, which is important given that choice is limited for many of the most remote farmers. High yield is an important attribute of hybrid maize to farmers, although so is the performance of the variety when intercropped with other crops (e.g. usually rows of maize interspersed with rows of beans). Various consumption attributes are also important to farmers including taste and poundability; or how easy it is to pound the maize into a flour that is used to make the traditional maize meal dish (nsima). Storability is also important to farmers, a quality which varies based largely on the hardness of the maize shell and is important given that farmers need to make seed last throughout the year. Production characteristics including resistance to pests and drought are also important to farmers. The quantity of seed required and seed costs are the least cited attributes by farmers most likely due to the minimal variation between varieties.

Table 3
Mean values of attributes associated with familiar maize varieties.

Variable	Mean	Std. Dev.
Good seed availability	0.68	0.46
High yielding	0.63	0.48
Good intercrop	0.57	0.50
Poundability	0.55	0.50
Tastes good	0.55	0.50
Good storage	0.53	0.50
Pest resistance	0.52	0.50
Drought resistance	0.52	0.50
Requires less fertilizer	0.37	0.48
Low seed cost	0.33	0.47

Notes: Data recorded for N = 711 varieties.

Fig. 4 depicts the difference between farmers' perceptions of the duration of hybrid varieties and how seed companies classify the duration. We asked farmers to categorize the varieties as early, medium, or late maturing given the variation in the sub-classifications of maturity used by seed companies discussed above. There are numerous reasons why farmers may perceive varieties to be different than seed companies. Seed varieties may perform differently on farmers' fields which cover a wider variety of soil types and soil fertility than controlled crop trials run by seed companies or SCCI. Research has demonstrated that some government recommended application rates in SSA are not necessarily economically optimal (Sheahan et al., 2013). In part, over application is due to the limited physical response to fertilizer from soils that are degraded and constrained by factors such as low soil organic matter (Marenya and Barrett, 2009).

The overlapping classification of seed maturity displayed in Table 2 may also generate ambiguity between farmer's perceptions and seed company classifications. Farmers in the study area perceive medium maturing varieties to be earlier maturing on average than seed companies and early maturing varieties as later than the seed company's classifications. Overall, there is a reversion to the mean—where on average farmer's perceptions of the maturation period of most varieties falls between early and medium maturity resulting in little overall distinction between the duration of different varieties.

4.2. Impact of late planting

The blurring of variety classification is also evident in farmer's management practices. As Fig. 5 shows, the distribution of planting dates is extremely similar across the different seed types in spite of the variation in the purported "days to maturity" stated by seed companies. For all classes there is a relatively normal distribution of planting dates centered around the first week of December. In effect, farmers are planting varieties at the same time, regardless of the seed company's designation of maturity class. This is particularly troubling for farmers on the right tail of the distribution for medium maturing and local varieties who are planting these maize varieties well into December. Planting this late in the season decreases the likelihood that the rainy season will be sufficient to meet crop needs. Late planting also puts farmers at risk of crop loss to dry spells without sufficient time to replant a new crop.

The 2014–2015 growing season illustrates the pitfalls of late planting well since there was a significant dryspell late in the season. Recall that in Fig. 3 there was no rainfall detected at Mochipapa station between March 3 and April 1. A dryspell late in the season is not likely to impact very early and early maturing varieties that were planted in November, at the beginning of the rainy season. However, a dryspell is likely to have a large impact on the yield of maize that was sown in December. Drought stress is most significant from insufficient moisture in the four-week period around tasseling, so varieties that were planted approximately 60 ± 28 days around the dryspell (in December) are the most likely to be impacted.

In a year without a dryspell, we would expect maize yield per hectare to be relatively consistent across the season. However, Fig. 6 demonstrates a decreasing trend in mean yield as the planting date gets later. The data are self-reported maize yields and the sample size is relatively small so the results are not intended to represent this relationship across time and space. Rather we display the yield data to demonstrate the difficulty in predicting the optimal planting date. It is difficult to predict the performance of any duration hybrid maize variety that is not irrigated because of the uncertainly of dry spells, which is common across SSA. Earlier planting is not necessarily an adaptation strategy that ensures higher yields nor is it necessarily a more risk averse behavior except that if a maize crops fails early in the season, the probability of success from replanting is higher.

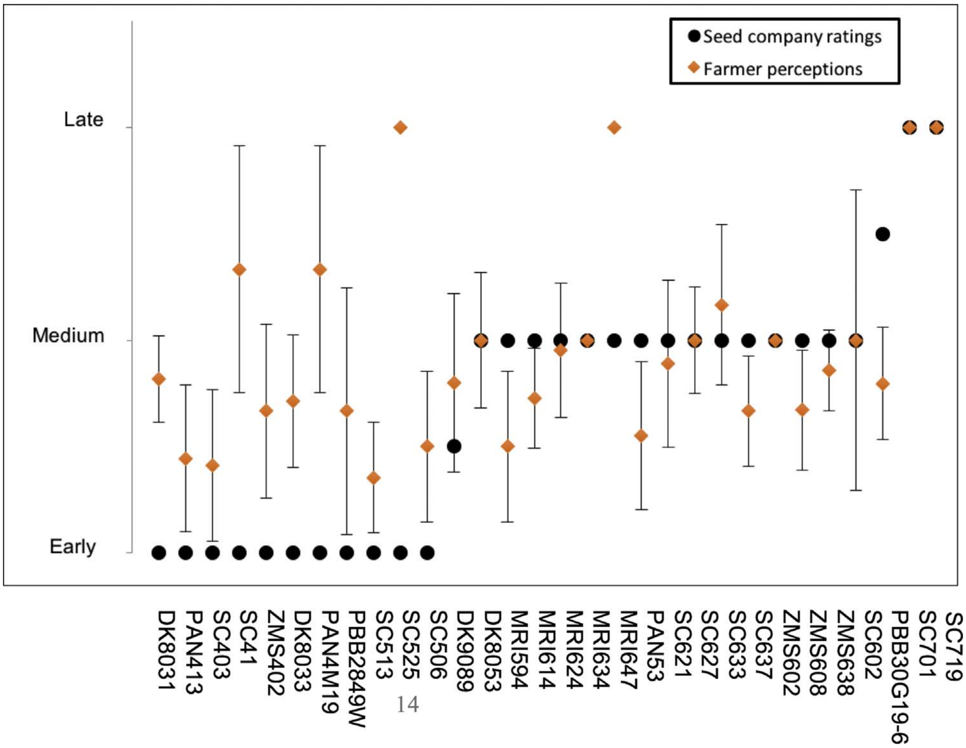

Fig. 4. Characterization of seed maturity by seed companies and farmers (error bars represent standard deviation of farmer perceptions).

Fig. 7a and b illustrates the differences in maize yield by the classification of seed maturity. Fig. 7a overlays the mean yield in the study area with the potential yield estimated by the seed companies. We used the lowest potential yield estimates in each classification. For example, early maturing maize varieties ranged from 5000 to 8000 kg/ha but we just used the lower bound estimate for illustrative purposes. Actual maize yield is typically less than 25% of what the seed companies purport the varieties are capable of. Again, the yield estimates are self-reported and the sample is relatively small so the actual data are very rough estimates designed to illustrate a point.

Potential yield is supposed to increase by maturity period (from very early to medium), the longer a crop is in the field the more maize it will produce, as demonstrated by the increasing trend of the potential yield displayed in Fig. 7a. However, this is not the trend in the actual data. Fig. 7b is a close up of Fig. 7a, displaying just the mean yield by each class of seed. While the relationships are not statistically different due to the extremely wide variation in yield from farm to farm they illustrate the point that the relationship of increasing yield with maturity classification does not always hold true. In this case medium maturing varieties yield slightly lower than early maturing varieties on average. The most likely explanation in this case is that medium maturing hybrid maize was more impacted by the timing of the 2014–2015 season dryspells than very early and early maturing varieties.

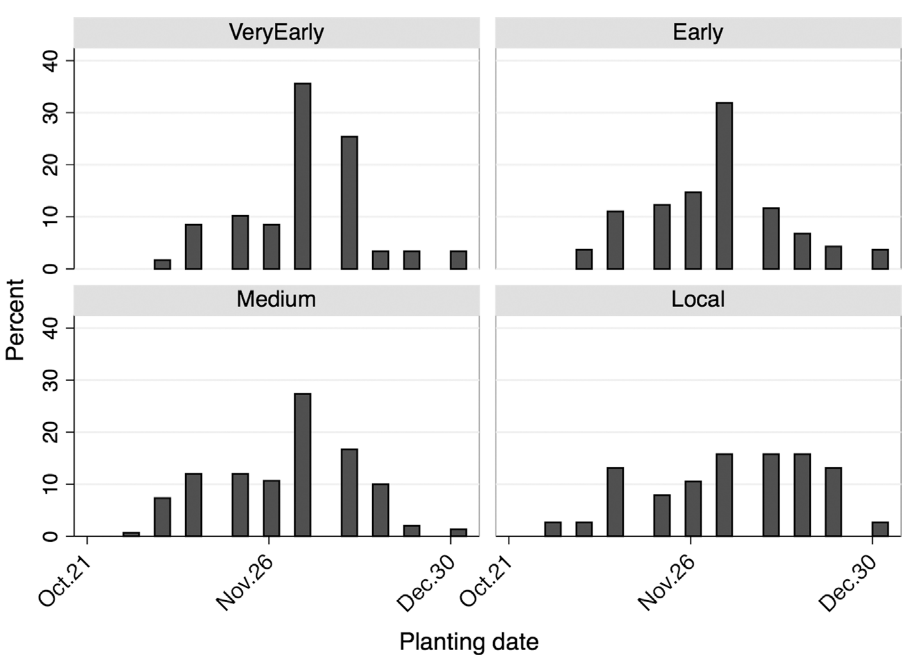

Fig. 5. Farmer planting date by variety maturity classification.
Note: N = 56 (Very Early), 122 (Early), 167 (Medium), and 29 (Late).

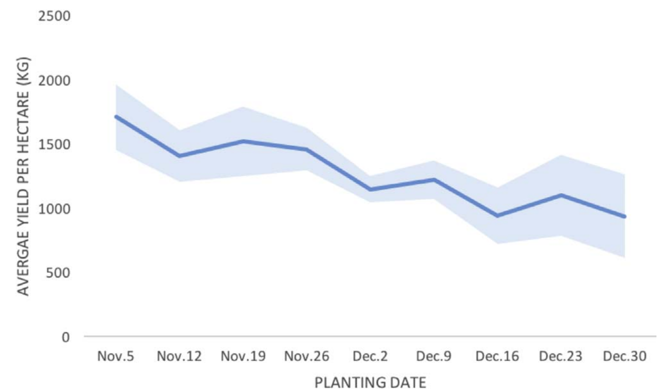

Fig. 6. Mean yield by planting date for all seed varieties planted in the 2014–2105 season (n = 467).
Note: Broader area demonstrates 95% confidence intervals around the mean.

4.3. Determinants of maize seed choice

In this section we describe a model to examine the determinants of hybrid maize seed choice. We pay particular attention to farmers' perceptions of the frequency of drought, the impact of drought on maize yield, and their perception of whether the onset of the rainy season is changing.

4.3.1. Model estimation

In order to understand the determinants of seed choice we use a set of seemingly unrelated regression (SUR) equations where the dependent variable is binary, indicating whether a farmer had planted a variety that is classified as very early, early, medium maturing hybrid or a local variety. The local classification covers a range of well adapted open pollinated varieties and local land races. An SUR model is appropriate here since farmers plant multiple types of maize seed simultaneously and thus the error terms of the equations for each variety are correlated. An SUR is advantageous over a multinomial logit model which assumes independent observations. The categories of predictive factors in the model include a vector of socio-demographic characteristics, a vector of management decisions such as planting date and diversity of maize plantings on the farm, and a vector of variables that characterize farmers' perceptions of climate variability.

Socioeconomic variables included in the model consisted of farmer age, educational attainment, household size, and farm size. We also include distance to markets where agricultural inputs are purchased as a geographical variable. Based on the household asset data we constructed an asset index using a procedure similar to that developed by the Demographic and Health Surveys (DHS) Program and the World Bank (Rutstein and Johnson, 2004). The index is calculated based on household ownership of key assets that were owned by more than 5% or less than 95% of the households and is the first principal component from a principal component analysis (PCA) (Filmer and Pritchett, 2001). Each household asset for which information is collected is assigned a factor score generated through the PCA giving us a scale of continuous asset ownership for the households. The factor score or first principle component is then ranked from high to low and this variable is divided into quintiles. We also estimated total self-reported off-farm income for each household. And finally, we include a set of variables looking at their access to information and assistance: whether or not they were part of an agricultural cooperative and whether they participated in the FISP program last year.

4.3.2. Perceptions variables

The explanatory variables related to perceptions include a) farmers' perceptions of the probability of climatic events expressed as their expectation of the frequency of occurrence of an event converted into a probability, b) perceptions of whether the onset of the rainy season is changing, and c) farmers' expectations of the yield advantages of hybrid compared to local maize under low rainfall and late planting. We included a set of variables to characterize farmers' previous experiences with low and high rainfall events. We also included a variable indicating whether they had previous experience with drought or dryspells.

We asked farmers to estimate the frequency they believe they experience a drought year- the responses are displayed in Fig. 8. Farmers perceptions of how often they experience drought was bifurcated, with approximately half the farmers reporting less than five years and the other half reporting more than 10 years.

Another measure of farmers' perceptions of climate variability is how they think the onset of rains is changing. We asked farmers a series of questions about when they recalled the onset of rains in the last three seasons and display a summary of their responses in Fig. 9. Farmers were able to recall the dates of the rain onset in most cases. We then asked farmers when they perceived the rainy season to begin approximately a decade ago. To approximate farmers' perceptions of whether the rains were getting later we created a variable that is the difference between when they perceived the rain to start in the previous season and when it started a decade ago.

We also characterize farmers' perceptions of the performance of hybrid maize varieties compared to local varieties during a normal year, a year with dryspells, and a year when the rains were late and planting was delayed until January 1st (displayed in Fig. 10). To understand how farmers perceive the impact of drought on hybrids we asked them if they planted 20 kg of local or hybrid maize seed on a given date (December or January 1st), what would they expect the

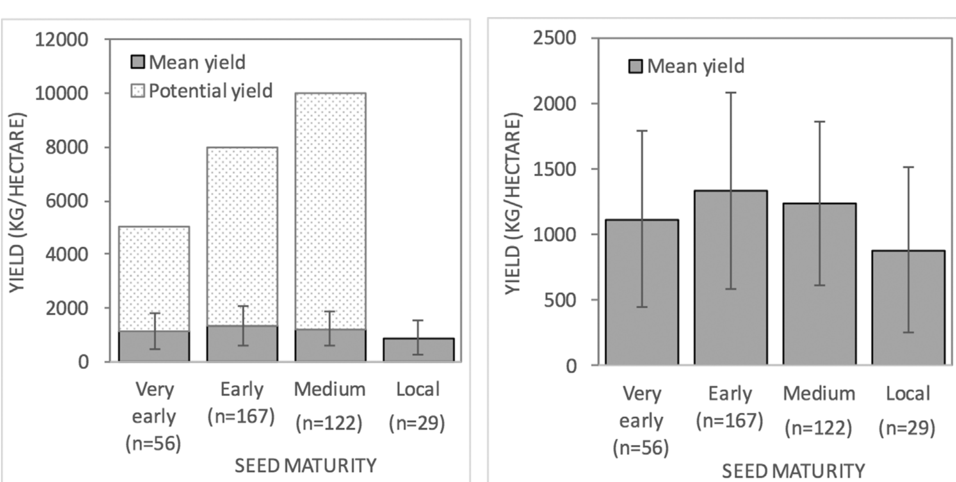

Fig. 7. a & b. Actual mean yield per hectare by seed maturity class overlaid on potential yield published by seed companies (left); mean yield per hectare by seed maturity class (right).

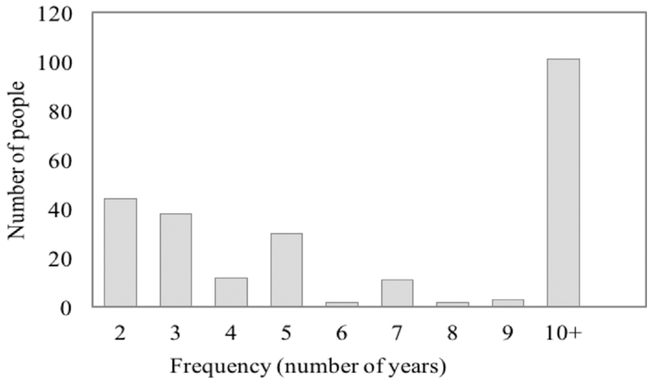

Fig. 8. Farmer expected reoccurrence of drought.
Note: 10+ indicates respondents who perceive a drought to occur more frequently than every 10 years.

harvest to be? Farmers in this sample perceive hybrids to roughly perform twice as well as local maize across all scenarios, if not slightly better under dry spells and late rains.

Previous experience with climatic events is also likely to influence one's perception of future climate event occurrence and thus the level of uncertainty when making maize seed choices. We asked respondents if floods, drought, or dryspells had affected their household in the past 6 years. Floods affected 9% of respondents, drought affected 18%, and dry spells affected 83% respondents.

4.3.3. Determinants of seed choice

When estimating the SUR of the odds of planting very early, early, medium, and local varieties of maize, we clustered the standard errors at the household level to account for farmers who planted more than one planting of a given maturity class. Only two farmers planted late maturing hybrids so we were unable to perform statistical analysis on this maturity class. The majority of farmers planted either early or medium maturing varieties.

Only 23% of farmers planted a very early maturing variety and the only significant predictor is that the likelihood of planting an early maturity variety increases with the number of total maize plantings a farmer made.

The odds of planting an early maturing variety decrease by five percent each week a farmer perceives the rains to be getting later over the last 10 years. This supports the notion that farmers' perceptions

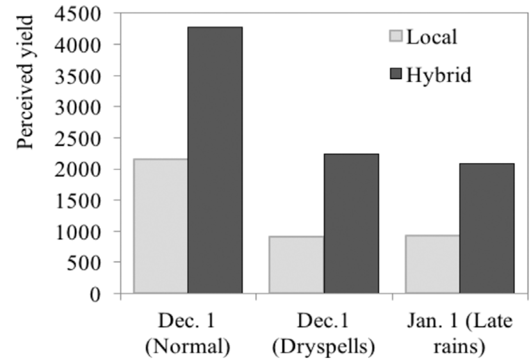

Fig. 10. Mean perceived yield of 20 kg of local versus hybrid maize seed with different planting dates under various conditions (n = 244 farmers).

about the climate influence their decision to plant an early maturing variety. These farmers tended to be older, less educated, and more likely to hold a land title than farmers who did not plant an early maturing variety. The odds of planting an early maturing variety increase by approximately three percent each week of the growing season (Table 4).

Farmers who planted medium maturing maize varieties were not impacted by perceptions of climate variability. These farmers were on average more educated and had been recipients of FISP, which tends to give out medium maturing hybrids because they are suitable for a wider geographical area of Zambia.

Farmers who planted a local maize variety were also impacted by perceptions of the climate as they perceive hybrids to be more impacted by dryspells. These farmers tend to be older and further from improved roads. The later in the growing season the less likely farmers were to plant local varieties, which makes sense given that they tend to have a longer growing period than hybrids (by as much as three months with very early hybrids).

5. Discussion

5.1. Seed choice and misinformation

The proliferation of hybrid maize adoption in Zambia is intertwined with the history of institutions and policies promoting hybrid maize. Liberalization of the seed market flooded Zambian farmers with choices

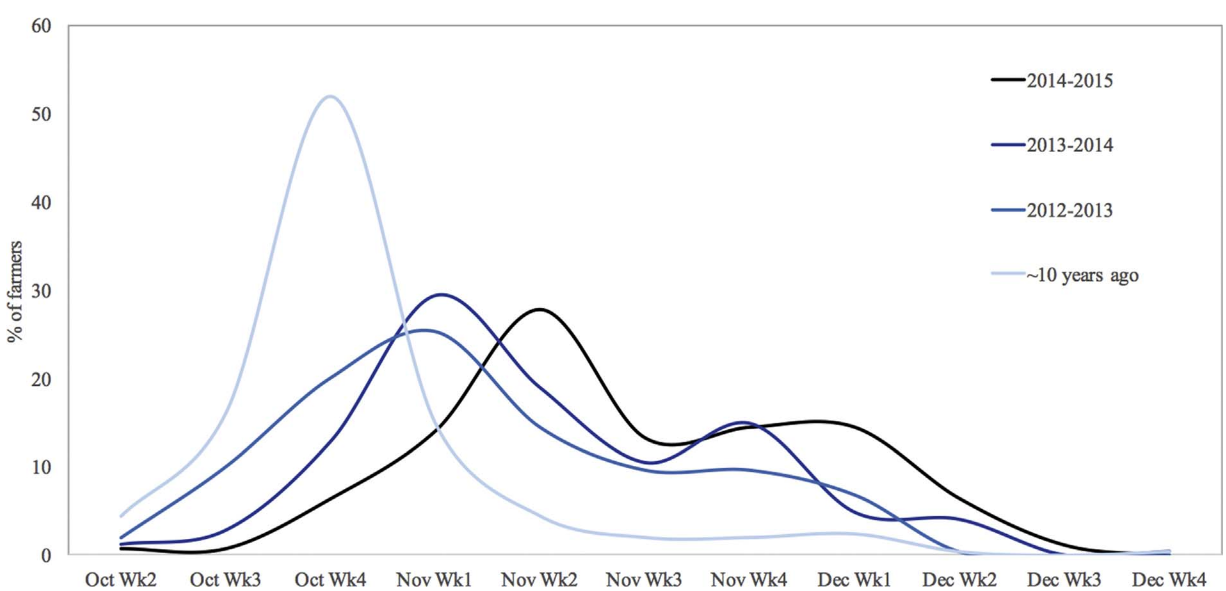

Fig. 9. Farmer perceptions of the changing onset of the rainy season.

Table 4
Seemingly unrelated regressions of seed choice.

	Very early		Early		Medium		Local	
	Coef.	P > |z|	Coef.	P > |z|	Coef.	P > |z|	Coef.	P > |z|
Drought probability (%)	0.149	0.33	0.008	0.96	0.030	0.85	0.35	0.73
Effect of dryspells on hybrids (%)	−0.006	0.52	−0.008	0.40	−0.009	0.33	−2.00**	0.05
Later onset of rains (weeks)	−0.015	0.26	−0.033**	0.02	0.022	0.14	1.07	0.29
Age (years)	−0.001	0.57	0.005*	0.06	−0.004	0.15	1.77*	0.08
Asset Index	−0.034	0.11	−0.038*	0.09	0.013	0.58	0.07	0.95
Education level (years)	−0.030	0.18	−0.052**	0.03	0.060***	0.01	−0.14	0.89
Total household labor (people)	0.009	0.43	0.009	0.45	−0.013	0.30	−0.79	0.43
Off farm income	0.000	0.16	0.000	0.11	0.000	0.32	−0.81	0.42
Cooperative member	−0.116	0.37	0.038	0.78	0.187	0.18	0.31	0.76
Participated in FISP (2014–2015)	−0.078	0.51	−0.090	0.47	0.332***	0.01	−0.25	0.80
Distance to improved road	0.000	0.86	0.000	0.74	0.000	0.26	−2.33**	0.02
Hold land title (Yes)	−0.088	0.25	0.149*	0.06	0.017	0.84	−1.70	0.09
Earliest planting date (week)	0.017	0.32	0.032*	0.08	−0.019	0.31	−1.80*	0.07
Number of fields planted	0.100***	0.00	0.181***	0.00	0.201***	0.00	4.82***	0.00
Constant	0.383	0.18	0.328	0.28	−0.376	0.22	−0.25	0.80
Observations (yes)	56		167		122		29	
Observations (total)	241		241		241		241	
R-squared	0.087		0.1778		0.2585		0.150	
RMSE	0.401		0.419		0.430		0.290	
chi2	21.26		48.45		78.11		39.59	
P-value	0.0952		0.000		0.000		0.000	

Note: Asterisks denote statistical significance at the *10%, **5%, and ***1% level.

and the use of e-vouchers now allows them to choose their preferred varieties. However, it is unclear whether farmers have access to the necessary information to navigate such a complex decision-making environment. With this backdrop we find heterogeneity in preferences and little consensus between farmers and seed companies about the attributes of the varieties, particularly in terms of the maturity period.

Uncertainty about maturity classifications illustrated in Fig. 4 is in part due to the climatic variation and frequent drought stress in dryland parts of Africa. Within a district a seed variety can have such a wide range of responses, particularly in terms of the number of days to maturity, that the classifications are effectively meaningless. If there is wide ambiguity about the maturity period of a seed variety then seed maturity classifications may simply lead farmers to conclude that the classification is not useful information. Similarly, if seed companies provide yield information to farmers that is not representative of how the varieties actually perform on farmers' fields, this may simply confuse farmers further and make them less likely to view seed company information as reliable (Fig. 7).

There are also limits to farmers' ability to process information, possibly leading to cognitive overload (Iyengar and Lepper, 2000). Farmers receive some information from the seed package, through contact with the agrodealers, seed company representatives, other farmers and through advertisements or crop trials on lead farmers' fields. In addition, farmers pay attention to what seeds have done well for them in the past and with other farmers in their social network. But given research demonstrating that stress and poverty in particular can impede cognitive function (Mani et al., 2013), it is very likely that farmers struggle to organize and process the incomplete information that reaches them.

5.2. Seed availability

As expected, high yield is one of the most important attributes of seed varieties to farmers but they also select varieties for myriad other reasons (displayed in Table 3). Numerous studies have confirmed the importance of both production and consumption attributes to subsistence farmers in developing countries (for example: Waldman et al., 2014; Ortega et al., 2016). Pest and drought resistance are important production attributes to farmers but are not often advertised effectively. According to SCCI records, few hybrid varieties are explicitly characterized as "drought tolerant" varieties in Zambia and in low rainfall areas like Choma district all maize varieties must have some drought tolerance given the ubiquity of dryspells. Storing maize is a major challenge across Africa (Thamaga-Chitja et al., 2004) and hybrids tend to have greater than 40% storage loss, which is much higher than local maize varieties on average (Morris, 1998). While attributes like yield are important, farmers value seed varieties for a multitude of reasons that are not explained by information on the seed packaging or in literature disseminated by seed companies.

There is also evidence (in Table 3) that the availability of seed is a very important factor in determining which seed varieties farmers choose, in contrast to what they may have chosen based on their actual preferences for other attributes. Some maize varieties have historically been more available than others because they are disseminated through government run programs and there may exist path dependency related to those varieties among a "loyal customer base" (Smale et al., 2015). And while a variety typically does not remain in production for more than five to six years, seed companies frequently introduce and market new and improved versions of previous varieties. At the same time the choice of seed varieties available to farmers varies by the distribution of agro-dealers and seed company representatives, with fewer choices generally found in rural areas. So while there may be an overabundance of choices on the market if farmers travel to urban areas, for many farmers who purchase seed locally their choices are constrained based on availability.

5.3. Are farmers using the early maturing maize varieties as breeders intend them to be used?

Farmers employed a wide variety of planting dates in the 2014–2015 season, spanning a 9-week period (see Fig. 5). It is apparent from the data collected here that the interaction of the planting date and rainfall patterns can alter the "potential" yield of maize hybrids. Minimizing the time it takes a maize plant to mature physiologically is the major contribution of early maturing hybrids as they allow farmers to cope with late planting. While seed companies may consider varieties to be "drought resistant" without soil moisture from rainfall there is little opportunity to plant earlier than most farmers currently plant. This is evidenced by the rain onset observed during the 2014–2015 season.

There is heterogeneity in environmental conditions at the national, provincial, district and even farm level in Zambia. The upper plateau of the Southern Province has relatively little topography, but even micro-topographic factors can cause two fields within a small spatial area to have different levels of soil moisture. This environmental heterogeneity at multiple scales creates variation in the effective length of the growing season. In southern Zambia and other arid parts of SSA, the rainy season is short and farmers' decisions about when and what to plant are critical. There is evidence from the regression results that farmers who plant later in the season are more likely to plant early maturing hybrids but there is also evidence that they are planting medium and late hybrids as well as local OPVs late into the growing season. This suggests that some farmers do not grasp the concept of variable maturity, do not put much stock in it, or cannot afford to follow recommended practices.

5.4. How do farmers' perceptions about climate variability influence seed choice?

The regression results suggest that perceptions and uncertainty about future climate events influence maize seed choice. This is consistent with research demonstrating that risk perceptions related to the climate influence climate adaptation behavior (Esham and Garforth, 2013; Jain et al., 2015). This finding and research from the psychology literature suggest that perceptions about climate uncertainty likely influence other agricultural decisions. Known cognitive biases such as status quo bias (Samuelson and Zeckhauser, 1988; Kahneman et al., 1991) also likely influence low maize yields in SSA in ways that have yet to be explored. For example, if farmers are optimistic about the future rains they may be more willing to take a risk and plant medium maturing hybrid varieties given the higher yield payoffs, before knowing when they will be able to sow the crop.

Similarly, we found that farmers' previous experience with varieties can influence future agricultural decision-making. If a farmer had a bad experience with hybrids in the past they may become more risk averse and more likely to plant OPVs. There is research demonstrating both that hybrids perform worse than OPVs under conditions of low fertility or abiotic stresses (Friis-Hansen, 1992) and that hybrids perform better under stress (Smale and Heisey, 1997). Risk can mean dramatically different things to different people (Slovic et al., 1986). Planting an early maturing hybrid could be understood by one farmer as a form of risk aversion in the sense of accepting a lower maize yield in exchange for lower exposure to weather fluctuations (compared to a later maturing variety). Or planting an early maturing variety could be understood as taking a risk by another farmer who is more comfortable planting traditional OPVs that they have more experience with and have seen perform well under drought conditions.

We also found that farmers' perceptions of the onset of the rainy season influence seed choice. The earlier a farmer perceives the rains to have started historically impacts the choices they make in the present season. The odds of planting an early maturing variety decrease the later they perceive the onset of the rains, which is particularly relevant for farmers who purchase seed before they know when the rainy season will start. If their perception of the rainy season onset is biased, which is common with complex phenomena such as climate change (Weber, 2010), they are likely to make ill informed decisions. The accuracy of farmer perceptions of rain onset and climate change is an understudied phenomenon and deserves further attention.

6. Conclusions

The choice of maize seed variety is a critical decision for farmers on the brink of food insecurity in Africa. Now that many African farmers are inundated with choices of hybrid maize seeds, it is important that they understand the tradeoffs involved. Presenting farmers with greater choice of maize seed varieties allows them to tailor their selections to their individual cropping systems, but there are significant constraints to translating more choice into improved maize yield. We identify three factors that appear to influence maize seed choice and may contribute to depressed maize yields in Africa: 1) a discontinuity of information between farmers and seed companies about seed maturity and performance, 2) a challenge in classifying seed varieties that results from the heterogeneity in growing conditions, and 3) perceptions related to climate variability that may cause farmers to be more risk averse.

Choice overload resulting from liberalization of the seed market complicates the decision making environment farmers face. This cognitive overload is compounded by a mismatch in perceptions about the seed varieties between farmers and seed companies, which we highlighted. There is conflicting information about the maturity classification of the seed varieties as well as the yield potential of these varieties. This lack of clarity pollutes the decision making environment for farmers, most of whom have little educational background and little bandwidth to devote to processing complex choices. Successful crop breeding does not necessarily translate into adoption, effective use, and improved food security without successful information transfer to farmers.

Another reason why misinformation exists is related to the wide heterogeneity in the performance of very similar varieties across a heterogeneous landscape. The variation in soil type and quality is significant within this small region and what may work well for one farmer does not for another. Having more targeted information about precipitation diversity and soil quality or more on farm trials with farmers would facilitate better decision making among farmers when it comes to selecting appropriate cultivars.

We also found evidence that maize seed choice is driven by climate perceptions—perceptions of the probability of drought, how hybrids perform under drought conditions, and perceptions of rain onset. We found variation in how people think about the likelihood of future drought occurrence and we also found a tendency of farmers to perceive the rainy season onset to be getting later. We found variation in how farmers perceive hybrids to perform under various conditions compared to OPVs and evidence that this impacts seed choice. More research is needed to understand how farmers form perceptions of climate events and how this impacts their planting decisions.

Hybrid maize has become the status quo in Zambia bolstered by decades of government investment in breeding and input subsidy programs. The institutionalization of hybrid maize has largely been a top-down process and hybrids are now cultivated by greater than 80% of Zambian farmers, but with limited success in raising yields (Mason et al., 2013; Sitko et al., 2012; Resnick and Mason, 2016). Programs like FISP promote adoption of hybrid maize despite variable yield performance under smallholder environments as is the case with drought tolerant maize in other parts of Africa (Holden and Fisher, 2015). Greater exchange of information with farmers including involvement of farmers in the breeding and crop development process would improve the efficiency of hybrid maize seed choices.

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