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Abstract*

To address the combined challenges of hidden hunger and climate vulnerability, crop breeding efforts over the last decades have focused on releasing crop varieties with resilient traits and higher nutrient content. Ensuring that those newly released varieties reach the types of farmers most likely to benefit from these enhanced seed traits ultimately will determine the return to those breeding efforts. This paper analyzes the effectiveness of selected demand- and supply-side interventions that aimed to increase the reach of biofortified maize seeds among diverse smallholder populations in Guatemala. We introduce experimental variation in demand-side subsidies and information designed to encourage farmers to try the biofortified climate-resilient seeds, and supply-side subsidies for agrodealers to promote the seeds to a wider customer base. Subsidizing agrodealers can leverage market incentives, while demand-side interventions, more traditional policy tools, can allow more precise targeting. We study the effect of these scaling approaches on short-term uptake, longer-term willingness to pay, and sustained adoption by different types of farmers.

JEL Codes: O12, O13, H20
Keywords: climate adaptation, biofortification, scaling improved seeds, nutrition, gender-differentiated take-up, Indigenous

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1 Introduction

Agriculture remains the main source of income for large shares of the rural population in low- and lower-middle-income countries. For many of the most vulnerable among them, it is also the main source of their own food consumption and nutrition. Smallholder farmers in these settings are facing a myriad of challenges – irregular rainfall, cyclones, environmental degradation, pests and diseases, and macro price shocks, to name just a few – jeopardizing their livelihoods and food security. Public investment in R&D can theoretically play a role in offering solutions for some of these challenges, and breeding climate-resilient and biofortified crop varieties is often thought to hold particular promise. Yet slow and incomplete scaling of innovations resulting from such crop breeding efforts often seems to limit their potential returns.

Theoretically, there are a number of reasons why seed varieties of staple crops with "resilience" traits may not be scaling. Each seed variety offers a bundle of many different traits (yield, seed price, commercial value output, taste, nutrition, climate resilience, and pest susceptibility, to name only a few); farmers need to make trade-offs between these traits and have imperfect information about many of them. In addition, the returns to some traits (like climate resilience) are stochastic, while others (e.g., biofortification) have higher social than private returns. Furthermore, those with the easiest access to, or most information about, new seeds are also not necessarily those with the highest private returns. As the combination of human capital externalities and information asymmetries limits demand, the private sector – which helped drive the spread of high-yielding varieties during the Green Revolution – typically does not have incentives to scale these technologies. Supply-driven scaling models through the public sector or NGOs, on the other hand, often suffer from weak accountability and misaligned incentives. This paper analyzes the effectiveness of a scaling approach that aims to leverage private sector incentives, while also addressing the market imperfections limiting demand through information and subsidies.[1]

We focus on the case of recently released maize varieties in Guatemala that are biofortified – containing high levels of zinc, iron, and protein – and also purposely bred to increase resilience to climate shocks, reducing in particular the risk of crop losses from strong winds, a common and increasing climate hazard in Central America. The yields of these biofortified varieties compare favorably to traditional varieties and low-performing hybrids, but they come with a yield penalty compared to expensive hybrids marketed by international companies. Because biofortified seeds are sold through markets as a private good, they do not have canonical

[1]The paper focuses on scaling of innovations after they have been released and hence abstracts from the equally interesting question of optimal models for new seed development. Private seed companies understandably focus on developing seed varieties with marketable traits such as weight, storage, and processing potential. The information asymmetries and externalities limiting scaling also mean that breeding for higher nutritional content or resilience is likely to be undervalued in private markets relative to its potential public benefit. The biofortified seed variety we study results from public investment and charitable contributions that subsidized the start-up costs associated with breeding, selection, testing, and release.

features of public goods in that they are neither nonrival nor nonexcludable. However, private markets are likely to undersupply biofortified varieties without public investment in their production and distribution, as the (perceived) private returns to farmers that grow them are likely to be smaller than the social returns. This is in part due to the unobservability of the nutrient-enhanced content when selling on the market. In addition, even when harvests are used for the households' own consumption, farmers may undervalue the human capital benefits resulting from higher macro- and micronutrient content as they can be difficult to observe, the returns to such nutritional improvements may only come in a distant future, and/or benefits typically befall a different generation than the one making the investment decision.

While the principle of subsidies and information interventions to address these market imperfections is straightforward, there are a number of key design challenges to overcome for effective scaling of these varieties. For subsidies, a key challenge is how to ensure that they are additional rather than inframarginal; that is, how to provide opportunities for vulnerable smallholder farmers growing mainly for self-consumption to benefit from improved nutrition, while not wasting resources on wealthier commercial farmers who do not primarily grow for home consumption and also do not require public subsidies to meet their nutritional needs. A key insight around which our partner Semilla Nueva (SN) has designed their scaling strategy is that the biofortified seed's yield penalty means large commercial farmers should self-select out of these varieties (hence serving as a screening mechanism).[2] Biofortified seeds can then be sold through agrodealers with subsidized prices calibrated to the low end of the seed price distribution (with an average sales price around 30% of that of the highest-cost varieties).

We study two enhanced approaches to scaling the biofortified seed dissemination, taking SN's strategy as a starting point: demand-side information and subsidies designed to encourage smallholder farmers to try the improved seeds, and supply-side subsidies for agrodealers to promote the biofortified seeds to a broad customer base. Supply-side subsidies can leverage market incentives and offer a potentially scalable policy option. Demand-side subsidies through discount vouchers, on the other hand, represent a more traditional policy tool that, in principle, can enable more precise targeting by delivering vouchers directly to the type of farmers whose families can be expected to benefit most from the biofortified seeds (though such targeting can be costly in itself). Targeted dissemination of information and discount vouchers can help reach farmers growing traditional (non-hybrid) varieties who may otherwise be unaware of new seed varieties at certain agrodealers. To the extent that one-time experimentation is enough to lead to subsequent adoption, such targeting can be short-lived.

The optimal balance between one-time subsidies to allow for experimentation and learning by doing and long-term subsidies to compensate for externalities is an open question. Questions on optimal design of interventions to address information asymmetries also abound. Tar-

[2]Wealthier farmers are often commercial growers that supply domestic markets. In principle, large-scale commercial production could reach vulnerable households through retail sales in post-processing markets. In practice, however, most low-income rural households primarily consume maize from their own production. Maize varieties also tend to get mixed during commercial storage, which dilutes the nutritional benefits.

geted information interventions can, for instance, be designed to convey information about the multiple traits that characterize the new seed varieties, allowing farmers to make an informed decision accounting for trade-offs between possible more and less desirable traits; relying on agrodealers, on the other hand, implies accepting that the information being conveyed to the farmers will be driven by their commercial interests (which could lead to an emphasis on positive traits if agrodealers are myopic). Exactly because seed varieties constitute a bundle of many different traits, one can wonder whether information provision needs to be comprehensive or rather focused on specific traits, should be done by technical experts, and for how many seasons such learning needs to be facilitated (given the stochastic nature of many of the relevant traits). Alternatively, farmers' information acquisition could come through word of mouth (learning from others) or learning by doing.

A particular pertinent question for the biofortified varieties is whether scaling can be done in ways that benefit rural populations at high risk of malnutrition. In Guatemala, that includes children in female-headed and Indigenous households, and many smallholders more generally. Understanding whether subsidies or information approaches are more effective at reaching such vulnerable groups is hence of particular importance. It is possible that farmers belonging to different groups evaluate the trade-offs between different traits of seed varieties differently. It is often hypothesized, for instance, that female farmers may put more weight on nutritional benefits when making seed choices. Indigenous farmers, on the other hand, may value the local origin of seed varieties, while smallholders growing open-pollinated traditional varieties may not want to switch to hybrids for a variety of reasons, including the price (as recycling seeds from their own harvest is almost free) and the potential perceived need to make complementary investments in fertilizer or other chemicals. Liquidity constraints may also vary a lot between different groups of farmers, as can their openness or ability to experiment with new seeds.

Because of these type of differences in preferences and constraints, we hypothesize that the response to different demand- and supply-side interventions could substantially vary between the different population groups of interest. Ultimately, benefits of biofortified seeds to diverse sets of farmers and their families can only occur if they consider it worthwhile to switch, at least partially, from varieties they are currently growing to biofortified ones. Empirical insights on whether, and for whom, various demand- and supply-side interventions are effective at encouraging such switches can help inform scaling approaches.

Our partner Semilla Nueva has been implementing supply-side subsidies through their network of about 100 agrodealers in the country since 2017 and has used a multifaceted strategy to spread awareness and information about biofortified seeds. To answer the questions outlined above, and to inform their longer-term scaling strategies, we designed a study to experimentally vary the intensity of the existing strategy and also added demand-side subsidies to evaluate whether they help sustainable extent reach. Specifically, we enrolled 14 agrodealers, 40 villages, and 957 farmers in a pilot experiment. Villages were assigned to one of three demand-side treatment arms: 1) control, 2) information session only, and 3) information session plus discount voucher. Each agrodealer was assigned one village per treatment arm. Half of the agrodealers were cross-randomized to be eligible for a sales bonus for each farmer who purchased biofortified seeds. To experimentally estimate price elasticities, vouchers were issued with four different discount levels which were randomly allocated to individual farmers. Thus, while the study was intended as a pilot to test the relatively complex cross-randomized design at the village level, it is powered to analyze differences in short-term adoption of different levels of demand-side subsidies through the individual randomization of discount levels. We study the impact of these interventions on short-term uptake, longer-term willingness to pay and intent to purchase among the diverse smallholder populations.

The results show relatively large uptake of the demand-side subsidies and moderate participation in information sessions. Impacts on longer-term adoption and willingness to pay among farmers exposed to price discounts and information sessions was smaller but significantly positive, in particular at high discount rates. These results confirm that demand-side subsidies can be effective at encouraging farmers to experiment with new seeds and that this can lead to longer-term demand. Even so, while the highest levels of subsidy led to modest increases in intent to purchase in the year following the experimentation, the average willingness to pay stayed much under the price at which the biofortified seed is currently marketed at the agrodealers. This points to large remaining hurdles for the majority of farmers. Moreover, intention-to-purchase and willingness to pay are much more limited for female farmers, even if high subsidies or supply-side incentives were effective at increasing their short-term exposure. On the other hand, Indigenous farmers and farmers not cultivating hybrids at baseline also react to the demand-side subsidies in the short run, and for them this exposure does translate in larger intended purchase in the year following the experimentation. The impact of subsidies on the price they are willing to pay for biofortified seeds is negative, however, suggesting they are only interested in buying at very low prices.

We contribute to the literature that studies market mechanisms to distribute novel technologies with features that have a public interest. The academic literature has experimentally tested vouchers combined with information for farmers (Carter et al., 2021; Gignoux et al., 2023), supply-side information (Dar et al., 2024), supply-side incentives (Liverpool-Tasie et al., 2024), or increased access (Bernard et al., 2023). To the best of our knowledge, supply- and demand-side interventions have not been studied together. The evidence on the effectiveness of different interventions to reach specific target groups of farmers is also limited.

In analyzing farmers' response to the various interventions, we relate to the large literature studying farmers' decision-making regarding technology adoption. For low-income farmers, technology adoption can be costly when it increases expenditure on complementary inputs or requires adopting new complementary practices (Laajaj & Macours, 2024; Estefan et al., 2024). Overall, reconfiguring input mixes can increase profits (Emerick et al., 2016), but risk aversion, uncertainty, and lack of trust can deteriorate farmers' willingness to try new technologies or reduce the perceived benefits (Bold et al., 2022; Hoel et al., 2022).

The prior literature has also focused on the intensity of information and the size of the subsidy to promote adoption. A common approach is to use demonstration plots and public extension services so that farmers can observe new planting material on a plot that is near their own plots (Emerick & Dar, 2021; Bird et al., 2022). In most cases, the role of suppliers in the input markets is absent from discussions on adoption, with the notable exception of Dar et al. (2024). Often, farmers are provided small packs of seeds for experimentation or purchased seed is directly delivered to communities (Bird et al., 2022; Boucher et al., 2024; Aggarwal, Jeong, et al., 2024; Dillon & Tomaselli, 2024). However, high transaction costs associated with traveling to agrodealer locations to purchase seeds have been shown in several contexts to be an important barrier to seed adoption, potentially offsetting real yield gains from adoption (Suri, 2011; Aggarwal, Giera, et al., 2024). We contribute to this literature by studying a scaling approach that actively leverages the incentives of agrodealers for seed dissemination and by studying seed choices that are inclusive of those market transaction costs.

Overall, this study aims to explore the value different farmers attribute to biofortified maize varieties, the variation in price elasticity associated with these traits between different farmers, and the effective messaging and subsidization strategies that can be used to promote the adoption of these varieties. Data collection was designed to gain a comprehensive understanding of the economic, cultural, and taste-based constraints that influence farmers' perceptions and willingness to pay to adopt biofortified crops. We focus in particular on female farmers, on Indigenous farmers, and on farmers growing traditional varieties, as we hypothesize that their households would be the most likely to benefit from the nutritional value of the biofortified seed.

2 Background on Scaling Biofortified Maize in Guatemala

2.1 The biofortified and climate-resilient maize varieties

Malnutrition is a primary contributor to early childhood morbidity and mortality and an important cause of stunted growth and limited cognitive development in the earliest years of life. Given that maize is the main staple crop for an estimated 1.2 billion people worldwide, strategies that can improve vulnerable households' access to more and better-quality maize are considered to hold great promise for improving the nutritional status of many children. This is particularly relevant in Guatemala, where stunting rates and malnutrition have been stubbornly high for decades: 46.5 percent of children under 5 are stunted and 42 percent of the Indigenous population lacks sufficient zinc – an essential nutrient for proper development and a healthy immune system (WorldBank, 2020) – and most rural households grow their own maize for home consumption. Female-headed households represent a significant portion of Guatemala's population (25%) and are especially vulnerable to food insecurity (INE, 2018; WorldBank, 2024).

Biofortification of staple crops was introduced to help fight malnutrition and micronutrient deficiency (Low et al., 2017). It involves enhancing the nutritional content of the edible portion of the crop with targeted breeding (H. E. Bouis & Saltzman, 2017; Finkelstein et al., 2019). Despite the genetic promise of biofortification, scaling of biofortified crops has faced various challenges in different settings (Foley et al., 2021). Demand-side constraints may limit their diffusion, including plausibly low demand resulting from the fact that nutrient enhancement is a trait that can be hard to observe for farmers (Banerji et al., 2013). Although there is a literature studying different scaling strategies (Karandikar et al., 2018; Smale et al., 2013), few studies have focused on establishing rigorous causal evidence. Very little is known in particular about interventions that leverage scaling through private sector actors (such as agrodealers).

Building on the historic, cultural, and economic significance of maize for smallholders in Guatemala and the broader Meso-American region, our Guatemalan NGO partner, Semilla Nueva built on earlier breeding efforts by the International Maize and Wheat Improvement Center (CIMMYT) to release three biofortified hybrid maize varieties in the country starting in 2017. These varieties have higher zinc, iron, and protein compared to both traditional open-pollinated seed varieties (OPVs) and to other hybrids available in the market. The benefits of this enhanced nutrient content are potentially substantial: One hundred grams of tortilla made from biofortified maize can provide 50 percent of the daily recommended intake of zinc for children.

The released biofortified maize varieties were bred to be resistant to both drought and storms/high wind speeds to enhance farmers' resilience to climate-related events. This is particularly relevant given Guatemala's location in Central America, a region with high exposure to geo-climatic hazards derived from its location and topography and with high vulnerability to hurricanes and tropical storms from both oceans.[3] Apart from overall devastation, strong winds damage crops through lodging, leading to harvest loss. Results from SN monitoring data comparing results of the released biofortified varieties with other varieties demonstrate a significant decrease in maize losses from lodging and related rotting.[4] Because maize is a primary staple grown for home consumption, the welfare cost of maize harvest loss can be particularly high. The resilience traits that can help ensure quantity hence complement the quality enhancement from increased zinc, iron, and protein content, working in synergy to address malnutrition without requiring costly changes in local traditions. As the additional climate resilience contributes by increasing expected yields, the combination of positive attributes in the new varieties can

[3]The IPCC ranks the countries in Central America consistently among the highest in the world by risk of being impacted by extreme events (Castellanos et al., 2022). For the period 1992–2011, Honduras, Nicaragua and Guatemala were among the 10 most impacted countries by extreme weather events (UNISDR & CEPREDENAC, 2014), with the number of events increasing 3% annually (Bárcena et al., 2020). Guatemala is facing severe consequences due to the climate crisis, including droughts, heatwaves, and erratic rainfall and wind patterns. These factors have led to crop failures and migration, particularly affecting smallholder farmers and Indigenous communities (World Food Programme (WFP), 2022).

[4]Results from the monitoring data also show yield increases of about 24 percent (when compared to traditional varieties), with gains being similar in drought and non-drought conditions. See the Appendix for more details on the data, results, and analysis.

make them more attractive to farmers as long as farmers are aware of those attributes. Wind-resistance is observable to a certain extent, even in absence of strong winds, as it results from deeper and more developed roots, combined with stronger and shorter stems.

While the enhanced nutrient content and weather-resilience constitute traits of the SN seed that compare favorably to other varieties, other traits of SN could be seen as a disadvantage. Most directly, the higher nutrient content means that the SN maize is more appealing to different pests both during the growing season and afterwards during storage, making them susceptible to pest-related losses.[5] SN seeds also differ in color from commonly commercialized varieties, which could affect their market value, while taste-based preferences could make some farmers favor criollo varieties (traditional open-pollinated varieties) for home consumption.

2.2 Scaling new varieties by leveraging private sector incentives with subsidies and information

Semilla Nueva uses a multipronged subsidy approach to make the biofortified maize varieties available at scale in the different parts of the country and to provide farmers opportunities to learn about the new varieties: 1) Directly investing in seed production and distribution through their own networks of around 100 agrodealers, spread across the country, who get access to seed at subsidized prices and with whom they agree on a subsidized sales price; 2) Offering agrodealers a premium based on the quantity of bags of biofortified seed sold (mirroring approaches also used by international seed companies); 3) Subsidizing seed distribution to other national seed companies with whom agreements are signed to sell biofortified varieties with their own branding through their agrodealer networks, who then sell to farmers for the agreed upon subsidized prices; and 4) Working with the national agricultural extension system and with other NGOs to distribute seed donations (trial packs of free seeds) throughout Guatemala.

These subsidy approaches are complemented with a variety of interventions aimed at providing information about the traits of the varieties to a wide group of farmers. This includes demonstration plots, training sessions, large-scale marketing campaigns through social and traditional media (TikTok, Facebook, radio), and written materials (leaflets) and marketing materials (posters, raffles) at the agrodealer's shops.

Such scaling efforts have been expanding across the country in recent years (and Semilla Nueva also recently started using similar approaches in El Salvador), but there is still a very large scope to increase potential reach. In 2024, Semilla Nueva reached approximately 18,000 farmers through market sales and another 8000 farmers through collaborations with the Guatemalan and El Salvadoran governments. A challenge for further scaling among a key target population is that many smallholders rely on recycling traditional OPV seeds (maize being of

[5] Pest susceptibility during the growing seasons can be addressed with pesticides, while preventing storage losses does not imply chemicals but rather appropriate post-harvest drying and storage methods/facilities. Smallholder farmers that could benefit from biofortification may be constrained in using appropriate facilities as not all of them have, for instance, access to silos.

high cultural value for Indigenous communities in particular) and hence do not usually buy seeds for planting. This potentially limits their exposure to market-based efforts through the agrodealer network, and possibly also their openness to using new seed varieties.

2.3 Targeting through self-selection

Semilla Nueva's price subsidy implies that seeds are being offered at prices much lower than those of any other hybrids on the market. At the same time, yields are higher than those of the traditional open-pollinated varieties used by many Guatemalan smallholder farmers (that farmers access from recycling their own harvest). SN yields are on par with hybrids released by the national agricultural system or national seed companies, while their price is lower. Yields are, however, lower than high-performing hybrids from international seed companies that are also available on the Guatemalan market. This is indeed a key feature of SN targeting strategy, as it implies that subsidized biofortified varieties should be particularly attractive to semi-subsistence smallholder farmers who switch from OPVs or low-yielding hybrids, while larger commercial farmers are likely to select out. As the smallholder farmers are more vulnerable to climate shocks (they typically don't have access to irrigation) and as their children are more likely to benefit from the nutrient enhancement (as they largely use maize for home consumption and their children are more likely to suffer from nutrient deficiencies), the yield penalty means that the subsidies are more likely to benefit those farmers that have the highest return to the different traits. The combination of the price subsidy with the yield penalty, when compared to the highest performing hybrids, is akin to an ordeal mechanism (Alatas et al., 2016).

In Guatemala, about 40% of farmers purchase hybrid seeds, but purchase rates vary between 30% in the highlands to 85% in south and southeastern departments (ENCOVI data, authors' calculations). There are also strong regional patterns in nutrition insecurity, and vulnerable households are less likely to use hybrids. Evaluating to what extent the various forms of price subsidies and information allow increasing reach among household types with higher probability of nutrition insecurity (such as non-hybrid growers, female-headed households, or Indigenous-identifying households) is key to helping evaluate the returns to the subsidy program. For example, it is possible that it may be cost-effective for farmers with experience growing hybrids to switch to biofortified maize with relatively light-touch interventions, while more vulnerable households may need more information or higher subsidies before they decide to adopt new seeds. It is also possible, however, that more vulnerable households are just less aware of the existing subsidy, in which case information and training alone or incentivizing agrodealers to promote the biofortified seeds could have a bigger impact on their adoption rates.

Understanding the effectiveness of SN's approach of providing subsidized access through agrodealers to reach food-insecure households has great policy relevance. SN being an NGO, the cost of the subsidies they are providing through their agrodealer network are being covered through public and private donations. While most funding comes from private foundations, more recently the government of Guatemala has also committed to support SN's subsidy approach. Evidence on whether SN's supply-side subsidy approach allows reaching the targeted households is important to understand the potential returns to those investments.

3 Methodology

As SN's benchmark price is calibrated so that the seeds are competitively priced with low-segment hybrids, they offer a potentially appealing proposition for many low-segment farmers, even without taking into account the nutritional benefits. However, many of the farmers who could benefit from the SN varieties may not be aware of them. This could be, for instance, because they may not look for seeds to buy in the first place, because they may frequent agrodealers that do not offer biofortified seeds, or because they may not be told by the agrodealers about the price and other features of the biofortified seeds. Moreover, as for any agricultural technology, returns to the seed variety may be heterogeneous so that giving an opportunity to learn about their returns (either through own experimentation or through learning from others) could be an important prerequisite for widespread adoption. We therefore purposely designed various strategies to strengthen specific components of SN's subsidy and information strategies among randomly selected agrodealers, communities, and farmers to provide empirical evidence on the possible importance of those components to reach different types of smallholder farmers.

This paper presents results of a pilot intervention with 14 agrodealers, distributed across the country's major regions, that was designed to provide an initial test of both the feasibility and the potential impacts of those strategies, prior to a potential evaluation at scale.

3.1 Experimental design

The 14 agrodealers were selected among the list of about 100 agrodealers with which SN currently works, selecting 2 agrodealers for each of 7 SN technicians, who together cover all areas of the country in which Semilla Nueva is operational. This implies a sample that covers all major regions of the country, excluding altitudes above 1800 meters (i.e., the highest areas of the altiplano) where the seed varieties do not perform as well. Each of the 14 agrodealers was asked to nominate 3 villages with a large share of smallholder farmers who were not yet growing hybrids and who were within reasonable distance of the agrodealer shop and within the same municipality.[6] Villages entered the experiment after confirmation of interest with the villages' leaders. For 2 agrodealers, only 2 villages could be confirmed, yielding a total of 40 villages.

The experiment followed a 2x3 design to test supply- and demand-side interventions. A

[6] Most agrodealer shops are in the main town of the municipality. Households typically travel to those towns very regularly for household purchases, formalities, other business or jobs, or leisure.

random half of the agrodealers (one per technician) were informed that they were eligible for an extra supply-side subsidy, providing a bonus payment of 15 quetzales (about 2 USD) for each farmer who purchased SN seeds. The sales incentive was split between owners and sales personnel that work at the counter. Orthogonal to that supply-side variation, we randomize demand-side interventions among the three villages selected per agrodealer. Villages were randomly assigned to one of three arms: 1) Control, 2) Information session, and 3) Information session plus discount voucher distribution.[7]

The information sessions were to be conducted by the SN technician (extension officer) who trained farmers on hybrid-seed planting, informed them about the low prices, and provided in-depth information about the nutrition, agronomic, and climate-resilient benefits of the biofortified varieties. Apart from highlighting the positive traits of the SN seeds, technicians also explained that the higher nutrient content implies stronger vulnerability to pests both during the growing season and during storage, and they discussed possible mitigating actions. They also conveyed other relevant information such as the seed color. All farmers interviewed at baseline in those villages were invited to participate. In villages where some of the invited farmers were not fluent in Spanish, translation of the training content was to be organized through a village member. A training session gives farmers an opportunity to interact directly with staff, which can build trust and resolve other information uncertainties. Training sessions are a common approach used by public extension agencies and seed companies to provide information about seed performance, but one drawback of them is that the extra information only reaches farmers that choose to attend. Despite potential concerns with take-up, participants who opt in to participating may be more motivated to learn about new seeds.

In villages assigned to the information-plus-voucher treatment , farmers invited to the training sessions received discount vouchers for seed purchases during those sessions. These were presented in the form of a scratch card with random discount levels, between 25% and 75%, as compared to SN's benchmark recommended sales price, and were meant to encourage farmers to purchase biofortified seed. The discount vouchers made farmers eligible to purchase either a half or a full bag (as per their own preference) of SN seeds at the designated agrodealer shop. Other than the voucher distribution, the training session featured the same content as the information-only treatment group. The information-plus-voucher group hence received both more information and higher subsidies than the farmers in the control villages. Farmers in the control villages represent the benchmark (status quo) Semilla Nueva strategy. They may be exposed to the biofortified seeds if they happen to visit an agrodealer that is selling those seeds, or may learn about them from fellow farmers, but they were not to be exposed to any demand-side interventions.

All information sessions and voucher distributions were completed in March and April

[7]For the two agrodealers for which only two villages could be confirmed after the visits with the community leaders, one village from each pair is assigned to the control, and the other village to either the information-only or to the information-plus-voucher treatment.

2024, just before planting of the main agricultural season. Vouchers could be redeemed until the end of July 2024, to allow for late planting (as the start of the season can be delayed due to late arrival of the rains, as was the case in part of the country that year).

3.2 Data collection

A short quantitative baseline survey was conducted in February and March 2024, right after the community validation by the SN technicians and before the roll-out of the information session and voucher distribution. Baseline survey data were collected in all sample villages, with a targeted sample of 24 farmers per village (the final number of farmers is lower in some small villages where not enough farmers could be identified). The baseline data was collected in order to distinguish between different types of farmers of particular interest to understand the reach among diverse populations: those with prior experience growing hybrids versus those solely growing OPV (the latter group which we will refer to, henceforth, as criolleros or farmers growing criollo maize), farmers self-identifying as Indigenous, households where the main respondent or the main farmer is a woman, and farmers who did not yet know the participating agrodealer.

The roll-out of the implementation was tracked through detailed monitoring data, providing details on attendance to information sessions and vouchers received, as well as 2-weekly updates from the SN technicians on voucher redemption rates and overall program implementation at the agrodealer level, through the end of July 2024. Data from redeemed vouchers was digitized and matched to the universe of distributed vouchers to obtain redemption rates, providing a first individual-level variable of SN take-up during the main 2024 season for the information-plus-voucher group.

The individual-level voucher redemption data was complemented with an incentivized data collection strategy to characterize the full client base of each agrodealer during the same 2024 main season, and to quantify the number of farmers buying SN seeds. This was achieved by organizing a raffle at each agrodealer, as explained in detail in Appendix A. All agrodealer clients were eligible to participate in the raffle. Raffle tickets with information on purchases for SN seeds were used to calculate the number of farmers for whom the supply-side incentive was to be paid to the agrodealer. In addition, information on total sales values per agrodealer is available through SN monitoring data.

Endline data collection (conducted by an independent data collection partner) was conducted between March and May 2025. More than 95% of baseline farmers were re-interviewed. At this point, all farmers that also planted a second season in 2024 had harvested, and farmers were making plans for the 2025 planting seasons. Data was collected on each incidence of planting maize varieties throughout the 2024 year (both main and secondary season), including details about input use and harvests; preferences over the different traits of OPV, biofortified, and other hybrid seeds; knowledge questions reflecting possible learning from the information sessions; data on interactions with agrodealers as well as an incentivized willingness-to-pay (WTP) exercise and a discrete choice experiment on seed variety traits. To measure willingness to pay, farmers were given the opportunity to purchase a 10-pound bag of Fortaleza seed (brought by the enumerators to the house of the respondents), using a Becker-DeGroot-Marschak mechanism (BDM) to reveal the price they were willing to pay for the bag. Farmers were given an endowment presented as a compensation for the time answering the survey, so that liquidity constraints can be ruled out as a reason for offering any positive price.[8] More information on the WTP and the discrete choice experiment can be found in the Appendix.

The endline data collection includes recall on participation in the information sessions and voucher delivery, providing a second measure of take-up, as well as the ability to quantify fidelity with the experimental design.

Complementing the quantitative data, we rely on two rounds of qualitative data collection to derive optimal learning from the experiment. A January 2024 round was used to fine-tune the design and baseline survey instrument. A July 2024 round was used to derive insights regarding the implementation of the interventions, and regarding farmers' decision for take-up of biofortified seeds. The findings of the July round are summarized in the Appendix and informed the design of the endline data collection instrument.

3.3 Outcomes

The primary outcomes are the SN seed take-up rates during 2024, the intent to purchase biofortified seeds in 2025 (i.e., adoption in the year after the experiment), and the WTP at endline. Secondary outcomes include the preferences over different seed attributes.

Take-up (or short-term adoption) in 2024 is defined as a binary variable equal to one if the respondent at endline reported having planted biofortified seed at some point during 2024. For the farmers in the information-plus-voucher villages, this can be compared with the voucher redemption rates. While short-term adoption is interesting, the goal of providing vouchers and information is to provide farmers an opportunity to be exposed to the attributes of the new seeds as a way to sustainably affect seed adoption subsequently, when farmers would need to purchase seeds from local agrodealers without additional interventions (Fishman et al., 2022; Carter et al., 2021). At endline, which was conducted just before the beginning of the planting season, farmers were therefore asked their intent to purchase biofortified seeds for the 2025 main season (at market prices).[9] This provides a binary variable indicating the

[8] About 25% of farmers cite a zero price and only 12% cite a positive price between 0 and 25 quetzales, with no clear bunching at 25, suggesting that hard liquidity constraints related to the exact amount of the endowment are unlikely. The share with WTP at 25 quetzales or below does not differ significantly between treatment groups.

[9] The question asked at endline is "Do you expect to buy Fortaleza seed for the 2025 planting season?" Because 2024 purchases at discounted values involved purchases at the agrodealer where market prices were paid (which then in part were covered by the physical discount vouchers with random discount amounts), it is unlikely that farmers in answering the question would have answered based on the discounted value rather than the market value, given the absence of any discount vouchers in 2025. We cannot fully rule this out, however.

self-reported longer-term adoption decision.[10] In addition, we define two variables based on the incentive-compatible willingness-to-pay experiment, which was conducted by offering an actual bag of biofortified seeds for sale. The self-reported measure on intent to purchase at market prices was asked before revealing the possibility of buying the physical bag on the spot. The incentivized willingness-to-pay provides an actual observed purchase decision. The continuous value indicating the WTP is therefore the third primary outcome of interest. We also use the WTP answers to define a binary variable indicating whether the WTP is at least as high as the benchmark price of the biofortified seed at the agrodealer, providing the fourth primary outcome.

The primary measures are complemented with a series of measures to disentangle the mechanisms underlying these adoption choices, including results from a discrete choice experiment that decomposes farmer preferences for different seed attributes.

4 Empirical Specifications

4.1 First-stage compliance

First, we assess compliance with assignment using administrative data on the implementation of the demand-side interventions, voucher redemption data, and self-reported data on whether farmers attended training sessions and received a voucher. This informs the subsequent intention-to-treat (ITT) interpretation.

4.2 Impact on adoption

4.2.1 Impact of the demand- and supply-side interventions

For each of the four primary outcomes Y, we estimate the intent-to-treat using

$$Y_{ic} = \alpha + \beta_1 Info_c + \beta_2 InfoVoucher_c + \gamma X_{ic} + \varepsilon_{ic}, \tag{1}$$

where i is the individual farmer, c the village (community), *Info* and *InfoVoucher* the village-level assignment to treatment, and X the strata fixed effects and LASSO-selected controls.

To understand whether agrodealer supply-side subsidies drive adoption decisions, we estimate a separate specification to test the impact of the agrodealer being randomly assigned to receive the additional subsidy for each farmer buying biofortified maize:

$$Y_{ic} = \alpha + \beta_1 AgrodealerInc_c + \gamma X_{ic} + \varepsilon_{ic}, \tag{2}$$

[10] Among those knowing the biofortified seed, 31% report interest in purchase in 2025, with the average intended purchase quantity (21.5 pounds) being similar to the average quantity of seeds used on criollo plots. Almost none of those that reported intent to purchase had already bought the seed at the moment of the endline survey, nor did they have the seed in stock from previous seasons.

where *AgrodealerInc* indicates whether a farmer lives in a community belonging to the municipality of an agrodealer assigned to the extra supply-side intervention.

All estimates are intent-to-treat estimates using LASSO-selected controls and strata fixed effects with standard errors clustered at the village level.

4.2.2 The effect of different levels of discounts

We examine the role of being assigned to increasing voucher discount levels using the subsample of farmers in the *InfoVoucher* villages and regressing the outcome variables on a set of binary variables that reflect the different levels of distributed discounts $= \{25, 45, 60, 75\}$, with the lowest discount level, 25%, being the reference category.

$$Y_i = \alpha + \beta_1 \mathit{Voucher45}_i + \beta_2 \mathit{Voucher60}_i + \beta_3 \mathit{Voucher75}_i + \gamma X_{ic} + \varepsilon_i. \tag{3}$$

4.2.3 Impacts on reach among diverse farmers

One of the main goals of this study is to analyze whether certain components of the SN scaling strategy are more effective than others in increasing adoption among key target farmers. We focus in particular on 1) female farmers or female respondents (given higher levels of food insecurity in their households and possibly higher sensitivity to nutritional messaging); 2) Indigenous farmers (i.e., farmers self-identifying as Indigenous, which includes both Maya and Xinca, to be compared with Ladino farmers); 3) criolleros, that is, farmers that reported using OPV in 2023 (as compared to farmers that were already growing hybrid seed); 4) farmers that reported not knowing the SN agrodealer in their municipality at baseline; and 5) literate farmers (those with some schooling completed) which proxies both for general SES/wealth and ability to engage with written materials (such as the leaflets received during information sessions).

We estimate whether impacts of the various experimental variations are heterogeneous based on whether farmers belong to these different groups, as measured by the baseline covariates.

$$\begin{aligned} Y_{ic} = & \alpha + \beta_1 \mathit{Info}_c \times \mathit{Covariate}_{ic} + \beta_2 \mathit{InfoVoucher}_c \times \mathit{Covariate}_{ic} \\ & + \beta_3 \mathit{Info}_c + \beta_4 \mathit{InfoVoucher}_c + \beta_5 \mathit{Covariate}_{ic} + \gamma X_{ic} + \varepsilon_{ic}. \end{aligned} \tag{4}$$

Among farmers in the *InfoVoucher* villages, we also estimate whether price elasticities based on the assigned voucher discount are heterogeneous for these different groups.

$$\begin{aligned} Y_i = \alpha + & \beta_1 \mathit{Voucher45}_i \times \mathit{Covariate}_i + \beta_2 \mathit{Voucher60}_i \times \mathit{Covariate}_i + \\ & \beta_3 \mathit{Voucher75}_i \times \mathit{Covariate}_i + \beta_4 \mathit{Voucher45}_i + \\ & \beta_5 \mathit{Voucher60}_i + \beta_6 \mathit{Voucher75}_i + \beta_7 \mathit{Covariate}_i + \gamma \mathit{Covariate}_i + \varepsilon_i. \end{aligned} \tag{5}$$

5 Results

5.1 Characterization of the sample

To motivate the subsequent analysis of differences in reach between the different types of farmers, we first use the baseline data to understand the diversity among farmers in the sample. For consistency, we focus the descriptive analysis on the sample of farmers interviewed at endline, a total of 900 farmers from 40 villages (see Table 1). These are spread, by design, across the different regions of the country. Almost all of the households in the sample (98%) reported growing maize in all years, 87% of the respondents are the household head, and 83% are the main farmers. Average household size is close to 5, while there are 0.51 children below 5 years old per household.

With regard to the dimensions of heterogeneity of interest, there were 34% female respondents, and for 22% of households a woman is the main farmer. With regard to ethnicity, 45% self-identify as Ladino, 40% as Maya, and 13% Xinka (a non-Maya Indigenous group in the Dry Corridor). A relatively large share of households identifying as Indigenous speak Spanish at home (68%), and the remaining speaking Q'eqchi' (19%), K'iche' (8%), and less than 1% Mam. Among those not speaking Spanish at home, there is a relatively large share that speaks and understands Spanish. In total 86% of the sample speaks and understands Spanish, implying there are 14% of the households for whom information in Spanish about the seeds and the discounts may have been less accessible (given the incomplete or missing translation observed during the qualitative work).

The other relevant dimension of heterogeneity to consider is farmers' prior experience with hybrid seeds, smallholder status, and the intensity of their maize cultivation. A bit more than half (59%) of the sample bought maize seeds at the agrodealer in the previous year. A much larger share bought fertilizer (96%), herbicides (90%), and pesticides (87%). Consistent with the seed sales data, 54% of farmers report growing criollo maize (traditional open-pollinated varieties). Among those growing hybrids, the most common is Dekalb, a relatively high-yielding variety (marketed by Bayer), grown by 24% of farmers, while the even higher-yielding Pioneer only accounts for 3%. The various low-yield national varieties together sum to 17%. Finally, at baseline 2% of farmers had already grown Fortaleza (the brand that Semilla Nueva markets directly) in 2023, while another 2% were growing a biofortified maize variety from one of Semilla Nueva's partner companies (JC 5 Proteico). Most farmers only plant one maize variety per year, but about 40% report a second planting (with this share being similar at baseline and endline).

In line with land scarcity among smallholders targeted for inclusion in the study, the average land area in the sample is 0.82 hectares (s.d. 0.93), with the highest value being 13 hectares. About half own the land they cultivate, with the remaining mostly accessing land through fixed rent contracts.[11] In terms of access and remoteness, farmers are on average about 23 minutes away by car from the closest agrodealer (s.d. 18) indicating that most of them are used to traveling some distance to buy inputs. Finally, a very large share of farmers report having been affected by climate or environmental shocks in the previous year, with 94% reporting drought in 2023, and 86% report being affected by plant pests or diseases.

While the baseline instrument was designed to be very short, the endline data allowed further characterizing the sample along some key dimensions, using the means in the control communities (Table 2). This shows that education levels in the sample are low, with close to 30% of farmers reporting not having any education (Table 2), while only 14% of farmers have any secondary education. The vast majority of respondents (70%) report only having agricultural income (with the most important other income sources being business, salary, and remittances). Virtually all (96%) respondents report cultivated maize is primarily used for household consumption, with the most common secondary uses being animal feed (61%) and sales (42%).

Taken together, the descriptive evidence shows that the sample is dominated by semi-subsistence farmers for whom maize is the primary economic activity, so that the biofortified and resilience traits could potentially have great value for them. Endline data further confirm only a small fraction of them (13.5%) had already heard about the biofortified seed before 2024, indicating the potential for demand-side interventions to increase take-up. At the same time, importantly, almost all of the farmers already have regular interactions with agrodealers, as buying of commercial inputs is very common. This confirms that an important baseline condition for a system of seed subsidies through agrodealers to reach target farmers was met. Finally, diversity by ethnicity, gender, and prior experience with hybrid seeds within these groups of farmers is high, making the sample well-suited for an analysis of reach among these diverse populations.

5.2 First stage: Voucher redemption and compliance with experimental design

5.2.1 Monitoring data on attendance

During the roll-out of the information sessions and voucher distributions prior to the 2024 planting season, SN technicians monitored attendance. These data indicate that all 14 villages (one per agrodealer) targeted to receive the discount voucher distribution and information sessions received those interventions. However, not all baseline farmers participated in the sessions, with reported attendance on average about 74%. In the villages targeted to receive the information sessions only, 54% of baseline farmers were reported to have attended the information sessions.[12]

[11] While seed choice in sharecropping could be decided by the landowner, this only represents 5% of the sample.

[12] It is likely that the technicians informed village leaders that discount vouchers would be distributed during the information sessions for the villages in that treatment group, and that this helps explain the higher attendance. This

5.2.2 Descriptive results on voucher redemption

For the subset of villages where subsidy vouchers were distributed, redemption of the subsidy voucher was administratively tracked by the agrodealers.[13] This provides us with a first objective measure of the demand for SN seeds for different types of farmers and at different price levels (See Table A1 in Appendix H). Redemption rates vary with the subsidy level, as expected. The vouchers with the lowest subsidy level had a redemption rate of 23%, while the redemption rate of those with the highest subsidy level was twice as high at 52% (with the two intermediate levels at 36% and 33%). In most cases (89%), farmers bought a full bag. Overall, this is a quite high redemption rate, revealing a fairly high level of interest in trying the biofortified seeds at discount rates.

Combining the redemption rates with the baseline data characterizing different types of farmers provides the first evidence on the extent to which different subsidy levels allowed reaching different types of households (i.e., helping predict redemption rates of different types of households). We first show to what extent take-up of the discount voucher is correlated with several of the key baseline characteristics.[14] Given that use of biofortified seeds at baseline is very low, this allows analyzing to what extent the price subsidies are more likely to lead to adoption for some farmers compared to others. We consider the basic correlations between the probability of voucher redemption and a set of baseline covariates (captured by the coefficients in column 2 of Table 3, based on the bivariate estimation specified below the table). We also show results controlling for the identity of the technician responsible for implementing the intervention in a given region (through the agrodealer-pair fixed effects) in column 3 in Table 3 to test robustness when controlling for basic differences between regions and for implementation differences.

Table 3 shows that the gender of the main farmer does not correlate to redemption of the subsidy vouchers. As expected, farmers who last year already bought hybrid maize are much more likely (200%) to redeem the subsidy voucher, though this result is not robust to technician/region fixed effects.[15] Interestingly, once we account for fixed effects, Ladino farmers are less likely to redeem the vouchers. This suggests that groups characterized by ethnicity versus past hybrid use do not show the same patterns, a finding that we'll also see in the subsequent

is arguably also what we should expect technicians to do if they were to scale up the information-plus-voucher interventions, and the differences in take-up due to attendance would factor into the relative cost-effectiveness of the two types of interventions.

[13] All vouchers had a unique identifying number as well as the farmer's name, and agrodealers had to send redeemed vouchers to SN in order to be repaid the discount amounts.

[14] Because not all baseline farmers in the information-plus-voucher communities attended the sessions, a subset of the vouchers was not assigned during the sessions. As Table A1 shows, a total of 209 out of the 291 vouchers were distributed. To avoid selection bias, all estimates use the full sample of 291 targeted farmers in the information-plus-voucher communities. Individual redemption rates were obtained from agrodealers' records, and discount levels were from the information session administrative data. For farmers that did not attend the information session, we randomly assigned a discount level, preserving the original distribution of discount levels.

[15] Unsurprisingly, the small share of farmers that were already using biofortified seeds (Fortaleza or JC5 Proteico) are the most likely to use the discount vouchers. This result is robust to fixed effects.

results.

Table 3 further shows that voucher redemption is not related to land size, nor to knowing the agrodealer or to distance to the agrodealer.[16] These effects are similar with fixed effects. Finally, Table 3 shows that prior climate shocks do not significantly affect redemption rates, while past pests and diseases do. This result is robust to inclusion of agrodealer-pair fixed effects. Possibly this means that farmers perceive breeding to be more related to vulnerability to plant pests or diseases rather than climate shocks. It could also reflect farmers' unwillingness to reuse criollo seed affected by pests or diseases, and the discounted hybrid seeds could provide a relatively low-cost opportunity to access seeds that are disease-free. We will return to this point below.

5.2.3 Experimental results of impact of the subsidy level on voucher redemption

Figure 1 shows redemption of subsidy vouchers by discount level, with the lowest level being the reference group. Results for the full sample are shown on the right of the figure, with the other columns showing results for subgroups of the population. The figure generally confirms the gradual increase in redemption as the subsidy level increases for most of the subgroups. It further shows that take-up is not only lower overall for criollo farmers, but that in particular the two lowest subsidy rates lead to low redemption. Take-up at the highest subsidy level is the highest among female main farmers and those knowing the agrodealer.

5.2.4 Experimental impact of the supply-side subsidy on redemption

On average, farmers in communities assigned to the agrodealers with the extra supply-side incentive are not more likely to redeem vouchers than the other farmers. That said, Table 4 shows some intriguing results suggesting that the supply-side incentives increase redemption rates among farmers with certain characteristics. Notably, take-up of vouchers is significantly higher among female main farmers and among criollo farmers when the agrodealer received an extra incentive (column 3 and 5).

These results are exploratory only, as they are derived from a 7 to 7 comparison. Even so, they are intriguing as they suggest that the supply-side incentives may lead agrodealers to convince certain groups of farmers more than others (whether that is because they do more effort, or because certain groups are more sensitive to recommendations, or both), even if on average uptake does not increase. We will return to this point below.

5.2.5 First stage of demand-side interventions according to endline data

To complement the administrative data on attendance and voucher redemption, we asked a set of questions in the endline survey to obtain information on participation in the information

[16]Distance is measured in minutes by car, as motorized (public) transport is the most common transportation means.

sessions and receipt and use of vouchers as reported by the farmers themselves. While this information relies on their recall of events that happened about a year earlier (and hence likely suffers from recall error), it importantly provides a first-stage measure for all villages in the experiment. In addition, it also allows cross-validating information received from technicians and agrodealers (who may be less likely to report on deviations from the experimental design) with information received from independent answers by the targeted farmers.

Table 5 shows that this compliance verification indeed was important, as 35% of the farmers in the control villages report having benefited from an information session. Even so, exposure to information sessions is still 13 p.p. higher in the information-only villages, and 26 p.p. higher in the information-plus-voucher villages. The result for the control suggests that other actors (other NGOs, the government, etc.) may have organized information sessions in the control villages, or it could also reflect recall error by farmers.[17] Apart from possible contamination of the control, these results also mean that compliance in the treatment villages was imperfect. With 48% of farmers reporting participating in training in the training-only villages and 61% in the information-plus-voucher villages, attendance appears to have been lower than those reported in the attendance sheets. Again, this possibly reflects recall error, as it would seem somewhat likely that a relatively large share of people may have forgotten an information session that took place a year earlier.

Column 2 shows that for the voucher treatment there was no contamination of the control or the information-only villages. In the information-plus-voucher villages, about half of farmers recalled receiving vouchers, and that increases to two-thirds among those that recall participating in the information session.

Overall results in columns 1 to 3 suggest that while compliance was far from perfect, the experimental assignment does lead to significant differences between treatment groups in both information and subsidy levels, allowing us to interpret experimental differences between treatment groups broadly along the intended design. That said, the lower compliance with the information intervention assignment between the two treatment arms does mean that overall access to information may have been higher in the information-plus-voucher villages than in the information-only villages. This seems to be confirmed by results in column 4, which shows that in information-plus-voucher villages, people score better on a knowledge test designed to capture retention of the information shared with farmers in the information sessions.[18] The knowledge index is significantly higher in information-plus-voucher villages than in information-only villages (and is about twice as large in the information-plus-voucher villages than in the control). It is possible that these differences reflect better retention of in-

[17] Discussions with SN technical staff indicated that some of the control villages were exposed to pre-intervention field days, which some farmers may have reported as the intervention's information session.

[18] Similarly, farmers in the information-plus-voucher villages are also more likely to report having heard about biofortified seeds to start with (57% in information-plus-voucher villages, compared to 48% in the information-only villages and 31% in the control). The relatively large share in the control (compared to the baseline adoption rates) may be the result of non-compliance by the technicians in the control or could also just indicate that the baseline survey and the village identification process raised awareness about biofortified seeds.

formation received because of increased salience of the information due to the vouchers, rather than differences in whether information sessions were organized.[19] Either way, this result does mean that combining vouchers with information ended up making the information intervention more powerful than having information alone, an important factor for the interpretation of the ITT results on adoption in 2024, intent to purchase in 2025, and WTP outcomes.

5.3 Experimental impacts of information and subsidies on demand for biofortified seeds

In line with the relatively high redemption rates of the vouchers, the first column of Table 6 shows a strong and significant increase in growing biofortified seeds among farmers in information plus subsidy villages, while the ITT shows no impact of being assigned to the information session only. At endline, 39% of maize farmers in the information-plus-voucher villages reported growing biofortified seeds in 2024, compared to 10% of maize farmers in the control, with the difference being significant at the 1%.[20] The magnitudes are consistent with most farmers who redeemed vouchers also effectively having planted the biofortified seeds. This is corroborated by the self-declared use of the vouchers. The vast majority of farmers also reported not sharing the voucher (or the biofortified seed bought with the voucher) with other farmers.

The second column of Table 6 shows that farmers in the information-plus-voucher villages are also significantly more likely to indicate their interest to purchase biofortified seeds for the 2025 growing season. While the intent to purchase biofortified seed in the control is similar to use in 2024 (10%), exposure to the voucher treatment translates in an additional 12% of farmers indicating their intent to purchase in 2025. At face value, this suggests that a bit less than half of the farmers who were induced by the vouchers to try the biofortified seeds were convinced to grow it again the following year.

The results of the incentivized WTP measure (column 3 in Table 6) suggest however a more muted response. While the average WTP in the control is about half of the benchmark value of the seeds at the agrodealer shop, WTP is not higher in the treatment villages (and indeed the point estimates are negative).[21] Moreover, when estimating the share of farmers willing

[19] Column 5 shows that among those that remember attending the information sessions, the recall about topics covered during the sessions is similar for the three treatment groups, with people broadly remembering two topics. Descriptively, the most common topics farmers recalled were information on nutrition and yield, while recall on prices, crop management, and wind resistance was also relatively common.

[20] Results are very similar when only considering Fortaleza (the biofortified seed directly marketed by SN) or the combination of Forteleza and biofortified seeds from SN partner companies (for which we find very low adoption rates overall). Note also that about 5% of farmers in the sample report not having grown maize in 2024.

[21] The relatively low WTP in the control may, in part, be the result of liquidity constraints given that the bags had to be purchased on the spot. The effect of the liquidity constraint holds for both the treatment and the control. Note also that a substantial share of farmers offered WTP prices below the endowment value (about a third), indicating that liquidity constraints cannot be the only explanation for the low average values. The share of farmers offering prices below the endowment value is not significantly different between treatment groups.

to pay the market price (Table 6, column 4, 16% in the control), it appears to be significantly lower in the information-plus-voucher villages. The two WTP results together raise the possibility that the additional demand-side subsidies from 2024 may make farmers more reluctant to subsequently pay the market price. The results could also mean that after learning more about the biofortified seeds (through the information sessions, through their own increased use after purchase with discount vouchers, or from discussions or observations with other farmers in their village who also received vouchers), some farmers came to realize that their benefits are lower than they may have otherwise expected, and that therefore their WTP is lower. Analysis of WTP at different discount rates helps to disentangle these possible explanations.

5.4 Price elasticity of the demand for biofortified seeds

Table 7 shows that, broadly in line with the elasticity results on redemption, planting of biofortified seeds is 11 to 12 p.p. higher for the two highest discount rates compared to the lower ones (with final levels of adoption being of broadly similar magnitude as the redemption rates). Interestingly, the WTP measures also show positive significant signs for the high discount levels.[22] This means that those that benefited from the highest discounts were more likely both to have planted the biofortified seeds in 2024 and to be willing to pay higher prices in 2025 (compared to those with low discount values). Descriptively, we also find that those farmers that adopted in 2024 indeed have higher WTP in 2025. While the share of farmers willing to pay the market value remains low, finding higher WTP for farmers that benefited from higher discounts suggests that the low average WTP in the information-plus-voucher villages is not the result of benchmarking to a lower price due to the experience with the discount. It therefore seems more likely that the low WTP reflects the evaluation by the farmers of the seeds after village-level exposure in 2024, possibly because it allowed them to learn more about the various traits of these varieties.[23]

5.5 Experimental impacts on reach among diverse farmers

To understand whether information and subsidies are more or less effective at expanding longer-term adoption among groups of farmers that potentially could derive higher benefits, we estimate the ITT estimates of the information and information-plus-voucher treatments separately for groups of farmers with key characteristics of interest.

[22] Differences in purchase intentions for 2025 are not significantly different by discount rate, though the point estimate of the highest level is close to being significant.

[23] The results also indicate the reported intent to purchase and the incentivized WTP are not fully consistent with each other, which could point to experiment demand-effect bias in the results on intent to purchase, or be related to the specificity of the choices made in the WTP exercise (which, compared to market transactions, imply liquidity and quantity constraints, while they exclude transaction costs; see Appendix C). As the protocol for the WTP is held constant across treatment groups, and the results of the WTP therefore are internally valid, we generally put more weight on the WTP results in the interpretation. Reassuringly, those expressing intent to purchase do have a higher WTP on average.

Figures 2 to 4 show the ITT estimates for 2024 take-up (adoption), 2025 intent to purchase, and the WTP for diverse groups of farmers. Specifically, we show separate results for farmers who attended school (as a proxy for higher socioeconomic status and possibly having less liquidity constraints), criollero farmers, households with female respondents or female main farmers, Indigenous households, and households that know the SN agrodealer at baseline. Reflecting results for the total sample, the impact of the information-only intervention is not significant for any of the subgroups. ITT estimates on 2024 planting decisions for the information-plus-voucher treatment are, however, significantly positive for all these groups. Point estimates seem particularly large for female main farmers, suggesting that the demand-side subsidies may have been effective at reaching this target population.

That said, once we consider the intent to purchase in 2025, a different pattern emerges. Most strikingly, impacts are no longer significant for the female main farmer or female respondent. Together with the adoption results for 2024, this suggests that even if demand-side subsidies may be effective at providing female farmers an opportunity to be exposed to the biofortified seed, this does not translate into higher reported purchase decisions the following year (in contrast with the results for male farmers). This could point to liquidity constraints or lack of decision power limiting the ability of women to (re)purchase at market rates. It could also mean that exposure to the biofortified seeds made women realize traits they disliked about them, and on which they possibly put higher weights than men. We'll return to this point below.

In contrast, for both the criolleros and the indigenous farmers, stated intention-to-purchase rates are significantly higher in the information-plus-voucher villages than in the control.[24] Yet, interestingly, the incentivized WTP values are significantly lower for both of these groups (Figure 4). As the WTP is real stakes, it is possible that liquidity constraints (on the day of the survey) were more binding for these groups than for others. It could also be, however, that certain traits of the biofortified seeds lowered the valuation of the seeds by criolleros and indigenous farmers.

To understand the role of liquidity further, we consider the price elasticity of adoption by group in Figures 5 to 7. Figure 5 broadly confirms that take-up increases at higher discount prices for almost all groups. The intent to purchase for 2025 (Figure 6) is significantly higher for the high-discount group (as compared to the low-discount group) for the criolleros and Indigenous, but not for women. The later results confirm the earlier insight that women seem to face additional constraints preventing previous exposure from translating into sustained adoption. The pattern of results for WTP for different discount rates is not necessarily consistent with these findings, however, and indeed the WTP at different discount levels is overall hard to interpret. This possibly cautions against drawing strong conclusions regarding elasticities for subgroups, as sample sizes become small for each of the estimations (as can be inferred from the large confidence intervals).

[24]Point estimates for ITT effects on purchase in 2025 are (not surprisingly) the highest for farmers that knew the SN agrodealer at baseline.

5.6 Supply-side subsidy

Table 8 shows that assignment to the agrodealer incentive treatment did not significantly change biofortified adoption rates among the sampled farmers. Figure 8 shows results of testing whether the impact of the agrodealer incentive on 2024 adoption of biofortified seed is significantly different for certain subgroups. These heterogeneity results align with the results with the voucher redemption data, suggesting that agrodealer incentives may be more effective for female than male farmers and less effective for Indigenous than for Ladino farmers. However, in line with results on elasticities (Figures 5 and 6), higher short-term adoption among women induced by agrodealer incentives does not lead to higher intention-to-purchase rates for them in the following year. Indigenous farmers on the supply-side treatment arm are, however, less likely to purchase in 2025.

5.7 Summing up results on primary outcomes

Taken together, the results show first of all that information sessions do not seem to be a very effective strategy to increase uptake or adoption, and this conclusion holds for all types of households. The results on the information-only intervention come with an important caveat. Given the contamination of the control, assignment to this treatment led to only a modest difference in exposure to information between the control and the information-only villages.

Second, results also clearly show that demand-side information and subsidies together can be effective at increasing uptake. Moreover, at very large levels of subsidies this increased exposure to the biofortified seeds translates to increased willingness for sustained adoption and higher WTP. These results confirm that demand-side subsidies can be effective at encouraging farmers to experiment with new seeds, and that this can lead to longer-term demand.

Third, and equally important, the relatively modest magnitudes of the impact raises questions on effectiveness. Indeed, while subsidies do increase adoption and WTP, even the highest levels of subsidy lead to only modest intent to purchase rates in 2025. Moreover, the average WTP stayed much under the price at which the biofortified seed is marketed at the agrodealers. This points to large remaining hurdles for the majority of farmers.

Fourth, the subsidy intervention, and high subsidies in particular, can be effective tools to increase short-term exposure of women to the biofortified seeds. Nevertheless, this additional exposure leads to less sustained impacts and lower WTP than for men.[25] On the other hand, Indigenous farmers and criollero farmers also react to the demand-side subsidies on the short run, and for them this exposure does translate to larger intended sustained adoption. Yet, the impact of subsidies on their willingness to pay is negative, suggesting that they are only interested in buying at very low prices.

[25] Similarly, the supply-side subsidy seemed to increase take-up of biofortified seeds more for women than for men, but it also does not translate in higher purchases in 2025 or higher WTP.

6 Mechanisms

A main finding of the previous sections is that relatively few farmers seem interested in buying biofortified seeds at market prices (even while those market prices are substantially below those of other hybrid seeds), and that this remains true after having been able to experiment with the seed in 2024. This suggests either that the farmers did not perceive (sufficient) benefits from using the biofortified seeds or that there are other remaining constraints preventing sustained adoption. In this section, we first discuss input complementarities as a possible remaining constraint, and then focus on the various reasons for why perceived benefits may be low, starting from conceptualizing the choice of seeds as choosing between bundles with different combinations of traits.

6.1 The importance of complementary input investments

One possible reason why criollo farmers may be reluctant to switch to hybrid varieties (including biofortified ones) could be perceptions about the need to complement such seeds with additional investments in fertilizer, pesticides, or other chemicals. For pesticides specifically, the possible need for such complementary investments was indeed highlighted during the information sessions, given that the higher nutrient content makes SN maize attract more insects and other pests. Even if investments in complementary inputs may increase yield, this could reduce demand if farmers are liquidity constrained or if climatological risks make the returns to such investments uncertain. There may also be learning costs resulting from the complementarity between inputs that reduce demand (Laajaj & Macours, 2024).

Descriptively, we do not find any significant differences in the application or costs of fertilizers among criollo growers and those growing biofortified seeds, suggesting that the most obvious complementarity (hybrid seeds and fertilizer) does not seem to play a first-order role in this context. We do find, however, that growing biofortified seed goes together with significantly more investment in pesticides and herbicides, compared to criollo farmers. Compared to other hybrids, costs of fertilizer and herbicides are substantially lower for the biofortified seeds.

Going beyond the descriptive comparison, the intent-to-treat estimates on input costs in Table 9 confirm the potential importance of the complementary input decisions. Farmers in both treatment groups report higher expenditures on fertilizer, herbicides, and pesticides, with impacts being larger and more significant for the information-plus-voucher treatment. A notable exception is the cost of "tratador", the pesticide application bought together with seeds. These results suggest that the increase in chemical use is not resulting from reallocating the savings received from the discount vouchers to other immediate expenditures. The results are more in line with farmers having internalized the message around chemical application from the information sessions. Note that this is not the only possible explanation, as the plausible other hypothesis is that farmers, once they see the new seeds are performing well, decide themselves to invest in more complementary inputs to optimize returns (as in Emerick et al. (2016)). The increases in fertilizer and herbicides, which go together with the increase in pesticides, as well as the lack of impact on seed treatment at planting, all point in that direction. Finally, given that voucher redemption rates were found to be higher among farmers that reported having been affected by pests or diseases in the past, the results could also point to farmers' increased awareness on the need for pesticide investments in certain settings. Overall, these results point to the potential importance of complementary investments in understanding long-term adoption decisions. We flag this as an area for further research.

6.2 Understanding preferences for specific traits

Abstracting from the possibility of remaining frictions, seed choices ultimately also reflect farmers' preferences for the bundle of traits that each seed type represents. This subsection first presents data and analyses that can help understand preferences for specific traits. The next subsection then analyzes the possible trade-offs between the different traits in the bundle. As preferences and trade-offs can differ for the various types of farmers of interest, we also analyze such potential differences.

Consumption-related taste-based preference: As the farmers in our sample produce in large part for home consumption, people's consumption preferences are likely to play a role in seed choice. We therefore asked the respondents which seeds they prefer for consumption. Sixty percent of all farmers report preferring criollo maize for home consumption, while only 2% prefer biofortified seeds, and these proportions do not significantly change with treatment. A straightforward reason for low intention to purchase could hence be that farmers place a high value on their taste-based preference for criollo maize and are willing to forgo other potential benefits for it.

Origin-related preferences: A different working hypothesis when designing the pilot experiment was that, given the cultural value of maize in Guatemala, farmers – and Indigenous farmers in particular – may be reluctant to plant biofortified hybrid seed if they perceive them having foreign origin. Possible concerns about hybrid "foreign" seeds completely replacing criollo seeds (and the resulting loss of the local varieties) was also mentioned during qualitative work. A related concern farmers could have is uncertainty about the breeding method used to obtain the biofortified seed. While the biofortified seed is the result of traditional breeding, anecdotal evidence suggests some may erroneously associate it with genetic modification. GMOs are illegal in Guatemala and could be seen by farmers as containing certain unknown risks (whether health or otherwise).

To understand the importance of these considerations, we included a series of knowledge questions at endline. Among the farmers familiar with the biofortified seed varieties, the vast majority (82.5%) report not knowing in which country the seed originates. Among those reporting a country of origin of the seed, the majority believe them to be Guatemalan (with Mexico the next most common category). The share of farmers indicating not knowing the country of origin is very similar to what farmers report for Dekalb, the most common high-yielding hybrid. Strikingly, it is even higher (95%) for the common varieties released by national seed companies. Together, these descriptive results suggest that foreign origin does not seem to be a primary concern for most farmers.

Similarly, only 5% of farmers knowing about biofortified seeds at endline believe them to be GMO. While half of farmers indicate they do not know the breeding method, the remaining correctly report they result from traditional breeding. Farmers also seem to understand the hybrid nature of the seeds, as there is only one farmer in the sample reporting having obtained biofortified seeds from their own prior harvest (while among other hybrid farmers, 9% report doing so). The low share of farmers reporting them to be genetically modified suggests that this possible misconception is not a primary driver for low demand.

Finally, when answering questions on the most preferred and least preferred traits of different maize seeds, no farmers reported national origin, breeding method, or concerns of loss of local varieties as negative traits (neither for the biofortified seeds nor for other hybrids), nor did they mention the local origin of criollo seeds as a positive trait.

Together, these results suggest that even if farmers have a strong taste-based preference for consuming criollo seeds, there is overall little supportive evidence of concerns with breeding methods or origin per se driving these preferences. This also holds for Indigenous farmers. Indeed, many of the Indigenous farmers, in particular in Peten, have a commercial focus and are already growing different types of hybrids.

Preferences related to traditional gender roles in seed selection: We also investigated a related but slightly different hypothesis originating from the anthropological literature, suggesting that women may value criollo seeds particularly highly because of their traditional role in selecting seeds from the prior harvests (FAO, 2017). Our data show, however, that only in 21% of households a woman is in charge of seed selection. Indeed, even when a woman is the main farmer, it often appears to be a male household member that selects the seeds. As such, traditional gender roles for seed selection are unlikely to be an important factor driving seed preferences in our sample.[26]

[26]Seed selection on average takes about four hours, so that the time savings from not having this additional task when planting hybrid biofortified seed is also unlikely to substantially change the benefit-cost ratio. People report that they would allocate time otherwise used for seed selection to other income-generating activities (in agriculture or elsewhere) or domestic tasks, with the latter answered by two-thirds of women. See Appendix Tables A2 and A3.

6.3 Insights on the trade-offs between bundles of traits

6.3.1 Discrete choice experiment

To better understand how farmers value the trade-offs between the many different traits bundled together in each maize seed, we administered a discrete choice experiment (DCE) designed to elicit willingness to pay for specific seed attributes within a larger bundle, following Train (2009). During the endline survey, farmers were asked a series of seven comparisons between maize seed pairs, with random variation within each pair on five different seed attributes: yield, seed price, nutritional content, grain size (as a proxy for market value), and wind resistance (as a proxy for yield variability). These attributes vary across available seed varieties, but farmers must make trade-offs when selecting which seeds to plant. To understand this trade-off, the discrete choice experiment asks farmers to choose between the hypothetical seeds in the pair, with each seed characterized by a combination of these five seed attributes. See Appendix D for more details on the methodology. A mixed logit model is then used to estimate the relative importance of each attribute for the respondents' choices, with the seven different comparisons between the pairs of hypothetical seeds serving as separate observations.

The DCE results reveal that farmers demonstrate strong and consistent preferences for wind-resistant maize seeds, with willingness to pay approximately 31 quetzales per pound across all subgroups and treatment conditions (column 1 of Table 10). Farmers show modest willingness to pay for nutritional content (8 quetzales per pound for high protein, zinc, and iron) and large grain size (5 quetzales per pound). They value higher yields at approximately 1.2 quetzales per pound for each additional quintal per manzana. The price coefficient is consistently negative and statistically significant across all specifications, confirming that participants understood the exercise and preferred lower-priced options, all else constant.

While the mixed logit specification suggests that there were, on average, no significant differences in valuation of the different attributes between the control and the villages with demand-side interventions (Columns 2 to 4 in Table 10), converting the choices from DCE to separate choices for each attribute (using the trade-offs with price to obtain a WTP estimate) and also adding the agrodealer fixed effects (given stratification) shows that the demand-side interventions (information sessions and vouchers) did significantly alter some of the farmers' preferences – see Table 11. Results suggest that exposure to the information-plus-voucher intervention in particular changed preferences for some of the seed characteristics, notably wind resistance and, to a lesser extent, nutrition.

Subgroup analysis of the discrete choice experiment reveals some heterogeneity in preferences. Farmers that were already growing hybrids at baseline demonstrate significantly higher willingness to pay for wind resistance (37.6 vs. 21.8 quetzales) compared to criolleros, while non-Indigenous respondents show marginally higher willingness to pay for wind resistance than do Indigenous respondents (38.7 vs. 25.7 quetzales, p=0.059). Male and female farmers show similar preferences overall, though male farmers tend to have slightly higher point estimates for most attributes, including for nutrition. This last result goes against the prior that female farmers may put more weight on the nutritional traits, possibly pointing to an additional reason why short-term experimentation by women did not lead to sustained adoption. Overall, the results suggest that while farmers broadly agree on the relative importance of different traits, farmers' prior experience with different seed types as well as cultural backgrounds may influence their relative valuation of specific characteristics. This seems particularly relevant for those related to crop resilience.

These preference differences point to a potential important hurdle for increasing the reach of biofortified seeds among target populations. The high value that all farmers place on wind resistance indicates that breeding that was able to bundle wind resistance with biofortification in the same seeds may have been important to increase the attractiveness of the biofortified seeds and encourage take-up. The fact that wind resistance is, however, valued less for some of the key target groups (criollo farmers and Indigenous farmers) also means that this bundling may be less effective in increasing reach among those groups, as compared to other groups.

6.3.2 Trade-offs between a wider set of traits

The DCE represented seeds as bundles of five different traits. The choice of which five traits to include was based on qualitative insights and the traits of particular relevance to the study. Limiting the number of traits in the DCE is necessary both to make the comparisons understandable to the respondents and for statistical power. In reality, however, the number of traits bundled in a given seed variety is much more than five. It is arguably this high dimensionality and the need to consider the multiple trade-offs, many involving traits that are hard to observe, that complicates both the farmer's decision-making process and the researcher's ability to understand this process.

To complement the DCE, we therefore also asked the farmers direct questions about their least and most preferred characteristics of different seed varieties (criollo, biofortified, and the most common hybrid), starting from a much larger list of possible traits, to capture the high dimensionality of the choices. Analyzing this data leads to further insights on the malleability of farmers' preferences and hence on the impact of the demand-side treatments on the trade-offs different farmers consider.

Table 12 shows that exposure to the voucher treatment increased the likelihood of farmers mentioning nutrition, traits related to market value (grain size and color), and low seed costs as positive traits. This points to farmers increasing their value of those traits through exposure to the biofortified seeds. On the other hand, the farmers in the information-plus-voucher villages were also more likely to mention dislike of sensitivity to post-harvest losses and pests (Table 13). The large effect on dislikes of the post-harvest losses is consistent with biofortified varieties being known to be sensitive to post-harvest losses in particular (a message conveyed during the information sessions). Increased awareness to such losses points to a possible explanation for the limited longer-term demand. Sensitivity to post-harvest losses was indeed also emphasized during the qualitative data collection (see Appendix) as one of the main reasons not to replant Fortaleza, together with taste and color. Finally, the lower dislike for wind sensitivity in Table 13 is also worthwhile to note.

A possible interpretation of these results is that exposure to information and subsidies of biofortified seeds allowed farmers to learn (from the information sessions and through experimentation after redeeming the discount voucher) about a variety of characteristics of these seeds. This led them to update their priors positively about some characteristics and negatively about others, and this learning likely differed between farmers. On average, we do see an increased interest to adopt in 2025 among those with the highest exposure, suggesting that on net, the updating was positive. The fact that the WTP, even if it increased, stays much below the value at which seeds are being offered at the agrodealer also means that this positive shock was only modest in size. It seems likely that the average hides substantial heterogeneity.

Considering heterogeneity in stated preferences, we note that female farmers mention less traits overall, possibly indicating more limited learning from observation. They are also less likely to mention yield or seed prices. The latter would seem to go against more severe liquidity constraints affecting women's choices more than men's. Women also mention post-harvest losses more frequently, providing an alternative explanation for their lack of continued adoption. In line with our priors, criolleros mention yield and price less. For them, lack of wind resistance is the top reason to dislike a variety, followed by post-harvest losses. Indigenous farmers similarly mention the different resilience traits much more frequently than Ladino farmers.

The results on differences between groups on wind resistance in particular seem to contradict the findings from the DCE. The DCE has the advantage of making trade-offs between traits very salient, which could possibly explain these differences in findings. At the same time, their limitation is that not all traits can be considered. Post-harvest losses, for instance, which we find to be important for people's stated preferences, were not accounted for in the DCE. More research is needed to unpack some of the findings. This is arguably not surprising given the complexity of the multidimensional decision-making.

6.4 Direct evidence on climate-shock related damage

To complement evidence on different resilience traits possibly affecting longer-term adoption decisions, we also directly asked farmers to what extent their maize crop had been affected by different climate-related shocks. Estimates of the ITT effects of the demand-side interventions (Table 14) notably show relatively large negative coefficients for both drought and wind, implying farmers report less drought and wind damage after being exposed to the demand-side treatments, even if effects are not significant at conventional levels. The amount of harvests saved because of lower wind damage is particularly high for the information-plus-voucher group, with a reduction of 0.6 pounds from wind damage compared to the control mean of 1.54. While these results need to be revisited with a larger sample and increased power, the results pointing to less reported damage of both drought and wind are consistent with SN breeding objectives and are suggestive of farmers directly perceiving the climate-resilience benefits.

6.5 The role of information: Complementary evidence from randomized reminder messages

A notable finding from our main results is the very limited impact of the information sessions on adoption. It is theoretically possible that this limited impact is driven by the fact that farmers already had access to information about the biofortified seeds from their agrodealers. Indeed, SN's benchmark model counts on recommendations by the agrodealers as the primary channel for spreading information on the biofortified seeds. Endline data reveal, however, that few farmers report having benefited from promotional campaigns by agrodealers, with less than 5% having received any free inputs. Moreover, while about 20% report having tried certain inputs following the recommendations of the agrodealer, recommendations are much more common for herbicides, pesticides, and fertilizers (products for which agrodealers likely have higher profit margins) and are more limited for seed. Among the 18% who did get recommendations of seeds from agrodealers not participating in the experiment, recommendations regarding biofortified seeds were the second most common (after the high-yielding Dekalb). At the participating agrodealers, 24% of farmers had gotten seed recommendations, with close to two-thirds of recommendations being for biofortified seeds. Agrodealers talked most about yield and drought resistance, with only 15% of respondents mentioning that the participating agrodealer talked about nutrition. Finally, a possible limiting factor in information transmission by agrodealers is language. Only 10% of the participating agrodealers speaks an indigenous language (in all cases K'ekch'i). Among other agrodealers the respondents frequent, shares are higher (with 22% speaking K'ekch'i and another 10% speaking Q'uiche). Overall, information transmission through recommendations of the agrodealers hence seems quite limited.

To further understand the role of information and zooming in on information about specific traits, we draw on a second, ancillary sample of farmers to test whether receiving targeted information about a specific trait can be more or less effective in inducing farmers to try the biofortified seeds. To do so, we take advantage of a sample of farmers that had been chosen by the NGO to receive a seed donation in 2023 and who afterwards received an information session and discount vouchers in 2024.[27]

[27] As was done for farmers in the main sample, farmers in this group received an offer to attend an information session where they received a discount voucher scratch card (with a discount between 25 and 75% of the average market price) to purchase biofortified seeds in a local participating agrodealer. As these farmers were not drawn from the same sample frame, they represent a somewhat different farmer population than those in the pilot experiment (and they could redeem at a different set of agrodealers). This group arguably reflects how the NGO or the government would target farmers for donations in their business-as-usual distribution strategy. They notably contain a larger share of women farmers.

A random subset of this donation group was assigned to receive three SMS text message reminders (one week apart) during the 2024 planting season, highlighting different characteristics of the biofortified seeds. A first randomly selected group of farmers received three messages emphasizing the nutritional benefits of Fortaleza seed, mentioning the health gains for children in particular (e.g., "*¡La semilla Fortaleza hace que su familia esté bien alimentada, ya que aporta nutrientes que nos hacen más sanos!*"). A second randomly selected group of farmers received three messages with nutrition information that emphasized the specific micronutrients and their role (e.g., "*¡El maíz Fortaleza contiene mucho hierro! Sin hierro nos sentimos cansados, débiles y nos cuesta concentrarnos.*"). The third randomly selected group of farmers received three messages emphasizing the seed origin and agronomic properties of the seeds (e.g., "*¡La semilla Fortaleza es una semilla local, desarrollada por una organizacion sin fines de lucro guatemalteca y producida por agricultores como usted!*"). Messages were sent by simple text and in Spanish, with the sending phone number being marked as "Maize Fortaleza". To maximize power while also being able to handle possible spillovers, randomization of the text messages was done at the individual level through a saturation design at the village level (across 50 villages). As a result, the majority of targeted farmers in a village would have received one type of message, while we still have within-village variation that increases power. Apart from conveying specific messages, the SMS also likely served as a reminder about the biofortified seeds more generally.

Administrative data on voucher redemption allows estimating the intent-to-treat effects of these targeted reminders. Table 15 shows that generic nutrition messages and, to a lesser extent, the seed-origin messages increased voucher redemption. Interestingly, and in line with some of the results above, these ITT results are driven by households where the main farmer is male, with sensitivity of men to the nutrition messaging being particularly strong. In addition, and contrary to our initial priors, messaging around the local nature of the seeds seems to not have significantly shifted farmers who self-identify as Maya (with the point estimate being higher for the Ladino farmers), while Indigenous farmers did increase redemption in response to the nutritional messages.

Overall, these results confirm and extend some of the findings from the main experiment. Farmers put some weight on nutritional benefits, but such messaging is more effective for male than for female farmers. This could be because, as earlier results suggest, female farmers lack liquidity or decision power for information to translate into purchases. They may also have been less likely to receive the messages or to be able to read them. The results are also consistent, however, with male farmers putting higher value on nutritional benefits, as the discrete choice results also suggested. As these results go against our own priors based on the related literature, they indicate an area for further research.

7 Conclusion

This paper presents the learning from qualitative and quantitative data collection on a pilot experiment testing different scaling strategies for biofortified, climate-resilient maize in Guatemala. The experiment was designed to test the relative effectiveness of demand and supply-side interventions for increasing the reach of biofortified maize varieties among diverse sets of farmers across Guatemala, with particular attention to female farmers, Indigenous farmers, and those growing traditional varieties. Demand-side interventions aimed to address information and liquidity constraints possibly preventing farmers from experimenting with the relatively recently released biofortified varieties. These interventions involved information sessions organized in their villages and discount vouchers redeemable for purchase at participating agrodealers in their municipalities. Variation in supply-side incentives for the agrodealers aimed to test an alternative, and possibly more cost-effective, intervention for reaching a diverse set of farmers.

The results show relatively large uptake of the demand-side subsidies and moderate participation in information sessions. Impacts on longer-term adoption and willingness to pay among farmers exposed to price discounts and information sessions were smaller than initial uptake, but also significantly positive, with sizable point estimates at high discount rates. These results confirm that demand-side subsidies can be effective at encouraging farmers to experiment with new seeds and that this can lead to longer-term demand. Even so, the highest levels of subsidy led to only modest increases in intent to purchase in the year following the experimentation, and the average WTP stayed much under the price at which the biofortified seed is currently marketed at agrodealers. This points to large remaining hurdles for the majority of farmers.

Exposure to information sessions alone improved knowledge but did not lead to either short- or longer-term adoption. Results on the lack of impact of the information sessions need to be caveated, as lack of compliance with the experimental design led to a relatively high level of contamination in the control. This not only informs the type of adaptations needed for an experiment at scale, but also more generally points to the limits of complex experimental designs when studying a system based on crowding in private sector incentives. Despite compliance issues, the experiment still generated exogenous variation in learning opportunities for farmers, both through learning from experts (whether technicians or agrodealers) and learning by doing from their own experimentation with biofortified seeds. The relatively small impacts of the vouchers on the longer-term outcomes suggest caution on expecting large immediate gains from intensive demand-side interventions for seed innovations. Studying whether multi-year exposure to biofortified seeds could lead to larger impacts is a question that remains for future work. Similarly, more work is needed to fully understand the potential of supply-side incentives. While the experimental variation on the supply side introduced in this study led to limited longer-term adoption, this conclusion is derived from an underpowered comparison, hence should be interpreted with caution.

The study clearly points to some gender-specific responses. While qualitative insights pointed at greater receptivity and recall of nutrition-related messaging among women that participated in the information sessions, intent to purchase in 2025 and willingness to pay is much more limited for female farmers, even if high subsidies or supply-side incentives were effective at increasing their short-term exposure. On the other hand, Indigenous farmers and criollero farmers also react to the demand-side subsidies in the short run – while this is less the case for the supply-side incentives – and for them this exposure does translate in larger intended purchase in the year following the experimentation. Yet, the impact of subsidies on the price they are willing to pay for biofortified seeds is negative, suggesting they are only interested in buying at very low prices.

Additional analysis trying to disentangle the mechanisms of this set of results points to both remaining frictions and the complexity of multidimensional trade-offs farmers need to consider when making seed choices. Seed choices ultimately reflect farmers' preferences for the bundle of traits that each seed type represents. Our evidence allows highlighting the importance of certain traits (like taste and wind resistance) but also demonstrates that when decisions need to be made about bundles of traits, the inherent trade-offs involved can be hard to anticipate. This is particularly true as preferences can differ for the various types of farmers of interest, as our evidence suggests.

Together, these results reconfirm that biofortification of staple crops are not a panacea to address all nutrition problems among the diverse populations that characterize Guatemala but should rather be seen as one approach in a broader toolbox, as is more widely acknowledged (H. Bouis et al., 2024). The results do confirm the potential of demand-side interventions to increase take-up of biofortified crops, a necessary step to deriving the nutritional and climate-resilient benefits. As the analyses in this paper further help understand which types of households are more likely to benefit from biofortified maize once different information and subsidy programs address the initial adoption constraints, they also point to the types of households that may instead need to be targeted through fortification, supplementation, or diet-diversity approaches.

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8 Tables

8.1 Main descriptive tables

Table 1: Baseline descriptive statistics

	Mean	Min	Max	Obs
Household and farm characteristics				
Grows maize all years	0.976	0.0	1.0	900
Hh-head	0.873	0.0	1.0	900
Main farmer	0.827	0.0	1.0	900
HH size	4.641	0.0	14.0	900
Nb of kids below 5 y.o.	0.508	0.0	5.0	900
Female respondent	0.340	0.0	1.0	900
Female main farmer	0.222	0.0	1.0	900
Speaks and understands Spanish	0.856	0.0	1.0	900
Ethnicity				
Maya	0.403	0.0	1.0	900
Xinka	0.128	0.0	1.0	900
Garífuna	0.001	0.0	1.0	900
Ladino	0.448	0.0	1.0	900
Language spoken at home				
Spanish	0.683	0.0	1.0	900
K´iche´	0.081	0.0	1.0	900
Q´eqchi´	0.192	0.0	1.0	900
Mam	0.008	0.0	1.0	900
Usual purchases at the agrodealer				
Maize seeds	0.586	0.0	1.0	900
Herbicides for maize	0.896	0.0	1.0	900
Pesticides for maize	0.866	0.0	1.0	900
Fertilizer for maize	0.957	0.0	1.0	900
Seeds for other crops	0.143	0.0	1.0	900
Herbicides for other crops	0.201	0.0	1.0	900
Fertilizer for other crops	0.250	0.0	1.0	900
Other inputs	0.040	0.0	1.0	900
Maize varieties cultivated and land size				
Criollo	0.543	0.0	1.0	900
Dekalb	0.236	0.0	1.0	900
Fortaleza	0.023	0.0	1.0	900
HB 83	0.106	0.0	1.0	900
HR	0.001	0.0	1.0	900
ICTA	0.026	0.0	1.0	900
JC (21, 24, 25, 21 Plus)	0.036	0.0	1.0	900
JC 5 Proteico	0.023	0.0	1.0	900
Pioneer	0.034	0.0	1.0	900
Tropical Biofortificado ACP + Zn	0.000	0.0	0.0	900
Other	0.120	0.0	1.0	900
Land size (Hectare)	0.823	0.0	12.701	900

Source is baseline data. Sample includes only farmers who were tracked at endline.

Table 2: Endline descriptive statistics and education level (control group)

	Mean	Min	Max	Obs
Sources of income				
Only farming	0.697	0.0	1.0	330
Receives pension or other aid	0.006	0.0	1.0	330
Business	0.097	0.0	1.0	330
Salary	0.061	0.0	1.0	330
Other	0.036	0.0	1.0	330
Receives remittances	0.121	0.0	1.0	330
Education level				
Did not attend school	0.297	0.0	1.0	330
Incomplete primary education	0.361	0.0	1.0	330
Completed primary education	0.194	0.0	1.0	330
Incomplete secondary education - Basic	0.021	0.0	1.0	330
Completed secondary education - Basic	0.055	0.0	1.0	330
Incomplete secondary education - Diversified	0.009	0.0	1.0	330
Completed secondary education - Diversified	0.055	0.0	1.0	330
University	0.009	0.0	1.0	330
Does not know/Does not respond	0.000	0.0	0.0	330
Observations	330			

Source is endline data. The sample includes only the control group.

8.2 Tables on voucher redemption rates and compliance

Table 3: Voucher redemption rate by baseline characteristics

	(1)-(2) No FE		(3) With FE		
	α	β	β	Control Mean	N
Female main farmer	0.258***	0.012	0.041	0.251	291
	(0.08)	(0.09)	(0.08)		
Speaks and understands Spanish	0.130	0.155	-0.113	0.814	291
	(0.11)	(0.13)	(0.11)		
Maize for home consumption	0.200	0.062	0.040	0.981	291
	(0.19)	(0.19)	(0.14)		
Land dedicated to maize (ha)	0.255***	0.007	0.019	0.815	291
	(0.09)	(0.03)	(0.03)		
Criollo only	0.379***	-0.226**	-0.101	0.595	291
	(0.09)	(0.11)	(0.10)		
Maya	0.355***	-0.179	-0.023	0.586	291
	(0.12)	(0.14)	(0.12)		
Ladino	0.246***	0.041	-0.413***	0.358	291
	(0.09)	(0.15)	(0.13)		
Knows agrodealer (SN)	0.182***	0.160	0.067	0.437	291
	(0.06)	(0.11)	(0.05)		
Purchased at agrodealer (SN)	0.201***	0.132	0.017	0.409	291
	(0.06)	(0.11)	(0.04)		
Distance to closest agro (min)	0.302***	-0.002	-0.001	24.279	291
	(0.10)	(0.00)	(0.00)		
Drought (sequía)	0.278***	-0.018	0.188	0.940	291
	(0.06)	(0.09)	(0.15)		
Flooding (river/lake rising)	0.280***	-0.180*	0.028	0.126	291
	(0.08)	(0.10)	(0.03)		
Landslide, strong winds, etc.	0.252***	0.050	-0.132	0.172	291
	(0.08)	(0.11)	(0.10)		
Pests and diseases	0.100*	0.187**	0.114***	0.833	291
	(0.05)	(0.08)	(0.03)		
Lack of resources for crop inputs	0.220***	0.095	-0.106*	0.405	291
	(0.06)	(0.14)	(0.06)		
Agrodealer FE	NO	NO	YES		

This table reports estimates from the following linear probability model:

$$\Pr(\text{VoucherRedeemed}_i) = \alpha + \beta X_i + \varepsilon_i,$$

where X_i includes baseline household characteristics. Column (3) adds agrodealer-pair fixed effects. *Control Mean* shows the mean value of the covariate among those who did not redeem the voucher. Standard errors, clustered at the community level, are shown in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Voucher redemption rates by baseline characteristics and their interaction with agrodealer Incentives

	No FE			With FE			
	α	β	γ	β	γ	Control Mean	N
Female main farmer	0.294**	-0.230**	0.422***	-0.171*	0.401***	0.251	291
	(0.12)	(0.11)	(0.13)	(0.10)	(0.14)		
Speaks and understands Spanish	0.037	0.255*	-0.238	0.020	-0.265	0.814	291
	(0.04)	(0.14)	(0.24)	(0.11)	(0.20)		
Maize for home consumption	0.000	0.244**	-0.300	0.259***	-0.372	0.981	291
	(.)	(0.11)	(0.29)	(0.08)	(0.23)		
Land dedicated to maize (ha)	0.188	0.062	-0.077	0.063	-0.058	0.815	291
	(0.13)	(0.06)	(0.06)	(0.06)	(0.07)		
Criollo only	0.378***	-0.311**	0.138	-0.255*	0.359***	0.595	291
	(0.13)	(0.13)	(0.20)	(0.13)	(0.13)		
Maya	0.350*	-0.199	0.040	-0.078	0.192	0.586	291
	(0.18)	(0.21)	(0.28)	(0.16)	(0.27)		
Ladino	0.287**	-0.193	0.367*	-0.547**	0.207	0.358	291
	(0.14)	(0.14)	(0.22)	(0.24)	(0.18)		
Knows agrodealer (SN)	0.119*	0.244	-0.154	0.208**	-0.288	0.437	291
	(0.07)	(0.15)	(0.22)	(0.10)	(0.20)		
Purchased at agrodealer (SN)	0.141**	0.214	-0.150	0.153	-0.270	0.409	291
	(0.07)	(0.17)	(0.23)	(0.12)	(0.20)		
Distance to closest agro (min)	0.252**	-0.001	-0.003	-0.002	0.003	24.279	291
	(0.10)	(0.00)	(0.01)	(0.00)	(0.00)		
Drought (sequía)	0.375***	-0.143	0.227	0.054	0.268	0.940	291
	(0.08)	(0.12)	(0.15)	(0.10)	(0.17)		
Flooding (river/lake rising)	0.276**	-0.169	-0.113	0.055	-0.319	0.126	291
	(0.12)	(0.15)	(0.17)	(0.14)	(0.22)		
Landslide, strong winds, etc.	0.232*	0.054	-0.011	-0.124	-0.008	0.172	291
	(0.12)	(0.18)	(0.23)	(0.12)	(0.12)		
Pests and diseases	0.043	0.238*	-0.124	0.271*	-0.318	0.833	291
	(0.05)	(0.14)	(0.17)	(0.14)	(0.21)		
Lack of resources for crop inputs	0.165**	0.240	-0.257	0.085	-0.292	0.405	291
	(0.08)	(0.24)	(0.28)	(0.24)	(0.26)		
Agrodealer-pair FE	NO	NO	NO	YES	YES		

This table reports heterogeneous treatment effects from the following linear probability model:

$$\Pr(\text{VoucherRedeemed}_i) = \alpha + \beta X_i + \gamma(\text{SubsidioAgro}_i \times X_i) + \delta\,\text{SubsidioAgro}_i + \varepsilon_i$$

where X_i is a baseline characteristic and SubsidioAgro_i is an indicator for assignment to the voucher subsidy treatment. Column (1) does not include fixed effects; Column (2) includes agrodealer-pair fixed effects. *Control Mean* refers to the mean of the covariate among individuals who did not redeem the voucher. Standard errors clustered at the community level are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Compliance: First stage based on endline data

	(1) Attended info session	(2) Received a voucher	(3) Voucher | on info session	(4) Knowledge index	(5) Nb. topics remembered of info session
Information only	0.133**	-0.0196	-0.0476	0.616**	-0.149
	(0.07)	(0.03)	(0.04)	(0.31)	(0.18)
Information+Vouchers	0.261***	0.457***	0.644***	1.543***	0.0775
	(0.07)	(0.06)	(0.06)	(0.34)	(0.21)
Observations	900	900	425	900	425
Mean Control	0.35	0.01	0.03	1.62	2.19
P-value Info=Info+Voucher	0.11	0.00	0.00	0.01	0.12
P-value T-pooled=0	0.01	0.00	0.00	0.00	0.95

Standard errors are clustered at the community level and are in parenthesis. Agrodealers FE included. All columns have baseline controls selected by double LASSO. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

8.3 Main impact results

Table 6: ITT of demand-side interventions on adoption

	(1) Take-up Fortaleza	(2) Intent-to-Purchase 2025	(3) WTP	(4) Prob(WTP $\geq$ market value)
Information only	0.0240	0.0301	-2.748	-0.0303
	(0.04)	(0.03)	(2.53)	(0.02)
Information+Vouchers	0.291***	0.118***	-3.169	-0.0511**
	(0.06)	(0.03)	(2.89)	(0.02)
Observations	847	900	900	900
Mean Control	0.10	0.10	44.91	0.16
P-value Info=Info+Vouchers	0.00	0.02	0.89	0.36
P-value T-pooled=0	0.01	0.00	0.33	0.03

Standard errors, clustered at the community level, are reported in parentheses. Willingness to pay (WTP) is top-coded at 100 quetzales; the market reference price is 90 quetzales. All regressions include agrodealer fixed effects and baseline controls selected using the double LASSO procedure. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Price elasticities: ITT of assignment to higher discounts on adoption

	(1)	(2)	(3)	(4)
	Take-up Fortaleza	Intent-to-Purchase 2025	WTP	Prob(WTP $\geq$ market value)
Discount level 2	0.0207	-0.113**	5.247	0.0249
	(0.04)	(0.05)	(4.07)	(0.04)
Discount level 3	0.110***	0.00170	5.952	0.102**
	(0.04)	(0.05)	(6.08)	(0.05)
Discount level 4	0.123**	0.0534	11.03***	0.0357
	(0.05)	(0.03)	(4.02)	(0.05)
Observations	250	264	264	264
Mean Disc1	0.28	0.20	35.16	0.06
P-value: Disc2=Disc3	0.01	0.05	0.93	0.15
P-value: Disc2=Disc4	0.01	0.00	0.27	0.69
P-value Disc3=Disc4	0.73	0.42	0.24	0.19

Standard errors, clustered at the community level, are reported in parentheses. The excluded reference group is the lowest discount level (Q90 and Q50). All specifications include agrodealer-pair fixed effects and baseline controls selected via the double LASSO procedure.* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 8: ITT of supply-side incentives on adoption

	(1)	(2)	(3)	(4)
	Take-up Fortaleza	Intent-to-Purchase 2025	WTP	Prob(WTP $\geq$ market value)
Agro-incentive	-0.0396	-0.0410	-1.416	0.0212
	(0.07)	(0.04)	(2.97)	(0.02)
Observations	847	900	900	900
Mean Control	0.21	0.17	43.64	0.13

Standard errors, clustered at the community level, are reported in parentheses. Willingness to pay (WTP) is top-coded at 100 quetzales; the market reference price is 90 quetzales. All specifications include Asesor Técnico Comercial (ATC) fixed effects and baseline controls selected via the double LASSO procedure. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

8.4 Disentangling mechanisms

Table 9: ITT of demand-side interventions on input expenditure per hectare

	(1) Fertilizers	(2) Herbicide	(3) Pesticide	(4) Seed treatment
Information only	531.1	64.88**	51.95	-8.870
	(440.98)	(31.56)	(34.82)	(9.94)
Information+Vouchers	923.8	93.08***	94.94*	-15.13
	(619.23)	(32.41)	(52.73)	(12.05)
Observations	847	846	846	846
Mean Control	4353.66	311.61	200.69	83.31
P-value Info=Info+Vouchers	0.58	0.41	0.42	0.67
P-value T-pooled=0	0.18	0.03	0.13	0.40

Standard errors, clustered at the community level, are reported in parentheses. All specifications include agrodealer fixed effects and baseline controls selected via the double LASSO procedure.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 10: Discrete choice: Willingness to pay for different traits within a bundle

	(1) Pooled	(2) Control	(3) Information	(4) Information+Voucher	(5) P-Value (2)=(3)	(6) P-Value (2)=(4)	(7) P-Value (3)=(4)
Yield	1.190***	1.330***	1.137***	1.062***	0.644	0.496	0.843
	(0.186)	(0.303)	(0.286)	(0.252)			
Nutrition	8.341***	10.644***	5.165**	8.936***	0.103	0.583	0.170
	(1.417)	(2.589)	(2.141)	(1.723)			
Large Grain	5.250***	8.236**	2.282	4.673***	0.172	0.418	0.327
	(1.523)	(4.022)	(1.670)	(1.780)			
Wind Resistant	30.965***	32.802***	27.933***	31.447***	0.531	0.830	0.583
	(2.958)	(5.449)	(5.554)	(3.188)			
Price	-3.200***	-3.263***	-3.218***	-3.065***	0.887	0.409	0.610
	(0.121)	(0.186)	(0.258)	(0.150)			
SD Price	0.853***	0.918***	0.830***	0.833***			
	(0.120)	(0.192)	(0.202)	(0.185)			
Observations	11542	4294	3886	3362			

Standard errors are clustered at the community level and are in parentheses. Mixed logit model estimated in willingness-to-pay space and where coefficients are interpreted as willingness to pay in quetzales per pound of seed purchased.
$^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

Table 11: Discrete Choice: ITT of demand-side interventions on willingness to pay for different traits

	(1) WTP Nutrition	(2) WTP Wind Resistance	(3) WTP Large Grains	(4) WTP Criollo
Group 2 - Information only	0.190	0.895	-0.346**	0.166
	(0.20)	(1.67)	(0.15)	(1.61)
Group 3 - Information + Vouchers	0.333*	3.618***	0.119	1.759
	(0.20)	(1.21)	(0.14)	(1.58)
Observations	873	873	873	873
Mean Control	8.13	32.95	5.47	10.02

Standard errors are clustered at the community level and are in parentheses. All specifications include agrodealer fixed effects and baseline controls selected via the double LASSO procedure. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 12: ITT of demand-side interventions on preferences for seed traits

	(1) Prefers High Yields	(2) Prefers Pest Resistance	(3) Prefers Drought/Flood Resistance	(4) Prefers Wind Resistance	(5) Prefers Good Taste	(6) Prefers Marketable Features	(7) Prefers Low Seed Cost	(8) Prefers High Nutrition	(9) Prefers Post-Harvest Resilience
Information only	0.0279	-0.0143	-0.0202	-0.0372	-0.0878	0.0246	0.00925	-0.00561	0.0200
	(0.04)	(0.03)	(0.02)	(0.03)	(0.06)	(0.03)	(0.03)	(0.02)	(0.02)
Information + Vouchers	0.0422*	0.0214	-0.0230	0.0246	-0.0784	0.0493**	0.0840***	0.0535**	0.0193
	(0.02)	(0.02)	(0.02)	(0.02)	(0.06)	(0.02)	(0.03)	(0.03)	(0.02)
Observations	900	900	900	900	900	900	900	900	900
Mean Control	0.68	0.05	0.07	0.07	0.48	0.15	0.03	0.02	0.06

Standard errors are clustered at the community level and are in parentheses. All specifications include agrodealer fixed effects and baseline controls selected via the double LASSO procedure. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 13: ITT of demand-side interventions on dislikes of seed traits

	(1) Dislikes Low Yields	(2) Dislikes Pest Sensitivity	(3) Dislikes Drought/Flood Sensitivity	(4) Dislikes Wind Sensitivity	(5) Dislikes Bad Taste	(6) Dislikes Marketable Problems	(7) Dislikes High Cost	(8) Dislikes Low Nutrition	(9) Dislikes Post-Harvest Problems
Information only	-0.0558	0.0550*	0.0297	-0.0831**	0.0174	-0.0245	0.00949	0.00263	0.0743
	(0.04)	(0.03)	(0.03)	(0.04)	(0.01)	(0.02)	(0.06)	(0.00)	(0.05)
Information+Vouchers	0.0565*	0.0690**	0.0377	-0.0723*	-0.00530	0.0387	0.0584	0.00291	0.164***
	(0.03)	(0.03)	(0.03)	(0.04)	(0.01)	(0.03)	(0.06)	(0.00)	(0.06)
Observations	900	900	900	900	900	900	900	900	900
Mean Control	0.33	0.11	0.05	0.31	0.03	0.09	0.29	0.00	0.19

Standard errors, clustered at the community level, are reported in parentheses. All specifications include agrodealer fixed effects and baseline controls selected via the double LASSO procedure. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 14: ITT of demand-side interventions on farmers reporting climate-shock-related damage to maize yield

	(1) rain average	(2) drought average	(3) wind average	(4) rotten average	(5) Wind damage (ave. lbs)	(6) Rot damage (ave. lbs)
Information only	-0.0259	-0.0887*	-0.0537	-0.0665*	-0.193	-0.275
	(0.03)	(0.05)	(0.04)	(0.04)	(0.24)	(0.21)
Information + Vouchers	0.0249	-0.0773	-0.0597	0.0133	-0.599*	0.0864
	(0.05)	(0.05)	(0.05)	(0.04)	(0.33)	(0.32)
Observations	846	844	846	844	846	844
Mean Control	0.22	0.60	0.33	0.43	1.54	1.37

Standard errors are clustered at the community level and are in parentheses. All specifications include agrodealer fixed effects and baseline controls selected via the double LASSO procedure. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

8.5 Complementary results: Impacts of random SMS messages

Table 15: Impact of SMS messages on voucher redemption among sample of farmers who benefited from prior seed donations

	All	Main farmer		Ethnicity	
		Female	Male	Maya	Ladino
	(1)	(2)	(3)	(4)	(5)
Nutrition general	0.227***	0.109	0.511***	0.211**	0.209
	(0.09)	(0.10)	(0.16)	(0.10)	(0.24)
Nutrition specific	0.042	0.044	0.032	0.048	0
	(0.07)	(0.08)	(0.12)	(0.09)	(0.13)
Seed origin	0.138**	0.077	0.231**	0.093	0.182
	(0.06)	(0.08)	(0.10)	(0.08)	(0.13)
Strata	Yes	Yes	Yes	Yes	Yes
Region F.E.	No	No	No	No	No
Mean	0.12	0.133	0.094	0.138	0.107
R-squared	0.026	-0.016	0.111	0.004	0.043
Obs	272	169	103	189	66

This table reports the impact of SMS messages on voucher redemption among farmers who previously received seed donations. Each column presents results from a separate OLS regression with strata fixed effects. The outcome is a binary indicator for voucher redemption. "Nutrition general" refers to messages highlighting the general health benefits of SN maize; "Nutrition specific" emphasizes zinc, iron, and protein content; "Seed origin" refers to messages communicating that the seed is developed and produced in Guatemala. Standard errors, clustered at the community level, are reported in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

9 Figures

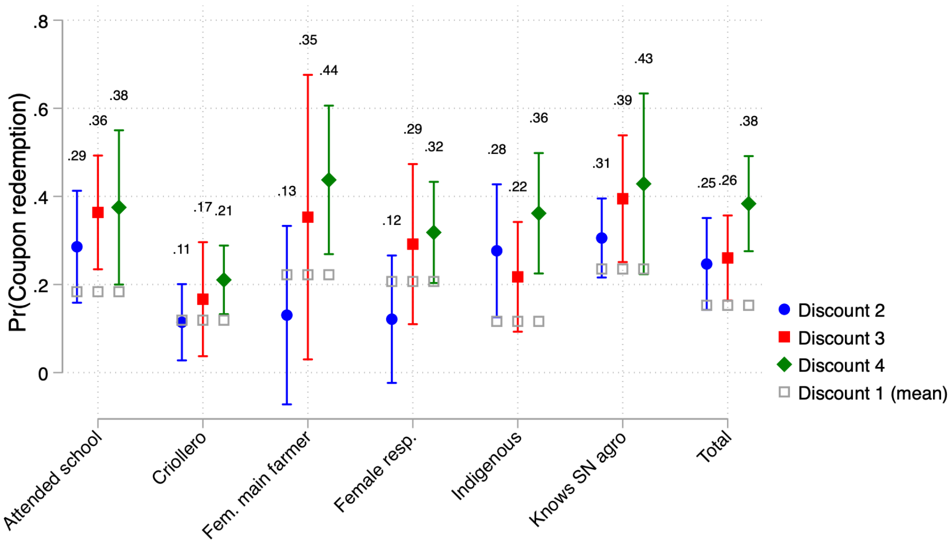

Figure 1: Price elasticities: Voucher redemption rates by discount level for diverse farmers

Notes: Each marker represents the estimated total outcome under the corresponding discount level, computed as the sum of the control group mean and the estimated treatment effect. Confidence intervals are based on cluster-robust standard errors and reflect 90% confidence intervals for the treatment effect. Upper and lower bounds are similarly adjusted by adding the control group mean. Hallow squares indicate the control group mean.

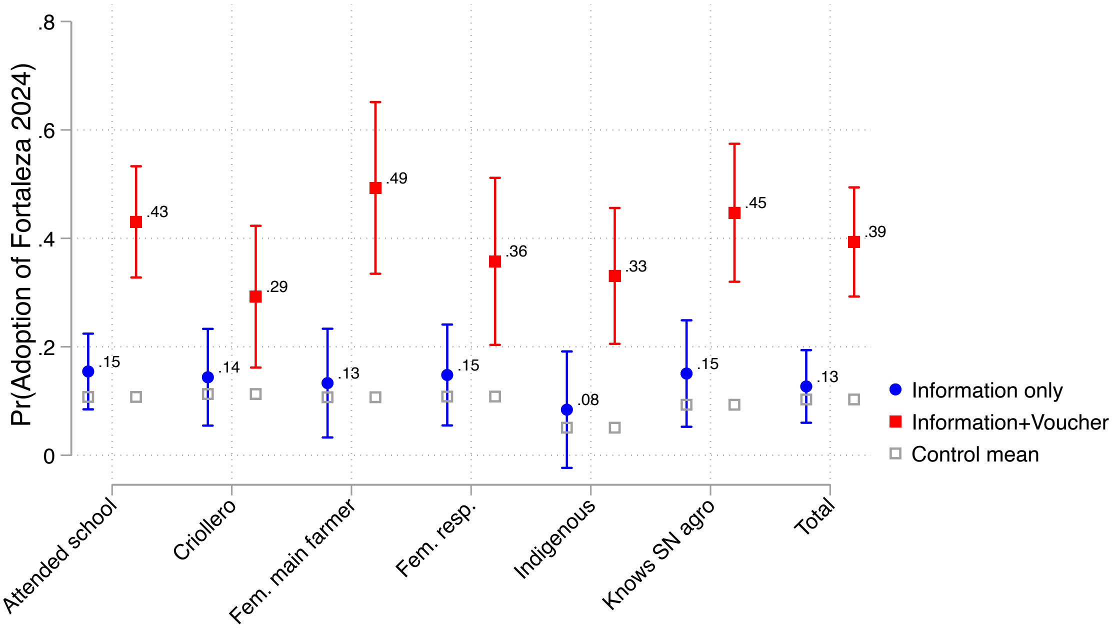

Figure 2: Adoption of biofortified seeds in 2024 for diverse groups of farmers

Notes: Each marker represents the estimated total outcome under the corresponding treatment arm, computed as the sum of the control group mean and the estimated treatment effect. Confidence intervals are based on cluster-robust standard errors and reflect 90% confidence intervals for the treatment effect. Upper and lower bounds are similarly adjusted by adding the control group mean. Hollow squares indicate the control group mean.

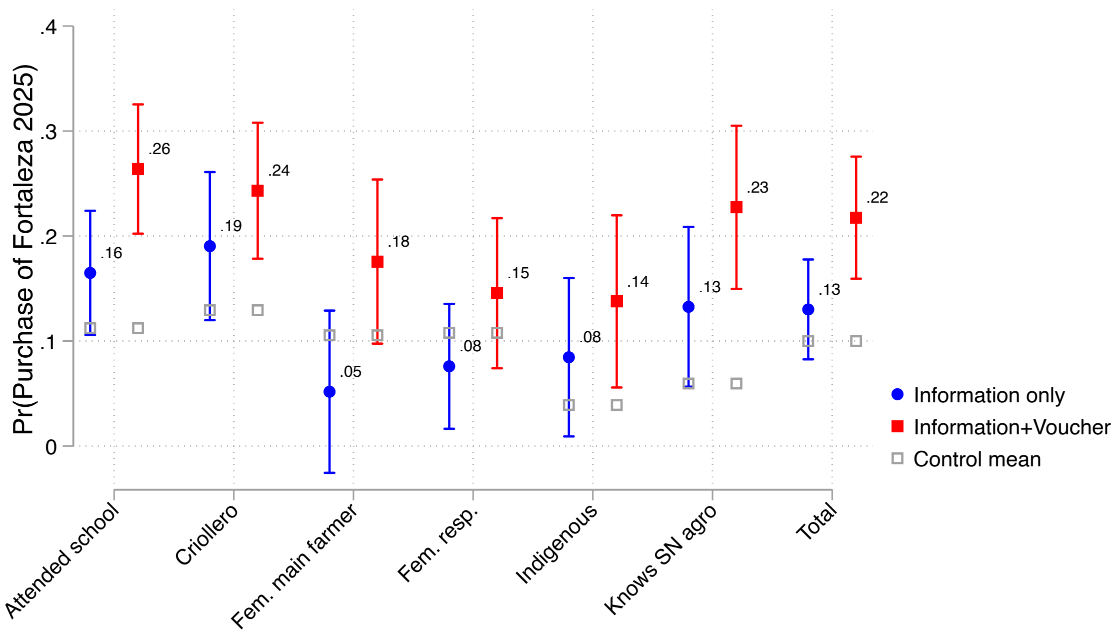

Figure 3: Purchase of biofortified seeds in 2025 for diverse groups of farmers

Notes: Each marker represents the estimated total outcome under the corresponding treatment arm, computed as the sum of the control group mean and the estimated treatment effect. Confidence intervals are based on cluster-robust standard errors and reflect 90% confidence intervals for the treatment effect. Upper and lower bounds are similarly adjusted by adding the control group mean. Hollow squares indicate the control group mean.

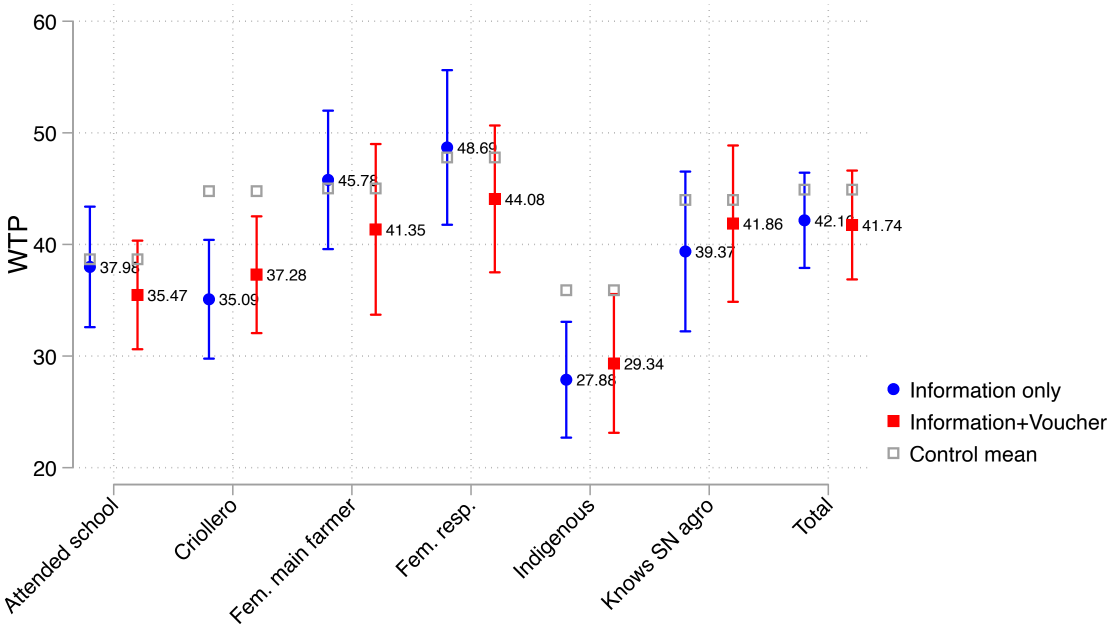

Figure 4: WTP for biofortified seeds in 2025 for diverse groups of farmers

Notes: Each marker represents the estimated total outcome under the corresponding treatment arm, computed as the sum of the control group mean and the estimated treatment effect. Confidence intervals are based on cluster-robust standard errors and reflect 90% confidence intervals for the treatment effect. Upper and lower bounds are similarly adjusted by adding the control group mean. Hollow squares indicate the control group mean.

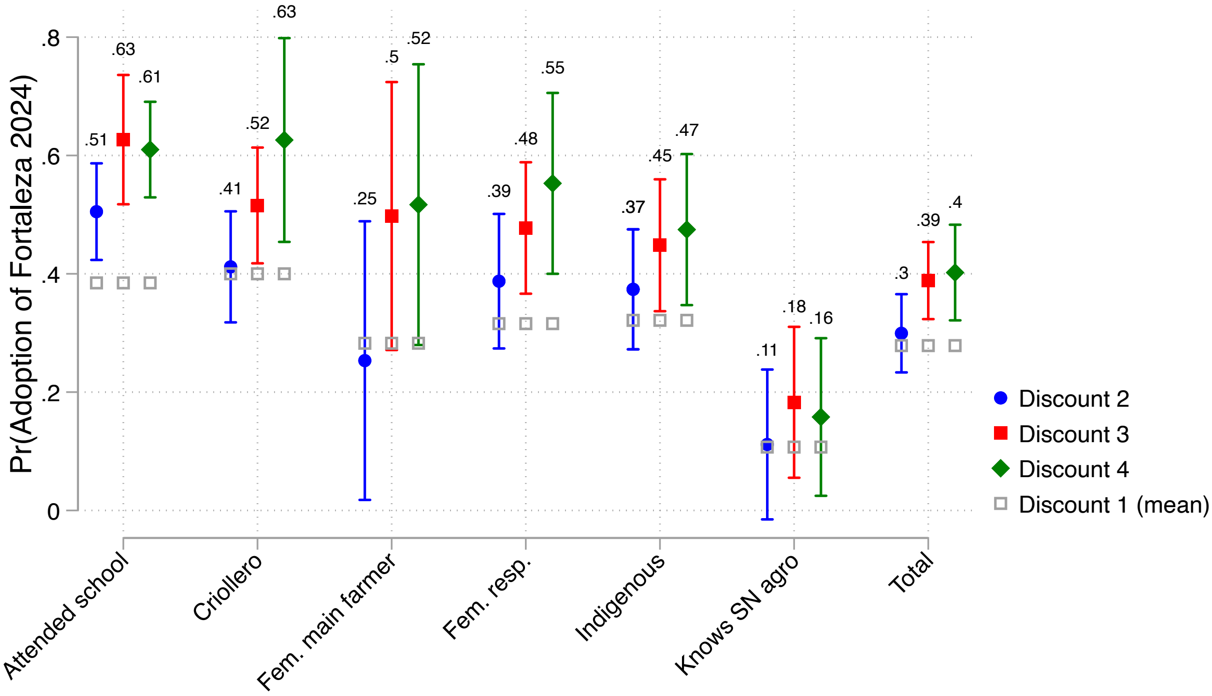

Figure 5: Elasticity of adoption of biofortified seeds in 2024 for diverse groups of farmers: Differences in 2024 adoption between 25% discount (benchmark category), 45% discount (blue), 60% discount (red), and 75% discount (green).

Notes: Each marker represents the estimated total outcome under the corresponding treatment arm, computed as the sum of the control group mean and the estimated treatment effect. Confidence intervals are based on cluster-robust standard errors and reflect 90% confidence intervals for the treatment effect. Upper and lower bounds are similarly adjusted by adding the control group mean. Hollow squares indicate the control group mean.

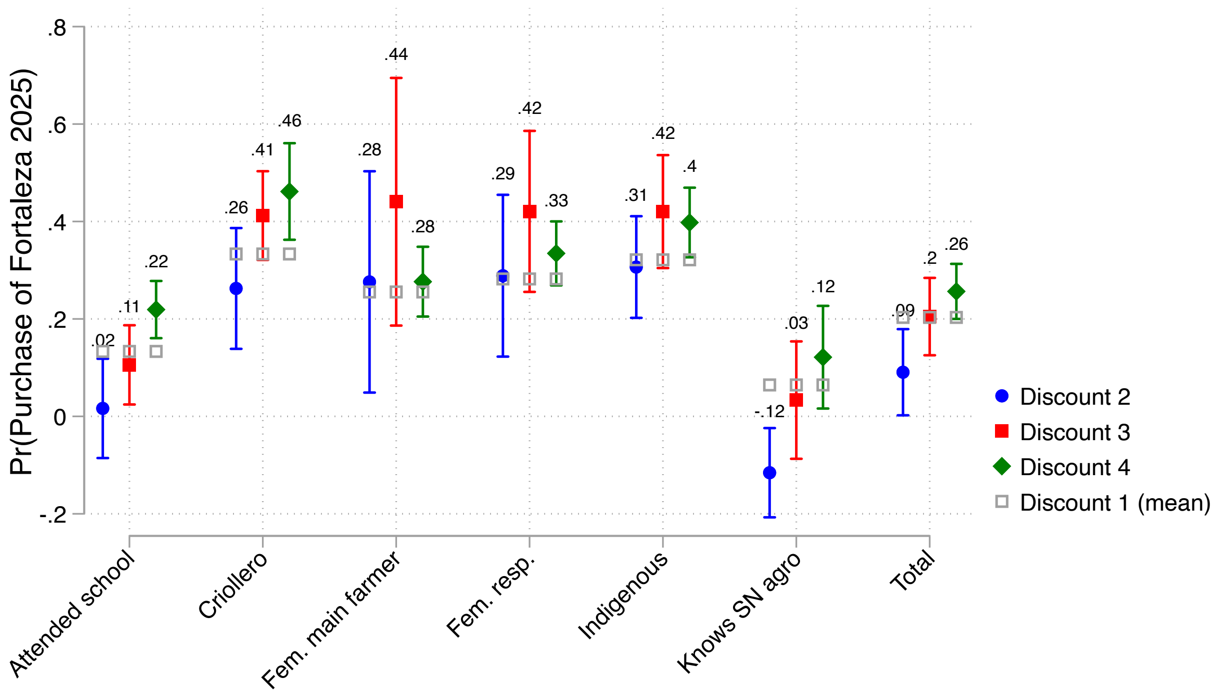

Figure 6: Elasticity of intent to purchase of biofortified seed in 2025 for diverse groups of farmers: Differences in 2024 adoption between 25% discount (benchmark category), 45% discount (blue), 60% discount (red), and 75% discount (green).

Notes: Each marker represents the estimated total outcome under the corresponding treatment arm, computed as the sum of the control group mean and the estimated treatment effect. Confidence intervals are based on cluster-robust standard errors and reflect 90% confidence intervals for the treatment effect. Upper and lower bounds are similarly adjusted by adding the control group mean. Hollow squares indicate the control group mean.

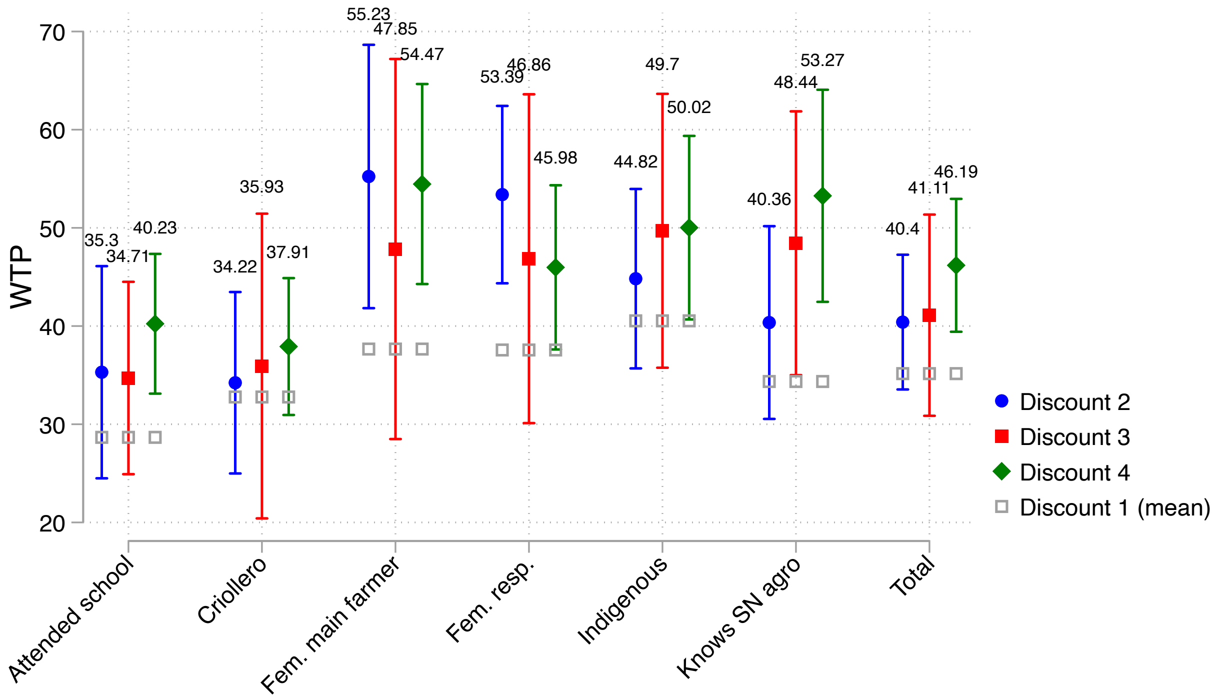

Figure 7: Elasticity of WTP for biofortified seed in 2025 for diverse groups of farmers: Differences in 2024 adoption between 25% discount (benchmark category), 45% discount (blue), 60% discount (red), and 75% discount (green).

Notes: Each marker represents the estimated total outcome under the corresponding treatment arm, computed as the sum of the control group mean and the estimated treatment effect. Confidence intervals are based on cluster-robust standard errors and reflect 90% confidence intervals for the treatment effect. Upper and lower bounds are similarly adjusted by adding the control group mean. Hollow squares indicate the control group mean.

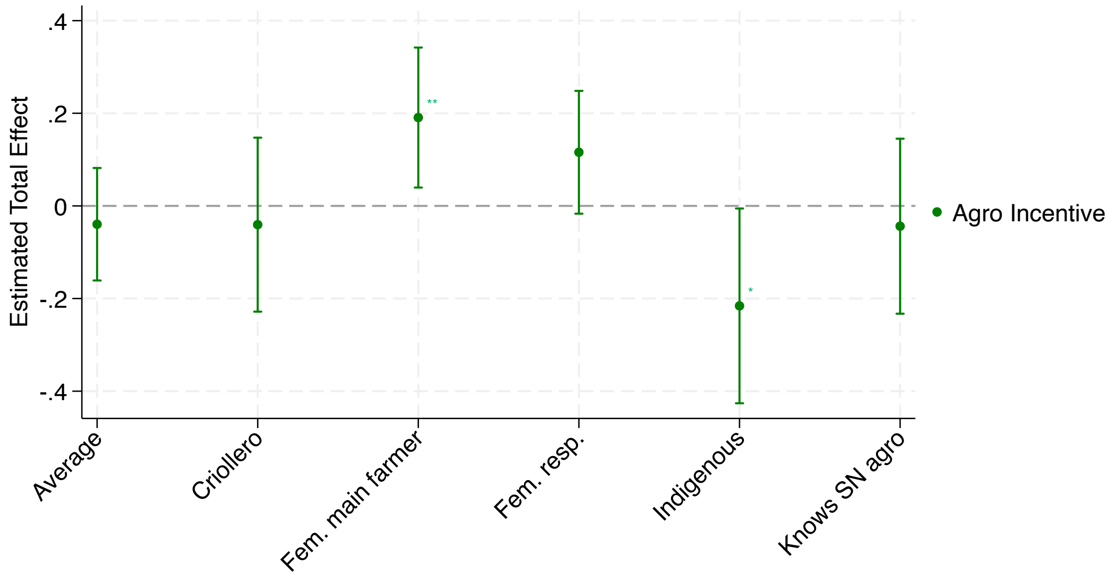

Figure 8: Treatment heterogeneity for the supply-side subsidy on adoption in 2024 for diverse groups of farmers

Notes: Controls selected using the double Lasso procedure. Sonfidence intervals are based on cluster-robust standard errors and reflect 90% confidence intervals. Asterisks indicate statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

A Incentivized Data Collection on Agrodealer Client Base and Farmers Purchasing SN

To characterize the client base of each agrodealer, and for SN to be able to compensate the agrodealers randomized into the supply-side incentives for each farmer buying SN seeds, client-level data needed to be collected for each agrodealer. This is a challenge as clients can come from communities other than those in our sample, and there are no natural catchment areas of agrodealers in this context (often there are multiple agrodealers in close proximity to each other, and while distance is one criterion explaining agrodealer choice, farmers select their agrodealer also based on other criteria, such as familiarity, past experiences, availability, quality, and price of the different products). To address this challenge, individual-level client data was collected through the organization of a raffle at each agrodealer.

All agrodealers were given a large stack of raffle tickets and a raffle box. They were asked to encourage each client to fill a raffle ticket, or to fill the ticket for the client. Each client visiting the agrodealer shop for a purchase, whether that was a purchase of SN seeds or not, was entitled to a raffle ticket. All raffle tickets were entered into the locked raffle box, after filling in name, phone number, and basic information on purchases, including whether they bought SN seeds. The raffle end date was set at the end of July to have the complete first season planting. At that point, three raffle tickets were randomly selected from each agrodealer's raffle box during a live-streamed lottery, with raffle prizes (value coupons, for a total value of about 125 USD, that could be exchanged for goods available at the agrodealer) provided by SN. The raffle was designed as a promotion campaign for the agrodealers – and qualitative work confirmed it was perceived as such – while also serving as data collection tool to estimate the client base of the agrodealers.

While all clients were eligible for the raffle, only raffle tickets with information on purchases for SN seeds were used to calculate the supply-side incentive to the agrodealer. Specifically, the information on the raffle tickets was digitized, and SN purchases were verified through phone calls. The 7 agrodealers randomly selected into the supply-side incentive were then paid 15 quetzales for each farmer who purchased SN seed. This procedure had been explained to the agrodealer at the start of the season, and technicians also reminded the agrodealers of the procedure during the follow-up visits throughout the season.

The validated data allow estimating the number of farmers purchasing SN seeds in each of the 14 agrodealers.

B Baseline Variables for Post-Double LASSO Selection

Table 16 presents the full list of baseline covariates included in the post-double LASSO selection procedure. These variables capture key household demographics, income sources, agricultural practices, maize varieties, and exposure to shocks, ensuring a comprehensive set of possible controls.

Table 16: Summary of baseline variables included in post-double LASSO selection

Variable	Description
Age	
age	Respondent's age (years)
Income source	
income_1–income_7	Income from: only farming, remittances, pension/support, business, wage, livestock, other
Shocks during 2024	
affected_1–affected_5	Drought, flood, landslide/wind, pests and diseases, lack of input resources
Household demographics	
homech, princip, all_year, gender, princip_sex	Household head, main farmer, grows maize every year, female respondent/main farmer
hh_size, child_b5, langsp	Household size, number of children under 5, speaks and understands Spanish
Ethnicity	
ethn_1–ethn_6	Maya, Xinka, Garífuna, Ladino, other, doesn't know
Language spoken at home	
lang_1–lang_25	Includes Spanish, K'iche', Q'eqchi', Mam, Chuj, Garífuna, Xinka, Itza', and others
Use of maize	
uso_maiz_1–uso_maiz_5	Household consumption, consumption by others, for sale, animal feed, other uses
Agricultural season 2024	
area_hec, criollo_only, seg_bajo, any_hyb	Land for maize (hectares), only Criollo grown, low-segment hybrid grown, any hybrid grown
Maize varieties cultivated in 2024	
var_1–var_14	Criollo, DK, Fortaleza, HB, HR, ICTA, JC, JC Plus, JC Proteico, Pioneer, Tropical Biofortified, other
Agrodealer access	
agro_sn, bought_sn, agro_dist	Knows SN agrodealer, purchased at SN agrodealer, minutes to closest agrodealer by car
Agrodealer purchases	
agro_1–agro_8	Purchases: maize seed, herbicides/pesticides, fertilizers for maize and other crops, other products

C Willingness-to-Pay Exercise

C.1 Purpose of the WTP exercise

We implemented a willingness-to-pay (WTP) exercise to estimate how much smallholder farmers value a 10-pound bag of Fortaleza hybrid maize seed. The exercise provided a monetary measure of seed demand under liquidity constraints and real purchase conditions one year after the intervention.

C.1.1 Elicitation method and design

We employed an incentive-compatible Becker-DeGroot-Marschak (BDM) mechanism (Becker et al., 1964) to elicit participants' maximum willingness to pay for a 10-pound bag of Fortaleza maize seed. Participants were asked to state the highest price they would be willing to pay, with enumerators explaining that any amount between 0 and 400 quetzales could be submitted, in increments of 5Q. This range was designed to encompass the plausible support of WTP while maintaining cognitive tractability.

We selected the BDM method for several reasons. First, it produces point estimates of WTP, offering greater precision than interval-based alternatives such as the multiple price list (MPL). Second, BDM has the advantage of being quicker to administer, which reduces respondent fatigue – an important consideration in field settings. Third, recent evidence from Burchardi et al. (2021) shows that BDM performs comparably to MPL in terms of participant comprehension, alleviating prior concerns about its complexity.

That said, and to account for some respondents that did face difficulties with the BDM, we designed the survey instrument so it would be routed to a MPL module if a respondent was unable or unwilling to provide a specific value (recorded as "don't know"). This fallback option was chosen for its more guided structure, which can be easier for participants to engage with in cognitively demanding settings (Alphonce & Alfnes, 2017). The MPL began at 40Q – the midpoint of the observed market price range – and followed a staircase format to identify the threshold price at which the participant switched from willingness to purchase to refusal. Starting at the midpoint minimizes the number of steps required to reach the respondent's maximum WTP and is not ruled out by any prior literature.

Each respondent was assigned a sealed envelope containing a randomly drawn price between 0 and 100 quetzales, in 5Q increments. Envelopes were labeled with the participant's name and sealed before the interview, ensuring that neither enumerators nor respondents could influence or anticipate the price. The random draw was explained as analogous to a lottery, a format that is well understood and trusted in the local context, thereby enhancing credibility compared to more abstract methods like table randomization. This method also helps farmers understand that attempts to bargain would not affect the final price.[28]

Enumerators used a standardized script to explain the BDM mechanism and emphasized its incentive-compatible nature: Overreporting could lead to paying more than the respondent valued the product, while underreporting could result in missing a favorable deal. The envelope price was explicitly described as randomly drawn and unrelated to market conditions to mitigate anchoring effects and discourage strategic responses.

To anchor valuations in reality, participants were informed that local agrodealers typically sold maize seed at 9–10Q per pound, or approximately 90–100Q for a 10-pound bag. They were instructed to consider only the cash they had available on the day of the interview, rather than hypothetical or future income.

The product was physically presented during the elicitation, and enumerators clarified that they were independent from the distributor (Semilla Nueva). Participants were reassured that their WTP responses would not influence their compensation or eligibility, and that there were no "correct" or "incorrect" answers.

[28]Bargaining for seed prices is also not common, as individual farmers are clear price-takers, and even the agrodealers themselves typically follow the price-setting guidelines given by the seed companies.

The BDM protocol – including the choice of price bounds, increment size, script, and framing – was extensively piloted. These pilots informed critical design features, including enumerator phrasing, visual aids, and logistical procedures, with the goal of maximizing participant comprehension and minimizing measurement error.

C.2 Payment and incentives

Each participant received a 25Q token of appreciation for their time and participation in the survey. This compensation was provided regardless of their decision to purchase the seed. If the price drawn from the envelope was less than or equal to the participant's stated willingness to pay, they were given the opportunity to purchase the 10-pound bag of Fortaleza seed at that price. The purchase amount was deducted from the 25Q token, and the remaining balance was paid to the participant in cash. For example, if the drawn price was 15Q, the respondent received the seed and 10Q in change. If the respondent's stated willingness to pay was higher than 25Q, and the price drawn from the envelope was less than or equal to the respondent's stated willingness to pay but higher than 25Q, the respondent complemented the 25Q endowment with their own money. If the drawn price exceeded the participant's WTP, they did not purchase the seed but still received the 25Q as appreciation.

C.3 Comprehension and confirmation

Prior to opening the envelope, enumerators administered comprehension checks to ensure that participants understood the incentive structure. If a respondent failed to answer correctly, the enumerator was required to repeat a standardized explanation before proceeding.

Final WTP values were confirmed with the respondent to ensure internal consistency. While participants were informed of typical market prices – approximately 90–100 quetzales for a 10-pound bag – the protocol did not restrict their responses to this range. The only constraint was the predefined upper bound of 400 quetzales, imposed for design and implementation reasons.

Participants were not discouraged from stating values above the market price, and a small share (4.44%) did so. When asked for clarification, many cited factors such as the convenience of delivery, the perceived quality or reliability of the product, or the value of not needing to travel to a store. These responses were treated as valid. The design intentionally allowed for this flexibility to ensure that elicited WTP reflected each respondent's full subjective valuation, including non-monetary considerations.

C.4 Non-compliance

While the majority of participants followed the WTP elicitation protocol as intended, a small number of cases exhibited non-compliance. Non-compliance occurred when participants were eligible to purchase the seed – that is, their stated WTP was greater than or equal to the envelope price – but ultimately informed the enumerators they were unable to complete the purchase.

Enumerators were trained to document these cases systematically. In all instances, respondents who declined to purchase despite being eligible cited liquidity constraints as the reason. Specifically, although participants had initially stated a willingness to pay, some were unable to assemble the necessary cash at the time of the transaction. No cases of procedural error or misunderstanding were recorded.

The overall rate of non-compliance was 7.96% among eligible buyers. These cases are included in the main analysis of revealed WTP. Excluding them does not materially affect the results. Their inclusion ensures that the analysis captures stated willingness to pay regardless of short-term liquidity fluctuations at the time of the transaction.

C.5 Interpretation and differences with real-world seed purchase decisions

While we use an incentivized mechanism to measure the WTP, it is important to note that the decision to purchase in the BDM experiment differs in at least three important dimensions from real-world decisions regarding biofortified seeds. First, the quantity to be bought was fixed at 10 pounds. This amount is substantially below the average amount of seeds planted by farmers in the sample (about 21 pounds for criollo and biofortified seeds and 34 pounds for other hybrids). The actual decision regarding quantities differs by agrodealer. Some agrodealers only allow sales of full bags (44 pounds), others allow by pound, which gives the farmers more flexibility. Second, farmers normally need to travel to agrodealers to buy seeds (and then also pay transport to bring the seeds back). In contrast, for the WTP experiment the bag was offered in their residence. Third, for real-life seed purchases farmers can choose themselves when they want to buy and can organize to have the necessary liquidity to do so. In the BDM exercise, decisions are constrained to the liquidity at hand. The token of appreciation of 25Q helps address some of this liquidity constraint, but only partially so.

D Discrete Choice Experiment

To understand how farmers value different characteristics of maize seeds, we administered a discrete choice experiment designed to elicit willingness to pay for specific seed attributes, following Train (2009). During the endline survey, farmers were asked to compare a series of maize seed pairs while randomly varying five different seed attributes.

- Yields: Expected harvest output, varied across five levels from 30 qq/mz to 90 qq/mz in 15 qq/mz increments.

- Seed price: Cost per pound, varied across four levels from free non-hybrid (OPV) seeds to 30 Q/libra hybrid seeds.
- Nutrition: Nutritional content levels, either high protein, zinc, and iron or low protein, zinc, and iron.
- Grain size: Physical characteristic of the grain that effects the sales value of the harvest. Grain size is either small or large. Large grains are more desirable when selling maize in output markets.
- Wind resistance: Plant resilience, either resistant to wind damage or not resistant to wind. This proxies for yield variability.

In practice, these attributes vary across available seed varieties, but farmers must make trade-offs when selecting which seeds to plant. To understand this trade-off, the discrete choice experiment asks farmers to choose between a pair of hypothetical seeds, each of which is characterized by a combination of these five seed attributes. For each seed attribute, different levels represent varying benefits and costs associated with seed selection. For example, higher-yielding seeds directly affect expected income, while seed prices represent upfront investment costs that must be weighed against expected returns.

Discrete choice experiments are designed to reveal which components of maize seed selection are relatively more valuable to farmers. They require participants to compare a series of pairs of seeds with different combinations of attributes and to state for each pair which seed they would prefer to plant on their farm. In the course of the DCE, farmers were shown seven pairs of seeds and asked to specify which was preferred for planting in the upcoming rainy season. For each seed, the level of expected yield and the seed price were listed, together with binary variables indicating high or low nutritional content, small or large grain size, and wind resistance (i.e., five attributes in total). The respondents' choices in the seven comparisons yields a binary choice data set with information on attributes and whether the respondent chose seed A or seed B for any given comparison. Attribute levels were randomly determined by randomizing within the survey.

A mixed logit model is used to estimate the relative importance of each level with the respondents' choices in the seven comparisons as separate observations. Econometric analysis of discrete choice data draws from a random-utility model and uses a mixed logit model to estimate choice probabilities that represent the relative importance of each attribute level. Coefficients can be interpreted as the group-level preferences for seed attributes. Local seed prices are used as the base price in the model.

Econometric analysis uses the following mixed logit specification:

$$
\begin{aligned}
Y_{ijk} = \alpha + & \beta_1 Price_{ijk} + \beta_2 Yield_{ijk} + \beta_3 Nutrition_{ijk} + \\
& \beta_4 GrainSize_{ijk} + \beta_5 WindResistant_{ijk} + \gamma_{ik} + \varepsilon_s plit
\end{aligned}
$$

Farmer i selects alternative j among choice sets k. Y_{ijk} is a binary variable that takes a value of 1 if the farmer chooses a certain variety of seeds. Each choice set pair has a fixed effect γ_{ik}. All models ran for 500 simulations and standard errors are clustered at the village level.

D.1 Results

Based on the discrete choice experiment results, farmers demonstrate strong and consistent preferences for wind-resistant maize seeds, with willingness to pay approximately 30–31 quetzales per pound across all subgroups and treatment conditions. This represents the highest valued attribute among all seed characteristics tested. The price coefficient is consistently negative and statistically significant across all specifications, confirming that participants understood the experiment and preferred lower-priced options, all else constant.

Farmers show modest willingness to pay for nutritional content (8–9 quetzales per pound for high protein, zinc, and iron) and large grain size (5–6 quetzales per pound), and they value higher yields at approximately 1.2 quetzales per pound for each additional quintal per manzana. Interestingly, the treatment interventions (training and voucher programs) do not significantly alter farmers' stated preferences, as evidenced by the lack of statistically significant differences between control and treatment groups across most attributes. This suggests that underlying preferences for seed characteristics are relatively stable and not easily shifted by short-term interventions.

Subgroup analysis reveals some notable heterogeneity in preferences. Hybrid-seed users demonstrate significantly higher willingness to pay for wind resistance (37.6 vs. 21.8 quetzales) compared to non-hybrid users, while non-Indigenous respondents show marginally higher willingness to pay for wind resistance than Indigenous respondents (38.7 vs. 25.7 quetzales, p=0.059). Male and female lead farmers show similar preferences overall, though male lead farmers tend to have slightly higher point estimates for most attributes. The results suggest that while basic preferences are consistent across groups, farmers' experience with different seed types and cultural backgrounds may influence their valuation of specific characteristics, particularly those related to crop resilience.

E Qualitative Insights on the Implementation of the Pilot Interventions

The qualitative fieldwork revealed a certain level of heterogeneity/variation in the implementation of the intervention. For a national-level pilot program, such variation is not unexpected, but important to understand. It also revealed challenges with certain parts of the implementation by the technical staff, leading to compliance issues, as well as heterogeneity in the decision-making by the agrodealers that will need to be accounted for in interpretation and subsequent scaling. The section below describes the main general insights from the qualitative work. These informed the design of the endline survey, and various of the qualitative insights described below were then confirmed through the quantitative results described in the main text.

E.1 At the community/farmer level

- The level of information retained from the information session was limited and mixed. The key traits about the maize that people recall are the yields and the wind resistance. Some also refer to information on management, price, and shape of the corn ear (notably the fact that leaves fully cover it, which protects against rotting).
- Many respondents did not recall any nutritional information. That said, the probability of recalling nutritional information was higher among female respondents. While the main farmer was the one invited to the information sessions and coupon distribution, in a number of cases it is the spouse or daughter that ended up going, typically because of time availability. As noted above, in those cases recall on the nutritional information was higher.
- Part of the imperfect retention/recollection could be due to lack of translation or incomplete translation in Maya-language-speaking villages. In most cases the technical staff of SN spoke in Spanish and relied on translators when needed.
- Randomized assignment of individual discount vouchers was broadly respected.
- Exchange or sharing of discount vouchers appears to have been limited.

E.2 At the agrodealer level

- There is some variation in the way agrodealers implemented the discount that farmers with coupons were entitled to. Understanding by the agrodealers of the discount vouchers, in general, seemed to be good. Deviations from the intended implementation therefore mostly seem to correspond to adjustments they made themselves (given their overall profit objective) rather than lack of understanding.
  1. Some agrodealers did not want to sell half bags (even if technically the coupon made farmers entitled to that) – these are agrodealers that also sell only full bags (44 pounds) in sales without coupons. Agrodealers can be concerned with being left with an opened bag of seeds if they sell for quantities less than a bag. Agrodealers that are already selling per pound get around this risk by increasing the price per pound (as compared to the price per bag).[29]

[29] Agrodealers also noted that SN could have provided smaller bags (half the size) to them for sale but did not do this (even if they use such smaller sized bags for other promotional purposes).

2. Other agrodealers gave farmers the value of the coupon in seeds without co-payment. That is, they used the coupon as a gift card, rather than a discount coupon.
3. Many agrodealers delayed sending the coupons to SN for repayment. This made tracking of redemption slow and difficult.

- The way the agrodealers implemented the raffle varies. Understanding by the agrodealers of the raffle seems relatively good, including separate incentives for the owner and the employee. In all cases visited, they were filling in raffle tickets for some of their clients, though in almost all cases this was far from systematic.

  1. Among clients of a given agrodealer, some farmers did not recall a raffle ticket being filled in and were unaware of the raffle.
  2. In at least one village without coupon distribution, farmers (while remembering very little about the information session) remembered the raffle and the agrodealer filling in a raffle ticket for them.
  3. In at least one agrodealer, there was one employee designated to fill in the tickets.

- The way the agrodealers understood the extra incentive on the supply side may have varied. At least one agrodealer understood correctly (and realized this would be verified with the raffle tickets that indicated they bought Fortaleza [i.e., the SN seed], and after a call to them to verify that they indeed bought Fortaleza).

- Agrodealers were very aware that the vouchers were for a study. This may have affected their behavior and that of the farmers (who may, for instance, have had expectations of future benefits).

- Some agrodealers actively promote Fortaleza (or at least they told the research team they did, which may in part be an experiment demand effect).

- Agrodealers in general like the different promotional activities – even if it entails extra paperwork. The extent to which this would be true at scale and/or when repeated remains to be seen. Part of this undoubtedly is related to the (perceived) degrees of freedom in implementation and the fact that this is free promotion.

F Qualitative Insights Regarding Farmers' Perceptions About SN Seeds and Decisions for Take-up

The qualitative field work was conducted at a time when planting for the first season was basically finished, and maize plants were at various stages of development, with none of them at the harvest stage. The interviewed farmers had generally positive perceptions about the yield, wind resistance, and maize ear (with leaves fully covering ears, avoiding rotting) characteristics. With regard to climate resilience, there was little discussion about drought resistance (possibly because many farmers had waited with planting while droughts persisted early season, and after the late planting it had been raining a lot). Resistance to strong winds (related to the lower stalks of the maize from SN seeds compared to criollo) was frequently referred to. Unsurprisingly, the low price also constitutes a key desirable characteristic recognized by farmers.[30]

Some, but definitely not all people complemented the positive assessment on the agronomic traits with a positive assessment of taste (sweet green corn) and nutritional value.[31] Some respondents also referred positively to resistance to a specific (but very common) disease (manja de asfalto), and to the wide leaves.

In terms of undesirable characteristics, farmers pointed to vulnerability to storage losses and to the color, which can make it hard to commercialize. Very few farmers or agrodealers expressed concerns about seeds being foreign or transgenic. Fears about potential loss of indigenous seeds was also not frequently referred to.

This last set of findings seems to hold among Indigenous farmers in contrast to one of the original hypotheses motivating this study. The results are indeed consistent with the relatively high share of hybrid farmers among some of the Indigenous groups in the sample (such as the K'echi' in the Peten). The data further clearly show that there are both criollero and hybrid farmers in all ethnic groups.

Finally, with regard to gender differentiation, the qualitative work revealed quite a few women that went to receive the seeds and participate in the information sessions, sometimes substituting for their husbands or fathers when they were unavailable. Among women who participated, messages about nutrition seemed to have been recalled better than among men, pointing to potentially important bandwidth constraints, with women possibly more likely to remember nutrition-related messages while men remembered more of the agronomical information. In at least one case, this translated in plans to specifically reserve the SN harvest for home consumption. Endline data collection did not confirm this gender hypothesis or gender-differentiated impacts.

[30]The positive evaluation of SN seems to contradict, to a certain extent, more skeptical assessments the qualitative work from January had revealed, when farmers notably had highlighted the lack of resistance to extreme drought or flood events, resulting in low germination. They had also flagged the lack of pest resistance. This illustrates the complexities with breeding for climate resilience, as different types and severity of shocks can appear in different seasons, and no crops can be bred to be completely resistant to very extreme weather events.

[31]Interestingly the nutritional value was questioned by at least one agrodealer who wanted to see scientific proof, pointing to the unobservability of the nutritional value.

G Climate Resilience of SN Seeds

Non-experimental results from SN's monitoring data provide an indication of the climate-resilient traits of the SN seeds. In particular, for lodging and for the climate resilience index (a composite measure of lodging and rotting), estimates with controls and region fixed effects show a 4-percentage point reduction (of a mean of 9%) in lodging and a .41SD increase in the climate resilience index, respectively. Estimates with farmer fixed effects are even higher, though obtained from a small sample size.

The non-experimental estimates further show yield gains of SN, as compared to traditional seeds (based on crop-cut data) that are of broadly similar magnitude under drought and non-drought conditions, with yield gains under drought conditions varying between 24 and 73%, depending on the drought definition and whether using regional or farmer fixed effects estimations. As these estimates were obtained on plots for which the SN technicians would have done regular visits, they may not reflect returns in farmers' real-world condition.

G.1 Methodological details of the climate-resilience analysis

The data for this analysis come from 2023 monitoring data from our partner organization, Semilla Nueva, based on crop cuts for yields and direct observations of crop damage by technicians. The first dataset has a sample size of 123 plots operated by farmers who were recruited at agrodealer shops when they purchased seeds (called purchase farmers). During the 2023 seed sales season (usually 4–6 weeks prior to planting), agrodealers were asked to write down the names of customers that purchased seeds (either the hybrid of Semilla Nueva or other hybrids) and were provided a small incentive for verified names. Names were also collected from traditional (landrace) maize growers who purchased fertilizer and/or other inputs but no seeds. This resulted in a list of about 2,000 farmers, from which a random sample was drawn. SN called farmers in that sample to ask if they were interested in participating in crop cuts. The second dataset includes 39 plots by farmers who were recruited after receiving a seed donation (called donation farmers). The donation farmers are composed of 21 farmers who grew traditional maize seeds in plots next to the new hybrid seed, totaling 39 plots (it does not equal 42 due to plot-level attrition). The purchase farmers only had yield measurement for one of their plots; therefore, that group is composed of 123 unique farmers. To improve power, we combine these two datasets for a total sample size of 162 plots, of which 51% grew the hybrid maize seed developed by Semilla Nueva (called new seed), 27% grew non-hybrid, traditional landrace maize seeds (traditional seed), and 22% grew other hybrids. All plots participated in a rigorous data collection process that included agronomic crop cuts to estimate yields, rot, and lodging. Plots were located throughout Guatemala in 17 different districts (departamentos), out of a total 22 districts in Guatemala, ranging in elevation from 0 to 2,100 meters above sea level. We focus on two approaches to evaluate climate resilience.

First, we combine two measures of crop stress associated with climate shocks into an index. We standardize and create a z-score index for the percentage rot and lodging – stresses that worsen as the result of extreme weather (drought, heavy rain, and wind). Rot affects maize ears, and lodging occurs when plants fall or are blown over. Percent rot is measured as the share of ears of corn from each crop cut that exhibits rot (molding or underdeveloped kernels). Lodging is measured by taking the percent change in plant density between visits 1 and 2 of the crop-cut data collection. We note that our collaborator carried out all crop-cut measurements and was aware which plots belonged to which seeds, which may introduce some preferential bias for NGO seeds. However, field technicians are typically trained in agronomy or agricultural science and were instructed to measure plots as accurately as possible.

Second, we compare maize yields for plots that experienced more dry days (relatively few plots experienced extreme rain in 2023). We create a binary variable equal to one if the plot is in an area that had above median number of dry days during the 2023 growing season. To do so, we merged in weather data for the 2023 agricultural season from open-meteo.com, a free weather provider with grid cells that range from 1 to 9km, depending on the best-available satellite data for a given spatial range. In total, we have 91 unique grid cells. The median number of dry days was 15. When constructed as a continuous variable, the number of dry days is inversely correlated with yields. Since there are likely non-linearities in dryness, splitting the sample by the median provides an average difference. We also test several alternative definitions for drought (see below).

G.2 Non-experimental results on climate resilience

G.2.1 Wind resistance and rotting

As noted above, for lodging and for the climate resilience index (the composite measure of lodging and rotting), estimates with controls and region fixed effects show a 4-percentage point reduction (of a mean of 9%) in lodging and a .41SD increase in the climate resilience index, respectively. Estimates are higher for the most rigorous estimates with farmer fixed effects (so comparing plots with traditional seeds versus SN seeds of the same farmer), 122 percentage points and 0.5 SD respectively, but rely on a small number of observations.

The strong findings on wind resistance are of particular interest, as the analysis of the discrete choice experiment confirms that farmers put a high value on wind resistance. Results suggest they value it 3 to 4 times as much as nutrition content or marketable features such as grain size, with the weight for wind resistance being comparable with that of substantial yield gains. This confirms that wind resistance in the Guatemalan context is a resilience trait that is particularly valued. The results on lodging (wind damage) are also in line with the suggestive findings in Table 14.

G.2.2 Drought

We compare yields on all traditional seed plots (n=42) with all new SN hybrid plots (n=80). First, to benchmark, note that traditional maize (non-hybrid seed) growers located in areas with above median drought intensity had average yields of 36 quintals per manzana (a local land measure approximately equal to .7 hectares). Traditional maize plots in below median drought areas had average yield that was 14 quintals higher than traditional growers in drought areas. Focusing then on the comparison with SN seeds, SN growers in non-drought areas had yields that were 31 quintals higher than traditional growers in drought areas. SN growers in drought areas had average yields that were 19 quintals higher than traditional seed growers in drought areas. Analysis adding department fixed effects, elevation, and whether the plot was intercropped confirm that average yield gain (compared to the traditional seeds) for new hybrid growers is similar in both drought and non-drought areas.

Conclusions are similar when using alternative definitions for drought (e.g., above 75 percentile of number of dry days or above median from the flowering stage till the end of the season). Restricting to dry days in mid-season (between day 40 and 60 as in Boucher et al. (2024)) further yields similar results. Furthermore, we don't see significant differences between SN hybrids and other hybrids under either drought conditions or non-drought conditions. This confirms the prior results that SN hybrids, while having a much lower price, do not perform worse than the average hybrid seed. Note however that those results are expected to be different if we were to compare with only the high-performing (and most expensive) hybrids.

H Appendix Tables

Table A1: Discount coupons assignment and redemption by discount level

	Assigned	Redeemed	Rates
Q90/Q50	48	11	22.92%
Q150/Q80	50	18	36.00%
Q210/Q145	57	19	33.33%
Q270/Q145	54	28	51.85%
Totals	209	76	36.36%

Table A2: Time spent selecting seeds and substitute activities: men and women

	(1) Mean	Min	Max	Obs
Hours spent selecting seed	3.832	-66.0	48.0	762
Activities performed instead of selecting seed				
Work on another crop or agricultural activity	0.671	0.0	1.0	762
Take care of livestock or perform tasks related to animal husbandry	0.056	0.0	1.0	762
Perform domestic tasks, such as cooking or cleaning	0.180	0.0	1.0	762
Take care of children or other family members	0.033	0.0	1.0	762
Search for temporary employment or engage in other paid work	0.127	0.0	1.0	762
Rest or sleep more	0.034	0.0	1.0	762
Attend school or participate in training	0.020	0.0	1.0	762
Sell products at the market or engage in commercial activities	0.016	0.0	1.0	762
Do manual or craft work for sale or personal use	0.013	0.0	1.0	762
Participate in community or social activities	0.009	0.0	1.0	762
Other	0.024	0.0	1.0	762
Observations	762			

Table A3: Time spent selecting seeds and substitute activities: women

	(1) Mean	Min	Max	Obs
Hours spent selecting seed	3.654	1.0	24.0	159
Activities performed instead of selecting seed				
Work on another crop or agricultural activity	0.333	0.0	1.0	159
Take care of livestock or perform tasks related to animal husbandry	0.050	0.0	1.0	159
Perform domestic tasks, such as cooking or cleaning	0.629	0.0	1.0	159
Take care of children or other family members	0.113	0.0	1.0	159
Search for temporary employment or engage in other paid work	0.019	0.0	1.0	159
Rest or sleep more	0.013	0.0	1.0	159
Attend school or participate in training	0.031	0.0	1.0	159
Sell products at the market or engage in commercial activities	0.031	0.0	1.0	159
Do manual or craft work for sale or personal use	0.006	0.0	1.0	159
Participate in community or social activities	0.013	0.0	1.0	159
Other	0.000	0.0	0.0	159
Observations	159			