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Review of Realized Yield Gains from Quality Seed and Improved Varieties

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Purpose

The objective of this review is to summarize evidence of realized yield gains across multiple focus crops from both improvements in seed quality and the introduction of improved varieties. The Agricultural Development (AgDev) team will use these data to inform their approach to working in informal seed systems (including evaluating the potential for improvements in seed quality to improve yield), and to explore the potential for improved varieties to further improve yields (through both informal and formal seed systems). The AgDev team will share these data during a co-chair meeting in September 2015 as part of a seed systems presentation.

Introduction

This brief reviews the evidence of realized yield gains by smallholder farmers attributable to the use of high-quality seed and/or improved seed varieties. *Smallholder farmers* are defined as farmers who typically cultivate less than two hectares of land. *Quality seed* is defined as seeds or cuttings (for vegetatively propagated crops, e.g. cassava) that are clean (pest and disease free), pure (genetically consistent), and vigorous (good germination and can establish well in the field). Quality seed can be of local varieties (landraces), locally-recycled improved varieties, or newly-released improved varieties. *Improved varieties* are defined as seeds or planting materials that have been bred or genetically modified to enhance desirable traits such as yield, drought tolerance, or pesticide resistance. When information about release dates were available, we included only improved seed varieties that were less than ten years old at the time of the study reporting on them.

The core questions that this brief addresses include:

1. What yield gains have been empirically attributed to the use of high-quality versus low-quality seeds for specific crops?
2. What yield gains have been attributed to the use of newly-released improved varieties versus local varieties or locally-recycled improved varieties for specific crops?
3. How do the expected yield increases from the use of quality seeds or improved varieties vary in different focus countries?

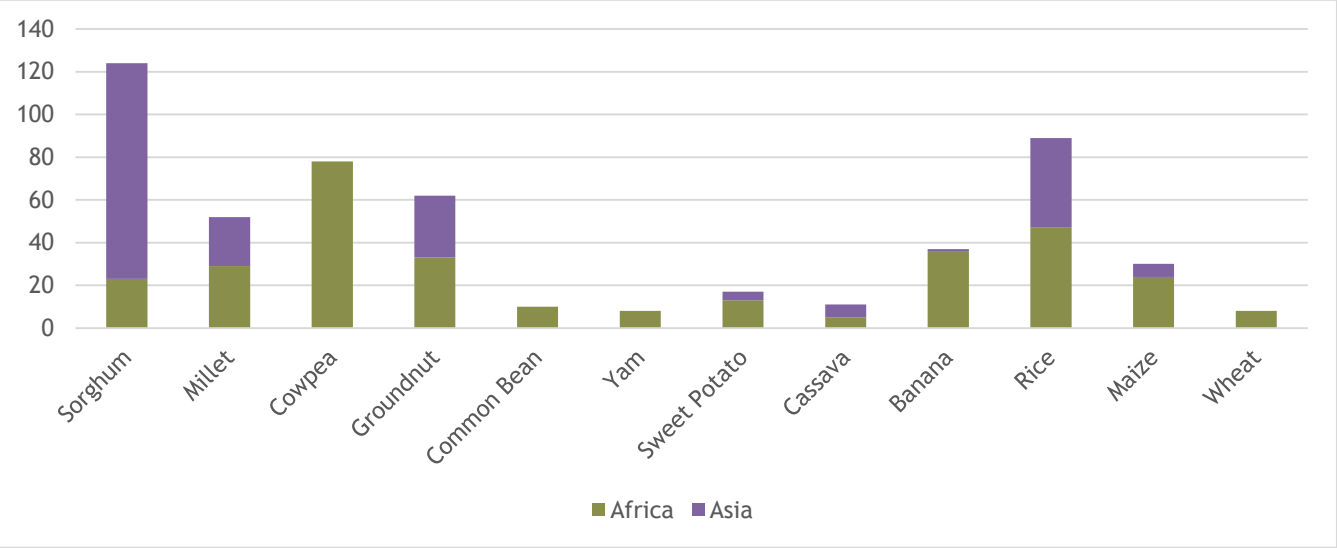
Methods & Data

We conducted searches of the academic literature using Scopus, Google Scholar and Agricola with various combinations of search terms including quality seed, clean planting material, improved variety, improved varieties, seed, yield, and the crops of interest for this study: sorghum, millet, cowpea, groundnut, common bean, yam, sweet potato, cassava, banana, rice, maize and wheat. In addition we reviewed the research repositories of international crop research institutions including CGIAR, FAO, IFPRI, CIMMYT, ICRISAT, ICARDA, IITA, CIAT, AIRCA, IRRI, and Bioversity International. Results were limited to articles published after 1990.

Our initial search resulted in 554 articles which appeared to be relevant from their title and abstract. After a secondary screening of the full text of these articles for methodology, geography, and relevance to the research questions (i.e. reporting of yield estimates), 240 were identified as candidates for full review.[1] In order to most accurately estimate the realized yield gains of smallholder farmers from quality seeds and improved varieties, we prioritized studies which provided yield estimates from experiments or studies carried out in farmer's fields or under farmer practices. 86 studies appeared to have rigorous methodologies and high relevance to the research questions. Of these 86 studies, 59 are included in the final sample for this review as having relevant data on differences in yield realized from the introduction of improved varieties or quality seeds. The remaining 28 studies were excluded either because they did not have yield estimates, because the difference in yield from improved varieties or quality seeds was not reported independently from another source of variability (e.g., nutrient constraints or drought stress), or because the studies focused solely on varieties under development for research or breeding purposes.

The final sample of 59 studies contains data on approximately 524 trials of improved varieties or quality seeds. Each study reported results from between 1 and 42 trials with an average of 8.9 trials per study. The vast majority of studies (48 out of 59) provide estimates of yield gain from improved varieties, though we identified 15 studies which systematically tested the yield improvement gained from using quality seed, 11 of which also included an improved variety. 33 studies focused on experiments or trials in sub-Saharan Africa (Africa) and 24 in South and Southeast Asia (Asia). 2 studies took place in other regions (Mexico & Tunisia) but were included in the dataset for their high relevance. Figure 1 provides an overview of the distribution of trials in the final sample by crop and geography.

***Figure 1**. Varietal Trials by Crop and Geography*



Findings reported in the remainder of this brief are restricted to a sub-set of 395 trials in Africa and Asia which included estimations based on comparisons to a control group. The 129 estimations from 11 studies that relied solely on baseline data or did not include a comparison group are omitted from this brief, but are available in the supplemental dataset. The studies include data from field experiments, participatory varietal selection trials, and other experiments under farmer's field and experimental conditions. Estimations for individual varieties were included wherever possible, however several studies reported on estimated impacts of adoption of any improved varieties as compared to local varieties and were reported as a single observation. All varieties, including some unreleased improved varieties reported on in the studies, are included in our sample. Controls used in the studies include local varieties and open pollinated improved varieties which had been recycled by farmers. In cases where trials used multiple controls, we use an average of control variety yield

[1] We were surprised to see so few results for some major crops, e.g., rice in Asia. Our search criteria may have excluded some papers if the research on improved varieties of these crops is: 1. old (pre-1990); 2. not based on farm fields (rather than lab-based assays), or 3. Excluded by search engines that don't capture key sources such as regional or non-English journals. We are happy explore some of these avenues if deemed worthwhile.

estimates. Similarly, results for both improved varieties or quality seeds, and controls from trials which took place over multiple growing seasons are averaged to provide one estimate.

For our calculations, all reported yield estimations are converted into t/ha. Estimates for banana and yam which are reported in Bunch Weight and kg/heap respectively, are not included in the tables below, but are available in the supplemental dataset. Each table in the following section includes the number of observations from varietal trials included (N), as well as the minimum (Min), maximum (Max), median and average yield gain in both absolute and percentage terms.

Results

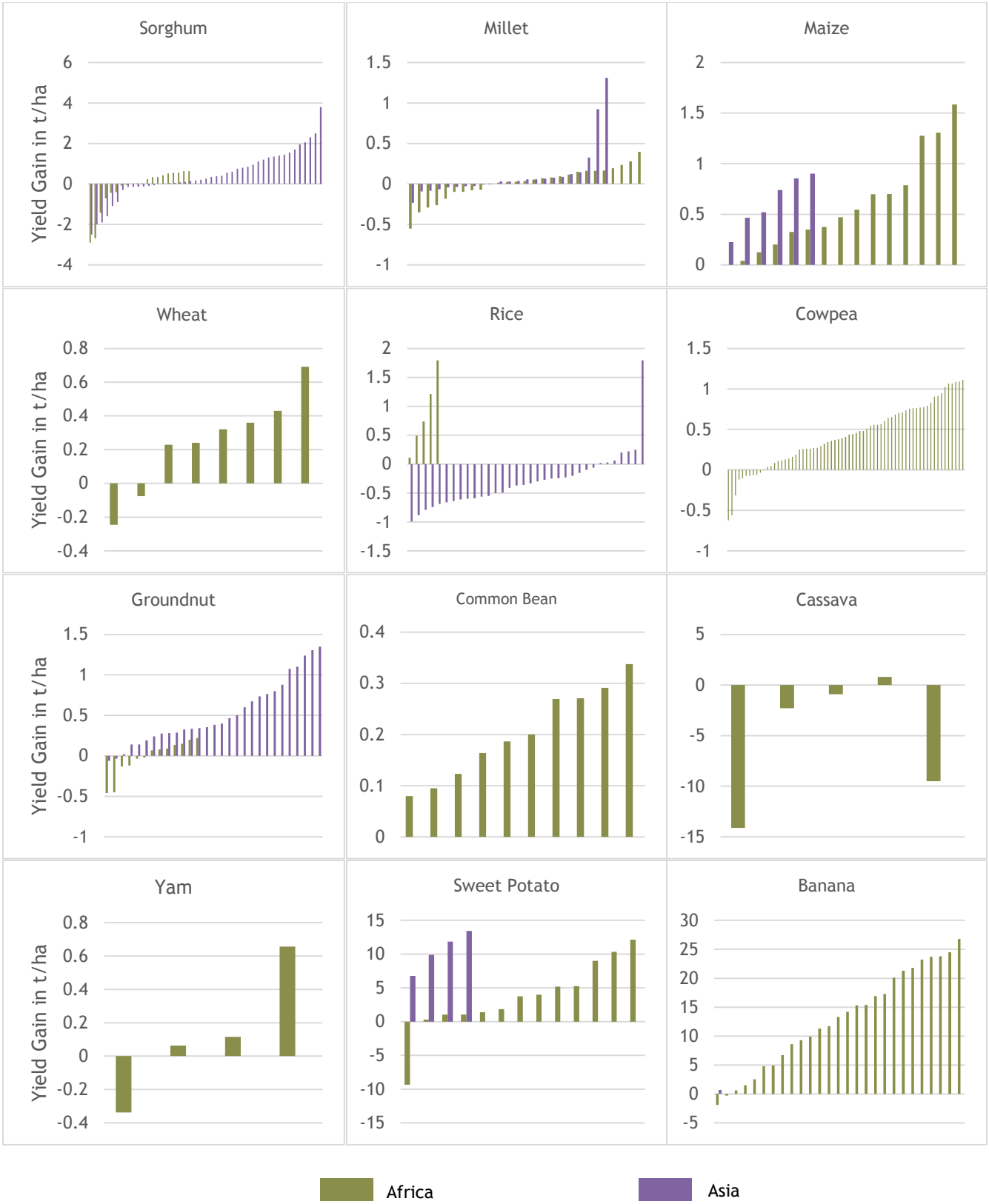
Our analysis suggests that in most cases, use of improved varieties and/or quality seed is associated with modest yield increases (Table 1). In the sample of trials reviewed, positive yield changes accompanied the use of improved variety or quality seed, on average, in 10 out of 12 crops, with rice and cassava as the two exceptions (discussed in more detail below).

***Table 1**. Overall estimates of difference in yield from quality seeds and improved varieties*

Yield Gain From Quality Seeds and Improved Varieties: Overview									
Crop	**N**	**Min**		**Max**		**Median**		**Mean**	
		t/ha	%	t/ha*	%	t/ha*	%	t/ha*	%
Sorghum	84	-2.90	-72%	3.8	380%	0.36	15%	0.34	26%
Millet	50	-0.55	-52%	1.31	164%	0.04	4%	0.06	11%
Maize	25	-4.32	-51%	1.58	168%	0.47	23%	0.26	28%
Wheat	14	-0.25	-17%	1.78	115%	0.56	21%	0.63	28%
Rice	42	-0.99	-20%	1.79	86%	-0.32	-6%	-0.21	-1%
Cowpea	69	-0.62	-54%	1.11	201%	0.39	38%	0.40	56%
Groundnut	43	-0.46	-29%	1.35	99%	0.28	30%	0.33	29%
Common Bean	10	0.08	13%	0.34	57%	0.19	33%	0.20	34%
Yam	4	-0.34	-60%	0.66	225%	0.09	26%	0.12	54%
Sweet Potato	17	-9.35	-39%	13.45	234%	5.2	40%	5.17	60%
Cassava	5	-14.1	-69%	0.8	4%	-2.3	-11%	-5.2	-25%
Banana	28	-1.9	-17%	26.8	244%	12.5	105%	12.42	109%

Figure 2 provides a visual representation of the distribution of yield gain estimates across all 12 crops, including both quality seeds and improved varieties in each region. More detailed analysis of the results by geography are presented in the following section.

Figure 2. *Empirical Evidence of Yield Gain by Region*



Regional Differences

Table 2 provides the estimates from 222 trials of improved varieties or quality seeds reported in 27 studies which took place in sub-Saharan Africa. We find empirical evidence of yield impacts for all 12 priority crops. Our estimates show that for most crops (9 out of 12), use of improved varieties or quality seeds resulted in increased yields. The largest gains are in banana, where trials of disease resistant hybrids and tissue cultured planting materials resulted in an average yield gain of 112%. The largest losses are reported in cassava, but all five estimates in the sample are from one study of a series of research station cassava trials in central Zambia in 2002-2004 (Barratt, et al., 2006), suggesting that this is an area for further research.

Table 2. Yield Gain From Quality Seeds and Improved Varieties: Sub-Saharan Africa

Crop	N	Min		Max		Median		Mean	
		t/ha	%	t/ha	%	t/ha	%	t/ha	%
Sorghum	21	-2.90	-72%	0.64	34%	0.04	2%	-0.19	-0.34%
Millet	27	-0.55	-52%	0.40	121%	0.04	7%	0.01	8%
Maize	15	0	0%	1.58	168%	0.47	20%	0.59	31%
Wheat	8	-0.25	-17%	0.69	115%	0.28	13%	0.24	21%
Rice	5	.11	8%	1.79	86%	.74	46%	.86	45%
Cowpea	69	-0.62	-54%	1.11	201%	0.39	38%	0.40	56%
Groundnut	14	-0.46	-29%	0.22	32%	0.02	4%	-0.05	0.39%
Common Bean	10	0.08	13%	0.34	57%	0.19	33%	0.20	34%
Yam	4	-0.34	-60%	0.66	225%	0.09	26%	0.12	54%
Sweet Potato	13	-9.35	-39%	12.15	234%	3.75	43%	3.54	67%
Cassava	5	-14.1	-69%	0.8	4%	-2.3	-11%	-5.2	-25%
Banana	27	-1.9	-17%	26.8	244%	13.3	106%	12.86	112%

Table 3 provides the estimates from 164 trials of improved varieties or quality seeds reported in 20 studies which took place in Asia. No control comparison estimates of yield improvements in wheat, cowpea, common bean, yam, or cassava in Asia were identified in our sample. This may be due to our search restrictions limiting our sample to research conducted after 1990, or in some cases could reflect underutilized crops (e.g. cowpea) in Asia. Our estimates show that for most crops (6 out of 7) where we do have data, use of improved varieties or quality seeds resulted in increased yields. Additionally, in each cereal crop aside from rice, yield increases are larger in Asia than in Africa. Our estimate of rice yield includes one study of yield performance of 37 high yielding varieties under drought conditions in eastern India. Because these results were produced under stress conditions they may be lower than expected yield gains under farmer's field conditions.

Table 3. Yield Gain From Quality Seeds and Improved Varieties: Asia

Crop	N	Min		Max		Median		Mean	
		t/ha	%	t/ha	%	t/ha	%	t/ha	%
Sorghum	63	-2.500	-64.10%	3.800	380.00%	0.55	18%	0.51	34%
Millet	23	-0.23	-14%	1.31	164%	0.03	2%	0.12	15%
Maize	6	0.23	23%	.90	69%	0.63	51%	0.62	50%
Wheat	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Rice	3	-0.99	-20%	1.79	46%	-0.45	-18%	-0.30	-6%
Cowpea	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Groundnut	29	-0.06	-5%	1.35	99%	0.38	38%	0.52	43%
Common Bean	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Yam	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Sweet Potato	4	6.75	22%	13.45	46%	10.88	39%	10.49	37%
Cassava	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Banana	1	N/A	N/A	N/A	N/A	0.60	14%	0.60	14%

Quality Seeds

The evidence of the impact of clean, certified, or other quality seed is limited. Table 4 provides the estimates from 42 trials that included quality seeds reported in 15 studies in both Africa and Asia. No control comparison estimates of yield improvements in maize, wheat, rice, or cowpea were identified in our sample. In all crops we have evidence for, besides cassava, use of quality seed was associated with yield increases. Sorghum and millet both showed yield improvements exceeding 100% on average, however each estimate comes from one study of the impact of improved production technologies, including quality seed and improved varieties along with a package of inputs (Reddy, et al., 2007; Ramakrishna, et al., 2004). The two observations used to estimate changes in cassava are also from the Zambian trial referenced above. These two observations compare cleaned material of farmer's varieties introduced from Malawi which may have been poorly adapted to local conditions (Barratt, et al., 2006).

Table 4. Yield Gain From Quality Seeds Alone: All Studies

Crop	N	Min		Max		Median		Mean	
		t/ha	%	t/ha	%	t/ha	%	t/ha	%
Sorghum	1	N/A	N/A	N/A	N/A	1.40	222%	1.40	222%
Millet	1	N/A	N/A	N/A	N/A	1.31	164%	1.31	164%
Maize	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wheat	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Rice	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Cowpea	0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Groundnut	9	-0.04	-0.05%	1.10	84.62%	0.1340	22%	0.30	28%
Common Bean	10	0.08	13%	0.34	57%	0.19	33%	0.20	34%
Yam	4	-0.34	-60%	0.66	225%	0.09	26%	0.12	54%
Sweet Potato	8	3.75	22%	13.45	234%	9.45	59%	9.00	91%
Cassava	2	-14.1	-69%	0.80	4%	-6.65	-32%	-6.65	-32%
Banana	3	0.60	11%	17.27	44%	2.54	14%	6.80	23%

Discussion, Limitations, and Research Gaps

The findings presented in this brief are limited to the availability of studies that isolate the effect of improved varieties and quality seeds on yield. While 38 of the studies we include report estimates from farmer's fields, many of the studies were from Participatory Varietal Selection Trials under controlled experimental conditions, and may not accurately reflect the variety selections or farming practices of smallholder farmers. Figure 3 presents the distribution of percentage gains in yield from improved variety and quality seeds across the entire sample. While we found strong evidence for cereal crops important to smallholders such as sorghum, millet, maize, and rice, evidence for other crops, such as roots and tubers were more limited and may represent an opportunity for further research. The reasons for limited evidence for Asia and for common crops such as wheat are less clear, but may be an artifact of our search methodology and not representative of the body of literature to date. One final consideration is that this brief only reports on changes in grain yield, and does not include data regarding other desirable traits such as yield stability, fodder yield, or soil improvement.

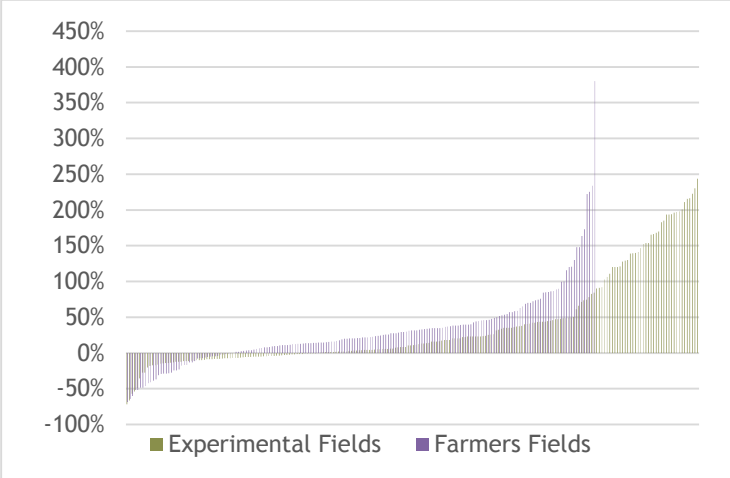


***Figure 3**. Percentage Gain in yield for QS and IV in Farmers' and Experimental Fields*

A complete dataset of our findings is included as a supplement to this brief.
Please direct comments or questions about this research to Principal Investigator Leigh Anderson at eparx@u.washington.edu.