7 Assessing the Effectiveness of Agricultural R&D for Groundnut, Pearl Millet, Pigeonpea and Sorghum in West and Central Africa and East and Southern Africa

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Introduction[1]

Arable land in sub-Saharan Africa is often cultivated during seasonal rains in regions where the supply of rainfall exceeds the demand for rainfall for only 2–7 months of the year. These rainfall supply and demand conditions define rainfed agriculture in the semi-arid tropics (SAT). In 1972, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was established in India with a global mandate to increase agricultural production in the SAT, thereby enhancing poor people's welfare in these rainfall-unassured production environments.

Technically, the SAT encompassed large areas of Australia, Latin America and Asia, but the geographic focus at ICRISAT was always on peninsular India and sub-Saharan Africa where most rural and urban poor lived. By 2020, the total population of people in Asia's and Africa's SAT is projected to be about 850 million, comprising a 70% share for Asia and a 30% share evenly split between West and Central Africa and East and Southern Africa (Walker, 2009). When ICRISAT was founded in 1972, the relative importance of the two continental populations was about 80% for Asia's SAT and 20% for Africa's SAT. The total SAT population in 1972 was only about 35% of the projected population in 2020.

Sorghum, pearl millet, groundnut, chickpea and pigeonpea are cultivated wholly or mostly in India's SAT. Sorghum, pearl millet and groundnut production also define West and Central Africa's SAT, where they account for 40% of arable cultivation. Sorghum, millet and groundnut are also cultivated on about 15% of arable land in the SAT of East and Southern Africa. ICRISAT's area mandate of the SAT provided the rationale for its crop mandate of sorghum, pearl millet, groundnut, chickpea and pigeonpea.

From its headquarters in Central India, ICRISAT began to invest in international agricultural research infrastructure and programmes in sub-Saharan Africa. Highlights include the following:

- Establishment of a research centre on pearl millet, groundnut and resource management in Niamey, Niger, in response to the needs of the dry SAT in the Sahel in 1983;
- Posting of ten internationally recruited plant breeders in country national programmes via a long-term grant from the

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United Nations Development Program (UNDP) starting in the late 1970s and ending in the early 1990s;

- Establishment of a regional office in Nairobi, Kenya, to attend to its crop and natural resource management mandate in East Africa;
- Initiation of the long-term Southern African Development Community (SADC)-ICRISAT groundnut project in 1982 at the Chitedze Research Station in Malawi for Southern Africa;
- Establishment of a regional research centre in Bulawayo, Zimbabwe, in the early 1990s to respond to its crop mandate in Southern Africa;
- Founding of a long-term partnership with the national programme in Mali in the late 1990s to conduct regional research on sorghum and groundnut;
- Establishment of the SADC/ICRISAT Sorghum and Millet Improvement Program in Southern Africa with major funding from USAID from 1983 to 2003.
- Longer term investment in 6-month applied training at its main station in Patancheru, India, of about 120 African crop improvement scientists and technicians annually from the late 1970s to the early 1990s.

The above is a non-exhaustive list of discrete resource investments that ICRISAT has made to improve productivity in sorghum, pearl millet, groundnut, and, to a lesser extent, pigeonpea and chickpea in sub-Saharan Africa. Institutionally and internationally, ICRISAT has not acted alone. Prior to and since independence, the French research institute Institut de Recherche pour Les Huiles et Oleagineux (IRHO) invested in genetic improvement, especially of high value and export crops, such as cotton and groundnut, in West Africa with stations in Bambey, Senegal, and sub-stations in Niger. Investments by IRAT (Institut de Recherches Agronomiques Tropicales) in the improvement of food-security crops, sorghum and pearl millet followed in the early 1960s. Since the 1960s and 1970s, a foundation for modern varietal change was laid by public-sector national agricultural research programmes (NARS) in the countries of sub-Saharan Africa. Starting in the late 1970s, in addition to the above players, USAID's Collaborative Research Support Projects (CRSPs) invested in crop improvement in sorghum, pearl millet and groundnut in many countries in West Africa.

Summing up, NARS, ICRISAT, the International Sorghum and Millet Innovation Laboratories of the United States Agency for International Development (USAID) – INTSORMIL – and the Peanut Collaborative Research Support Program of USAID (CRSP), and CIRAD (Centre de Coopération Internationale en Recherche Agronomique pour le Développement; formerly IRAT and IRHO) have invested in sorghum, pearl millet and groundnut crop improvement programmes in sub-Saharan Africa. An understanding of the performance of sorghum, pearl millet, and groundnut programmes from the perspectives of scientific capacity, output of released varieties and the level of adoption of these improved varieties is not, however, as comprehensive as in other staple food crops such as maize. This chapter attempts to systematically improve coverage on these aspects and thus inform on the performance of research on crop improvement for these staple food and cash crops in Africa's SAT.

This chapter is organized along regional lines. In presenting and discussing research results in each of the sections that follow, findings are reported separately for West and Central Africa's SAT and for the SAT of East and Southern Africa. This regional orientation is preferred to a crop-wise organization because several of the major findings are regional and apply to the same crops within a region of Africa's SAT. Teasing out lessons from a comparison of regional findings leads to a more fundamental definition of the problems, opportunities and successes of and from crop improvement than a comparison of results across crops. These lessons are described in the concluding section of the chapter.

Country Coverage, Methods and Data Collection

West and Central Africa

In West and Central Africa, six countries were originally targeted for assessing the effectiveness of crop improvement in groundnut, pearl millet and sorghum, which are the most important and extensively grown ICRISAT-mandated crops in the region. Country selection for the assessment was based on national production areas. Initially, Burkina Faso, Chad, Mali, Niger, Nigeria and Senegal were proposed for study. Although adoption inquiries were available in Chad at the project level on sorghum modern varieties (MVs), Chad, the only country from Central Africa originally targeted, was dropped because of logistical issues and resource limitations.

Fifteen crop-by-country observations are reported on in this chapter. Information on sorghum, pearl millet and groundnut were gathered in Burkina Faso, Mali, Niger, Nigeria and Senegal. The five countries account for about 83% of sorghum area in West and Central Africa, 87% of the area cultivated in pearl millet, and 62% of area cultivated in groundnut (FAO, 2011).

Representation is more than adequate because the largest producers in the region are included in the assessment. With a summed area approaching 4 million hectares, Nigeria and Senegal are the largest producers of groundnut. By the same measure, Niger and Nigeria are the heaviest producers of pearl millet in the region; all five countries harvest more than 1 million hectares of pearl millet annually. Sorghum production in the study countries exceeds 10 million hectares.

Data collection focused on varietal output (release), the strength of NARS and IARCs in food-crop commodity improvement, the level of adoption in important countries by food crop, and the contribution of genetic materials from different institutional sources in national varietal output and adoption.

Because groundnut, pearl millet and sorghum were in the 1998 global initiative, it was proposed that data collection be restricted to an update of information gathered in 1998. However, the 1998 global database did not cover West Africa adequately (Bantilan and Deb, 2003; Bantilan *et al.*, 2003; Deb and Bantilan, 2003). Few countries overlapped for a before-and-after comparison, and ICRISAT-related materials were emphasized in 1998. Therefore, the release database had to be constructed from scratch for each of the three crops in the five countries from 1970 to 2010. The database contains information on the following variety characteristics: official name of the release (and other local names if any), the year of release, the origin of the germplasm, the breeding scheme, genetic background (parentage, genetic ancestry, pedigree), institutional source of the material, the variety maintainer, the country of origin, the relevant agroecological zone (in terms of length of growing period in days and rainfall in mm), the genetic background and the release classification (type of material, NARS input). Varietal characteristics including the average yield potential (tonnes/ha, on-station and on-farm), plant height (cm), tillering, panicle length, weight of 1000 grains (g), panicle compactness, grain colour, plant type and other selected varietal traits were gathered where such data were available.

Data on scientific capacity were collected on the personnel by crop and institution in 2009 on the strength of sorghum, groundnut and pearl millet improvement programmes. The variables include the name of scientist, gender (male or female), age group, function, specialization, level of education and scientist (full-time equivalent (FTE)) status. Data on research investment in monetary terms were difficult to obtain due to attribution issues and time needs for accountants to gather information.

To collect the data on adoption of released varieties, focus and individual meetings with key partners, including breeders, agronomists, technicians, managers of seed companies, farmers' organizations, seed producers, etc., were to be conducted. After the first meeting in Niger, it was evident that stakeholders had difficulties estimating the potential area occupied by released varieties nationwide. It was easy, however, for scientists to point to individual locations at districts or regional levels and to assert the percentage adoption in those locations. Thus, individual interviews were carried out with scientists and selected technicians in the crop improvement programmes in the selected countries. Locations were geo-referenced and spatial areas were computed using geographic information system (GIS) tools. These spatial areas were aggregated to the national level and the proportion of area occupied by the variety relative to total cultivated area was taken as the estimate of adoption rate. For Nigeria, results from large nationally representative adoption surveys of households undertaken in northern Nigeria in 2009 and 2010 were used to estimate national adoption.

East and Southern Africa

Coverage in East and Southern Africa (ESA) also focused on five countries: Kenya, Malawi, Tanzania, Uganda and Zambia. Of the ICRISAT-mandate crops, commodity coverage was restricted to groundnut, sorghum and pigeonpea. In general, pearl millet is not cultivated much in this region. Finger millet is the dominant millet species. The area under chickpea is expanding in some countries from a very low base. Its area and production are heavily concentrated in Ethiopia. Chickpea in Ethiopia is reported on in Chapter 12, this volume.

Unlike West Africa, coverage in East and Southern Africa is unbalanced because some crops are of minor importance in one or more of the five countries. Groundnut's coverage extends to the five countries. The area of pigeonpea includes Kenya, Malawi and Tanzania. Sorghum's coverage is restricted to Kenya and Tanzania. Hence, ten crop-by-country observations are available for analysis in the East and Southern Africa region for groundnut, pigeonpea and sorghum crop improvement.

This coverage was strengthened by complementary research by INTSORMIL in the Sudan, which has more land under sorghum cultivation than any other country in Africa (Zereyesus and Dalton, 2012). That research has used the same protocols and has stored their information in the same database as those discussed in Chapters 3 and 4 of this volume.

Including sorghum in the Sudan, the 11 crop improvement observations comprise three observations all in Kenya with less than 100,000 tonnes of production, six observations between 100,000 and 350,000 tonnes of production, sorghum in Tanzania with about 750,000 tonnes of production, and sorghum in the Sudan with 4.2 million tonnes of production in 2009. Total production in 2009 summed to about 6.4 million tonnes across all study countries and crops in ESA, which is decidedly inferior to West Africa's total that approached 30 million tonnes for the 15 study countries in 2009.

Given the small and modest levels of production in nine of the eleven observations, it is reasonable to expect less representative coverage than in West and Central Africa (WCA) unless crop production is concentrated in very few countries. That is the case for pigeonpea because the three country observations account for 75% of production in all of sub-Saharan Africa. In contrast, coverage in groundnut is substantially lower at 45% of production. Production of sorghum in the Sudan and Tanzania represents about half of the regional production. There are 15 excluded groundnut-growing countries and 16 excluded sorghum-producing countries. Usually, these are characterized by small amounts of production but there are some major omissions. In groundnut, the Sudan with 37% of regional production is a large producer with an area that exceeds 1 million hectares. In sorghum, omitted countries that should be considered in the next baseline are Ethiopia, the centre of domestication of the crop, and Uganda where sorghum is used extensively in beer making. Production in these two countries adds up to more than one-third of the production in the region.

The data collected in East and Southern Africa are not as comprehensive as the data gathered in West Africa but they are very similar. An important difference is the manner in which the adoption estimates were deduced. The estimates in East and Southern Africa were based on a combination of sources that included expert opinion as well as secondary literature. In each country, discussions and workshops were held with breeders, seed producers and a variety of key stakeholders including those in the private sector involving crop improvement programmes or seed production for the specified crops. The results obtained from such expert opinions at the country level were shared with ICRISAT scientists before arriving at the final estimates. In more than 80% of the cases, the ICRISAT scientists' estimates were consistent with estimates from experts in each of the countries. Although it was easy to identify agroecological zones and districts where each of the varieties is grown, adoption estimates by district were difficult to derive with the desired degree of certainty and confidence.

Scientific Capacity of NARS

Although commercial hybrids of sorghum, pearl millet and even pigeonpea are readily available in other parts of the world, the private sector is still an insignificant player in genetic research in these crops in sub-Saharan Africa. For this reason, the scientific capacity of NARS in this section focuses exclusively on research in the public sector.

West Africa

This section reports on the strength of NARS proxied by the number of FTE scientists in each institution and programme, and the research intensities defined as the number of scientists per million tonnes of production in 2009/10. The number of scientists by crop and country programme is presented in Table 7.1, which contains three findings. First, a total of only 50–60 FTE scientists are working in groundnut, pearl millet and sorghum improvement programmes in the five countries in West Africa. Secondly, a measure of parity exists across all country programmes. All programmes have more than two FTE scientists and no programmes have more than ten scientists. Parity in the number of scientists is notable in the groundnut programmes that are staffed in the narrow range of 2–4 FTE scientists. With the exception of Senegal, which traditionally is an exporter of groundnut, sorghum and pearl millet, each command a greater allocation of research resources compared to groundnut. Thirdly, inter-country disparities in staffing are substantial. Mali accounts for more than one-third of scientists in pearl millet and sorghum crop improvement among the five countries studied from this region. Given the breadth and depth of Nigeria's investment in education relative to other countries in West Africa, its total of 5.5 FTE scientists in three economically important crops is unexpectedly low.

The estimated research intensities in Table 7.2 reinforce one of the story lines introduced in Table 7.1. Nigeria is characterized by very low research intensities across the three crops. The estimate of 0.3 for sorghum and 0.4 for pearl millet are two of the lowest research intensities found in the literature. Nigeria's apparent lack of commitment to research in groundnut, pearl millet and sorghum is strongly felt at the regional level. The weighted average research intensities range from 1.7 to slightly over 3.0 for the three crops. Per million tonnes of production summed across the three crops, Mali has allocated 17 times more scientists to genetic improvement research than has Nigeria. These low values for the coarse cereals and groundnut stand in sharp contrast to the estimate of 77.5 FTE scientists working on maize in Nigeria that resulted in an estimated research intensity of 10.3 (Chapter 6, this volume).

The other recurring theme centres on the parity in research attention across groundnut, pearl millet and sorghum for the five programmes. The estimated weighted averages in the last column of Table 7.2 range from 2.0 to slightly over 3.0 by crop. Although pearl millet is somewhat discriminated against in terms of its resource allocation of FTE scientists relative to its economic importance, estimated research intensities are not systematically higher or lower by crop across the five countries.

The country crop improvement programmes are heavily concentrated on breeding, with slightly over half of the total of 60 FTE scientists involved in this area (Table 7.3). Only Mali shows a relatively diversified allocation of scientific resources across disciplinary specializations. Entomology, pathology, agronomy and weed science also play supportive roles in several of the programmes. Mali, Niger and Senegal have invested in about 1 FTE scientist in postharvest technology. The low representation of biotechnologists and social scientists, including agricultural economists, is notable in Table 7.3. This could partially explain the low adoption of most of the varieties bred without involving farmers through participatory processes.

The scientists are well educated in terms of their qualifications. More than half of the scientists in Table 7.4 have PhDs. But what is most striking about the information presented in Table 7.4 is the low frequency of presumably younger scientists who only have BScs. They comprise only about one scientist in six.

Scientists in these crop improvement programmes in West Africa are few in number, well educated and old. The highest frequency 5-year age cohorts are 50–55 and 55–60 (Table 7.5). The concern for ageing scientists is especially relevant in Mali, Nigeria and Senegal. Only Niger has an age profile that would seem to facilitate on-the-job learning-by-doing that is essential to sustaining an effective crop improvement programme. The problem of ageing in key programmes poses a threat to national research capacity to undertake the crucial research needs

Table 7.1. Scientific strength of groundnut, pearl millet and sorghum crop improvement programmes by disciplinary area in West Africa, 2009.

Crop	Country	Breeding	Pathology	Molecular biology	Entomology	Agronomy	Seed production	Social science	Food science	Soil science	Total
Groundnut	Burkina Faso	1.2	1.0	0	0	0.2	0	0	0	0	2.4
Groundnut	Mali	0	0	0	0	2.0	0	0	0	0	2.0
Groundnut	Niger	2.2	0	0	0	0	0	0	0	0	2.2
Groundnut	Nigeria	1.2	0.3	0	0	0	0	0	0	0	1.5
Groundnut	Senegal	1.3	0	0	0	0.3	0	0	0	0	1.6
Total		5.9	1.3	0	0	2.5	0	0	0	0	9.7
Pearl Millet	Burkina Faso	3.0	0.3	0	0.5	0.3	0.2	0.1	0	0	4.4
Pearl Millet	Mali	1.5	0.6	0	1.0	1.5	1.2	0	0.3	0.3	6.4
Pearl Millet	Niger	3.0	0.5	0	1.0	0	0	0	0.5	0	5.0
Pearl Millet	Nigeria	1.5	0	0	0	0	0	0	0	0	1.5
Pearl Millet	Senegal	1.6	0	0	0.2	0.6	0.2	0	0.6	0	3.2
Total		10.6	1.4	0	2.7	2.4	1.6	0.1	1.4	0.3	20.5
Sorghum	Burkina Faso	1.5	0.3	0	0.5	0.3	0.2	0.1	0	0	2.9
Sorghum	Mali	3.2	1.0	1.0	0.2	2.0	0	0	0.3	0	7.7
Sorghum	Niger	3.0	0	0	1.0	0	0	0	0.5	0	4.5
Sorghum	Nigeria	2.0	0.3	0	0.2	0	0	0	0	0	2.5
Sorghum	Senegal	0.8	0	0	0.2	0.6	0.2	0	0.6	0	2.4
Total		10.5	1.6	1.0	2.1	2.9	0.4	0.1	1.4	0	20.0

Table 7.2. Estimated research intensities expressed in FTE scientists per million tonnes of production in 2009–2010 by crop and country.

	Research intensity by country					
Crop	Burkina Faso	Mali	Niger	Nigeria	Senegal	Weighted average
Groundnut	9.3	8.2	12.6	0.8	4.9	3.1
Pearl millet	4.3	5.2	1.6	0.4	5.3	1.7
Sorghum	1.9	8.3	5.3	0.3	14.8	2.0
Weighted average	3.5	6.8	3.1	0.4	6.2	2.0

Table 7.3. Number of FTE scientists by specialization and country in 2009–2010.

	Country					
Specialization	Burkina Faso	Mali	Niger	Nigeria	Senegal	Total
Agricultural economist	0.3	0.25	0.3	0.3	0.05	1.2
Agronomist	0.4	2.3	0.55	0.4	0.0	3.65
Soil scientist	0.0	1.5	0.0	0.0	0.0	1.5
Biotechnologist	0.0	1	0.0	0.0	0.0	1
Breeder	6.1	5.65	9.15	5.0	6.15	32.05
Entomologist	1	1.2	1.75	0.85	0.4	5.2
Food technologist	0.0	1.3	1	0.0	1.2	3.5
Genetic resources	0.25	0.0	0.0	0.0	0.0	0.25
Weed scientist	0.53	2	0.0	0.0	0.6	3.13
NRM expert	0.0	0.33	0.0	0.0	0.0	0.33
Nematologist	0.0	0.0	0.0	0.3	0.0	0.3
Pathologist	0.71	1.65	0.55	0.65	0.05	3.61
Physiologist	0.0	0.0	0.0	0.0	0.6	0.6
Seed technologist	0.4	1.2	0.3	0.0	0.6	2.5
Virologist	1		0.0	0.2	0.0	1
Total	10.69	18.38	13.6	7.70	9.65	60.02

NRM, natural resources management.

Table 7.4. Distribution of scientists by level of education and country in 2009–2010.

	Country					
Level of education	Burkina Faso	Mali	Niger	Nigeria	Senegal	Total
BSc	1.2	4.0	4	0.0	0.6	9.8
MSc	1.4	6.5	6.6	0.2	3.7	18.3
PhD	8.1	8.0	2.6	7.5	5.2	31.3
Total	10.7	18.5	13.1	7.7	9.5	59.4

of adaptation, identification and release of varieties. NARS have no succession plans to renew ageing staff.

East and Southern Africa

There are about 40 FTE scientists working in the ten national groundnut, pigeonpea and sorghum crop improvement programmes in East and Southern Africa (Table 7.6). With the exception of sorghum in the Sudan, the scientists work on several crops in larger cereal, grain legume, pulse or oilseed improvement programmes. Therefore, the actual number of scientists is 2–4 times larger than the FTE estimate that reflects the sum of the percentage allocations across all scientists working on the crop.

Table 7.5. Distribution of scientists by age cohort and country in 2009–2010.

	Country					
Age group	Burkina Faso	Mali	Niger	Nigeria	Senegal	Total
30–35	0.0	0.0	3	0.0	0.0	3
35–40	2.55	0.3	1.3	0.5	2.0	6.65
40–45	0.0	1.15	2	0.0	1	4.15
45–50	1.66	3.5	3.5	0.9	0.7	10.26
50–55	2.58	2.85	1.5	2.7	4.55	14.18
55–60	3.75	10.23	0.75	3.1	1.25	19.08
60–65	0.15	0.35	1.55	0.5	0.15	2.7
Total	10.69	18.38	13.6	7.7	9.65	60.02

With about 18 FTE scientists, Sudan is the only large national programme among the ten crop-by-country observations. Sudan is also the only programme that has invested in biotechnology that is beginning to pay dividends (ICRISAT, 2013). Four of the programmes, two in groundnut and two in pigeonpea, are very small with less than 2.0 FTE scientists in total. All of the programmes have invested at least 0.5 FTE scientists in plant breeding, the area of specialization of about 55% of the scientists in Table 7.6. About 20% of the scientific staff is agronomists. The other disciplinary areas are sparsely represented, although a few of the programmes have made a commitment to social science to provide research support.

The very high estimated research intensities in the last column of Table 7.6 for groundnut and pigeonpea in Kenya are typical of small crop improvement programmes with small quantities of national production. Estimated research intensities below 4.0 for groundnut and pigeonpea in Malawi are very low for grain legume improvement programmes. These estimates suggest that scientific staff strength is inadequate in Malawi or relies heavily on ICRISAT in-country support to address crop improvement in groundnut and pigeonpea. One or fewer FTE scientists in total for groundnut and pigeonpea in Malawi would seem to be unable to respond to research requirements of crops characterized by production levels approaching 200,000–300,000 tonnes per annum.

The estimated research intensity for the large sorghum improvement programme in the Sudan exceeds 4.0, which is high for a cereal that is planted on more than 7 million hectares with more than 4 million tonnes of production. In contrast, more rainfall-assured Nigeria with considerably less area and somewhat more production has an estimated research intensity that is only one-tenth of the estimate for rainfall-unassured Sudan. Compared to Nigeria, the sorghum programme in the Sudan is well staffed scientifically and also features a diversified allocation across several research support disciplines with the exception of social science.

Varietal Output

West and Central Africa

Between 1970 and 2010, Burkina Faso, Mali, Niger, Nigeria and Senegal released a total of 326 groundnut, pearl millet and sorghum varieties. Of these improved genotypes, 313 have information on year of release. Although more sorghum varieties (131) have been released than groundnut (87) and pearl millet (95) improved cultivars, the incidence of release follows the same temporal pattern in the three crops: total releases started from a relatively low but firm base in the 1970s, peaked in the 1980s and 1990s, and tapered off in the 2000s (Table 7.7). This increasing–decreasing pattern was more marked in pearl millet than in groundnut and sorghum as pearl millet releases peaked earlier in the 1980s and fell off more sharply in the 2000s.

Declining varietal releases in the recent past reflects decreasing efforts in genetic improvement

Table 7.6. Scientific strength of groundnut, pigeonpea and sorghum crop improvement programmes by disciplinary area in East and Southern Africa, 2009.

Crop	Country	Breeding	Pathology	Molecular biology	Entomology	Agronomy	Seed production	Social science	Food science	Soil science	Total	FTE scientists per million tonnes production
Groundnut	Kenya	1.0	0	0	0	1.0	1.0	0	0	0	3.0	139.8
Groundnut	Malawi	1.0	0	0	0	0	0	0	0	0	1.0	3.6
Groundnut	Tanzania	1.5	1.0	0	0	1.0	0	0.3	0	0	3.8	10.9
Groundnut	Uganda	1.0	1.0	0	1.0	1.0	0	1.0	0	0	5.0	19.4
Groundnut	Zambia	0.5	0	0	0	0.4	0.2	0	0	0	1.1	9.1
Total		5.0	2.0	0	1.0	3.4	1.2	1.3	0	0	13.9	13.6
Pigeonpea	Kenya	2.0	0	0	0	1.0	0	2.0	0	0	5.0	107.6
Pigeonpea	Malawi	0.7	0	0	0	0	0	0	0	0	0.7	3.8
Pigeonpea	Tanzania	0.5	0	0	0	0.7	0	0	0	0	1.2	9.9
Total		3.2	0	0	0	1.7	0	2.0	0	0	6.8	19.3
Sorghum	Kenya	1.5	0.5	0	0	1.0	0	0	0	0	3.0	30.3
Sorghum	Sudan	11.6	0.5	0.7	0.7	2.2	0	0	0.9	0.5	17.1	4.1
Total		13.1	1.0	0.7	0.7	3.2	0	0	0.9	0.5	20.1	4.7

Estimates on scientific strength for sorghum in Tanzania were not presented; therefore, this table refers to only ten crop-by-country observations.

caused by reductions in funding. Many countries in West Africa received World-Bank-funded loans to strengthen research and extension services during the 1980s to 2000. This is probably when most output was generated. Varietal output fell as the projects ended.

More releases in sorghum and pearl millet are a reflection of larger investments in those crops than in groundnut in West and Central Africa. INTSORMIL and ICRISAT were additional partners who made substantial investments in strengthening NARS in the sorghum and pearl millet crop improvement programmes.

The total number of releases is substantially higher in Mali than in the other four study countries of the WCA region (Table 7.8). Mali accounts for more than one-third of the total releases. Cropwise, Mali and Senegal have more groundnut releases; Mali and Niger have, by far, the highest number of pearl millet releases; and Mali, Nigeria and Burkina Faso rank first, second and third in the number of sorghum releases. At the other extreme, Burkina Faso, Niger and Senegal have released fewer than ten varieties in at least one of the three crops. These differences in total varietal output to some extent mirror the differences in scientific capacity discussed in the previous section.

Dividing the data in Tables 7.7 and 7.8 into two periods (1970–1990 and 1990–2010) shows that about half of the varieties were released before 1990 and half after 1990. However, this 50:50 split does not apply to each of the five countries. Nigeria with 45 releases had more varietal output from 1970 to 1990 than any other country. After 1990, Nigeria has only released a total of 14 varieties of groundnut, pearl millet and sorghum. Senegal and Niger also were characterized by fewer releases since 1990. In contrast, Mali has released 88 genotypes in the latter period and has made available more varieties in each crop than any other country since 1990.

In numerical terms, the steepest drop in releases between the two periods for any of the 15 crop-by-country observations occurred in sorghum in Nigeria. Prior to 1990, 27 sorghum varieties were released in Nigeria; post-1990 only five varieties have been approved for release.

Recent dry spells in generating varietal output are also evident in the release database. Senegal did not release an improved pearl millet or sorghum variety between 1990 and 2010. In the same period, Nigeria has released only three pearl millet varieties, Niger has released only three sorghum varieties, and Burkina Faso

Table 7.7. Number of varieties released by year range and crop from 1970 to 2010.

	Crop			
Decade	Groundnut	Pearl millet	Sorghum	Total
1970s	16	15	13	44
1980s	33	45	40	118
1990s	22	28	46	96
2000s	16	7	32	55
Total	87	95	131	313

Table 7.8. Number of varieties released by country and crop from 1970 to 2010.

	Crop			
Country	Groundnut	Pearl millet	Sorghum	Total
Burkina Faso	8	9	26	43
Mali	26	33	60	119
Niger	13	37	7	57
Nigeria	17	10	32	59
Senegal	23	6	6	35
Total	87	95	131	313

has released only one groundnut and two pearl millet varieties.

Since 1990 varietal output by crop is concentrated in two countries of the region. Mali and Senegal account for 31 of the 44 groundnut releases, Mali and Niger account for 32 of the 36 pearl millet releases, and Mali and Burkina Faso account for 75 of the 83 sorghum releases.

From the perspective of the development of crop improvement programmes, sufficient information was available on 172 entries in the release database to distinguish among different types of products from crop improvement. 'Purified varieties' refer to local landraces that were made as genetically homogeneous as possible and were subsequently released. 'Adaptation' refers to selection of finished elite varieties in multi-locational trials. Usually, these varieties are imported directly from germplasm distribution networks. The descriptor 'Crossing' in the following tables indexes varieties that were selected from crossed materials. The selected progenies could come from populations provided by IARCs or from crosses made by the NARS themselves. Progeny selection from segregating populations requires more applied plant breeding effort than selection of finished varieties, which, in turn, is more technically demanding than purification of landraces.

About 45% of the varieties were released following adaptation trials; 24% resulted from variety purification. Only about 30% of varieties released were developed from crossing (Table 7.9). These frequencies vary crop-wise where 81% of the groundnut releases resulted from adaptation trials against 15% resulting from crossing compared to sorghum or pearl millet where 35–40% of the releases were derived from crossing. In fact, there have been few mature breeding efforts in the region in groundnut except for ICRISAT and the University of Georgia's investment in Nigeria in the 1990s. The data in Table 7.9 also suggest that the release of purified landraces in this region was rare in groundnut but was common in the two cereals.

Across countries, the differences in the use of different sources and procedures for the release of varieties is not as marked across crops because adaptation trials and progeny selection are common to the five country programmes (Table 7.10). However, the release of purified landraces is mainly confined to Mali and Niger. The low incidence of crossing is surprising in a large NARS like Nigeria where breeding efforts on groundnut, pearl millet and sorghum seem to have declined over time.

The contribution of ICRISAT to the total releases since 1970 seems modest (Table 7.11). Only about 24% of the total releases had ICRISAT

Table 7.9. Distribution of varieties released by breeding scheme and crop in the five countries.

	Crop			
Breeding scheme	Groundnut	Pearl millet	Sorghum	Total
Adaptation	44	17	17	78
Purification	2	28	12	42
Crossing	8	25	19	52
Total	54	70	48	172

Table 7.10. Distribution of varieties released by breeding scheme and country.

	Country					
Breeding scheme	Burkina Faso	Mali	Niger	Nigeria	Senegal	Total
Adaptation	5	43	13	9	8	78
Purification	2	17	21	2	0	42
Crossing	6	23	11	5	7	52
Total	13	83	45	16	15	172

parents or were selected from ICRISAT progenies, lines or elite varieties. Attribution to ICRISAT is the lowest for sorghum (8% of varieties with an ICRISAT parent or crosses). In terms of number of ICRISAT-related varieties, the institute's presence has been more pronounced in pearl millet than in groundnut and sorghum. Only one groundnut variety and only eight sorghum varieties were selected from ICRISAT materials that were not ICRISAT-bred varieties or lines.

Low attribution was unexpected given ICRISAT's historical investment in crop improvement in West and Central Africa. A paucity of ICRISAT-related released materials in sorghum is partially explained by the lack of adaptability of some ICRISAT germplasm in the late 1970s and early 1980s when the breeding work started in the region. At the early stages, the breeding scheme was oriented towards the *Caudatum* race of material (popular in India and the USA), whereas the *Guinea* race of material was predominant in Burkina Faso and Mali. Poorly accepted releases of the *Caudatum* types were largely explained by preferences of farmers for tall *Guinea* types that produce plenty of stalks for use as construction material, fuel and fodder for livestock, and non-preferred cooking quality of the large white-seeded and chalkier grain of the *Caudatum* types that were more susceptible to diseases (particularly grain mould) and pests (including head bugs and grain-feeding birds) than the locally preferred *Guinea* race types.

Another reason for the low institutional attribution to ICRISAT that became apparent in consultations with stakeholders was the imprecise knowledge of variety information with regard to parents. There may be many more ICRISAT parents involved than was reported.

Through time, the relative importance of ICRISAT-related materials has increased from 11% of varieties with an ICRISAT parent or crosses during 1970–1980 to about 24% during 2000–2010 (Table 7.12). However, the number of ICRISAT-related releases mirrors the trend of total releases described in Table 7.12: it peaked in the 1980s and 1990s and has since declined.

Data on the contribution from other institutions such as INTSORMIL, CIRAD and the Peanut CRSP were not clearly elicited when the variety release database was assembled. At the stakeholder meeting that was held in Niamey with breeders and agronomists on 6–7 August 2012, partners were asked about pedigree information and institutional attribution. Results are presented in Table 7.13 by crop and Table 7.14 by country.

Table 7.11. Distribution of released varieties related to ICRISAT by crop from 1970 to 2010.

Germplasm origin	Crop			
	Groundnut	Pearl millet	Sorghum	Total
Not ICRISAT Germplasm	43	53	107	203
Parent ICRISAT/Cross NARS	1	0	4	5
Cross ICRISAT/Selection NARS	0	14	4	18
Cross ICRISAT/Selection ICRISAT	11	23	6	40
Total	55	90	121	266

Table 7.12. Distribution of released varieties related to ICRISAT by decade from 1970 to 2010.

Germplasm origin	Year range				Total
	1970–1980	1980–1990	1990–2000	2000–2010	
Not ICRISAT Germplasm	34	70	61	38	203
Parent ICRISAT/Cross NARS	0	0	0	5	5
Cross ICRISAT/Selection NARS	0	5	11	2	18
Cross ICRISAT/Selection ICRISAT	4	17	14	5	40
Total	38	92	86	50	266

Table 7.13. Distribution of released varieties by crop and institution that provided at least one of the parents.

	Crop			
Whose baby is it?	Groundnut	Pearl millet	Sorghum	Total
1970–1990				
CIRAD	2	0	0	2
ICRISAT	0	19	1	20
ICRISAT–INTSORMIL	0	0	1	1
IRAT	0	13	1	14
IRHO	11	0	0	11
Local and NARS varieties	19	14	40	73
CRSP, USA	2	0	0	2
Missing	10	7	9	26
Sub-total	44	53	52	149
1970–2010				
AMU	1	0	0	1
CIRAD	3	0	5	8
CRSP, USA	5	0	0	5
Taiwan	1	0	0	1
ICRISAT	5	37	8	50
ICRISAT–INTSORMIL	0	0	1	1
ICRISAT–Purdue	0	0	1	1
INTSORMIL	0	0	6	6
IRAT	0	13	3	16
IRHO	11	0	0	11
Local and NARS varieties	32	44	77	153
Tifton	1	0	0	1
USA	3	0	0	3
Missing	15	13	34	62
Sub-total	77	107	135	319

AMU, Texas A&M University; CIRAD, Centre de Coopération Internationale en Recherche Agronomique pour le Développement, France; CRSP, Collaborative Research Support Project; CRSP, USA, University of Georgia, USA; ICRISAT, International Crop Research Institute for Semi-Arid Tropics; INTSORMIL, International Sorghum and Millet CRSP; IRAT, Institut de Recherches Agronomiques Tropicales; IRHO, Institut de Recherche pour Les Huiles et Oleagineux (France).

Of the 257 varieties with parental information, 104 were linked to institutes external to the countries where the varieties were released. The other 153 varieties contained materials internal to the countries where they were released. Overall, 16% of varieties bred had ICRISAT germplasm, followed by 13% from CIRAD (includes IRHO, IRAT and CIRAD), 4% from INTSORMIL and 2% from universities (including Purdue University; Tifton Coastal Plain Experiment Station, USDA/University of Georgia; Texas A&M University; North Carolina State; Florida A&M; and Gujarat Agricultural University (Junagadh, India)). Crop-wise before 1990, the contribution of international institutions was high for pearl millet where about 60% of the varieties had a parent from an international organization, followed by groundnut with 34%. The estimate for sorghum was a very low 6%. The same pattern is observed during 1990–2010 by crop. The contribution of international organizations to pearl millet had, however, decreased somewhat and had risen for groundnut.

By country, the contribution of international organization averaged about 31% and has not changed much over time (Table 7.14). However, it is estimated that the contribution of international organizations decreased significantly in Burkina Faso and fell slightly in Mali, reflecting the increasing strength of INERA (Institut de l'Environnement et de Recherches

Table 7.14. Distribution of released varieties by country and institution that provided at least one of the parents.

	Country					
Whose baby is it?	Burkina Faso	Mali	Niger	Nigeria	Senegal	Total
1970–1990						
CIRAD	0	0	0	0	2	2
ICRISAT	6	3	7	0	4	20
ICRISAT-INTSORMIL	0	1	0	0	0	1
IRAT	5	2	5	0	2	14
IRHO	7	1	0	1	2	11
Local	1	15	13	43	1	73
Missing	2	1	8	9	6	26
Tifton	0	1	0	0	0	1
USA	0	0	0	1	0	1
Sub-total	21	24	33	54	17	149
1970–2010						
AMU	0	1	0	0	0	1
CIRAD	4	1	0	0	3	8
CIRAD-CRSP	0	0	0	0	5	5
Taiwan	0	1	0	0	0	1
ICRISAT	12	14	16	4	4	50
ICRISAT-INTSORMIL	0	1	0	0	0	1
ICRISAT-Purdue	0	0	1	0	0	1
INTSORMIL	0	5	1	0	0	6
IRAT	5	4	5	0	2	16
IRHO	7	1	0	1	2	11
Local	14	71	17	49	2	153
Missing	22	6	16	12	6	62
Tifton	0	1	0	0	0	1
USA	0	1	0	2	0	3
Sub-total	64	107	56	68	24	319

AMU, Texas A&M University; CIRAD, Centre de Coopération Internationale en Recherche Agronomique pour le Développement. France; CRSP, Collaborative Research Support Project; ICRISAT, International Crop Research Institute for Semi-arid Tropics; INTSORMIL, International Sorghum and Millet CRSP; IRAT, Institut de Recherches Agronomiques Tropicales; IRHO, Institut de Recherche pour Les Huiles et Oleagineux (France); Tifton, University of Georgia, USA.

Agricoles) of Burkina Faso and IER (Institut d'Economie Rurale) in Mali. This decline was compensated by small increases in external institutions' contributions in Niger, Nigeria and Senegal.

Nigeria's self-sufficiency in material related to released varieties is the most noteworthy finding in Table 7.14. Of 54 released varieties with pedigree information, only five were identified as coming from international sources. The absence of collaboration with French crop improvement research institutes was expected for Nigeria but the apparently low level of effective interaction with other international organizations, including ICRISAT, was surprising.

East and Southern Africa

In this section, we start by providing an overview of variety releases derived from ICRISAT-supplied germplasm for three of ICRISAT's mandate crops (groundnut, pigeonpea and sorghum) in 18 countries of ESA. We then move on to discuss variety releases in just the five countries within the region that were selected for the in-depth study. Again, these data are complemented by INTSORMIL's research on crop improvement in sorghum in the Sudan.

Table 7.15 shows the distribution of variety releases of groundnut, pigeonpea and sorghum across all 18 ESA countries over the period

1975–2010, which is further disaggregated into two time periods (before and after 1998). The results indicate contrasting trends in outputs between crops over the years. Variety releases for legumes increased substantially after 1998, reflecting maintained efforts by and funding for genetic improvement. In contrast, variety releases for sorghum have been decreasing since 1999, reflecting the closure of a large USAID-funded programme on sorghum and millet improvement in Southern Africa under the auspices of SADCC (Southern African Development Coordination Conference).

Within the study countries of Malawi, Tanzania, Uganda, Zambia, Kenya and the Sudan, the trend in varietal release for groundnuts and pigeonpea is consistent with the trend in the ESA region. As depicted in Table 7.16, the incidence of varietal release was at a low-level equilibrium in the 1960s, in the 1970s, and the 1980s of about 10 varieties released per decade. Releases gathered momentum in the 1990s and surged upward in the 2000s.

The character of the releases also changed over time. Before the 1970s, releases consisted mainly of shared landraces in the East African community and landraces from South Africa such as the popular groundnut cultivar Natal Common. In the past two decades, the frequency of landraces in releases has declined and the incidence of bred varieties has increased.

The character of releases also varies by strength of NARS and crop type. Sorghum breeders in the Sudan and Kenya have selected materials from their own parental crosses using NARS or IARC materials. In contrast, pigeonpea and groundnut breeders have released varieties mainly from adaptation trials of ICRISAT-bred materials.

Of the 105 releases in Table 7.16, 57 are related to ICRISAT. A few were distributed via ICRISAT from the Indian Council of Agricultural

Table 7.15. Number of varieties released for the period 1975–2010 released using ICRISAT-supplied germplasm in 18 countries in East and Southern Africa.

	Year				
	1975–1998		1999–2010		
Crop	Number of varieties	Percentage of total	Number of varieties	Percentage of total	Total
Groundnut	17	30.4	39	69.6	56
Pigeonpea	6	28.6	15	71.4	21
Sorghum	56	67.5	27	32.5	83
Total	79		81		160

Source: ICRISAT's variety release database.

Table 7.16. Varietal releases by crop and country across five time periods in East and Southern Africa.

Crop	Country	Pre-1970	1970s	1980s	1990s	2000–2011	Total
Groundnut	Kenya	5	0	0	0	0	5
Groundnut	Malawi	0	0	0	1	5	6
Groundnut	Tanzania	0	1	2	0	7	10
Groundnut	Uganda	0	0	0	1	5	6
Groundnut	Zambia	4	0	1	5	7	17
Pigeonpea	Kenya	0	0	2	1	4	7
Pigeonpea	Malawi	0	0	1	0	6	7
Pigeonpea	Tanzania	0	0	0	1	2	3
Sorghum	Kenya	0	2	2	3	7	14
Sorghum	Sudan	1	5	1	8	8	23
Sorghum	Tanzania	1	1	0	2	3	7
Total		11	9	9	22	54	105

Research (ICAR) to national groundnut programmes in the region. JL 24 and Robut 33-1 are two of the three old and still very popular improved cultivars that dominate groundnut production in India. Most others were ICRISAT-bred varieties. A few were derived from the use of ICRISAT parental materials. Two were efforts partnered by INTSORMIL and the Sudanese national programme, the Agricultural Research Corporation (ARC).

The majority of these ICRISAT-affiliated releases occurred in the 2000s, especially in groundnut and pigeonpea. However, ICRISAT-related release activity was higher in the Sudan in the late 1980s and early 1990s when a joint ICRISAT–INTSORMIL breeder was posted in the country at ARC.

Other institutions have also contributed to releases. INTSORMIL was associated with several releases in the Sudan. The private sector has also been involved in the production of several groundnut varieties in Zambia, a sorghum hybrid in Sudan and a sorghum OPV in Tanzania.

Although the data highlight many positive aspects of varietal output in ESA, three concerns are worth mentioning. First, the fact that Kenya has not released any groundnut cultivars since the 1960s is puzzling. Secondly, long dry spells in release behaviour were documented in a crop improvement programmes as mature as that of sorghum in the Sudan, which has recently released cultivars targeted for its smallholder traditional sorghum-production sector. Sudan only released one improved cultivar, albeit a very important one[2], between 1978 and 1991. Lastly, sorghum varietal output is declining in the region. This may reflect the substitution of maize for sorghum or the decline in sorghum consumption with urbanization. The interest in sorghum seems to be waning in several of the smaller producers in the region.

Before moving to the next section on adoption, a brief comparison in varietal output between West Africa and East and Southern Africa is timely. The two regions are characterized by two very different varietal release profiles over time, by the differences in importance of landrace releases vis-à-vis bred varieties, and by the level of influence of IARC materials in varietal output. All three aspects suggest a more favourable experience in East and Southern Africa than in West Africa.

Adoption of Improved Varieties

West Africa

The adoption estimates are derived from expert opinion and GIS information as described in the methods section of this chapter for groundnut, pearl millet and sorghum in Burkina Faso, Mali, Niger and Senegal. In Nigeria, estimates are taken from nationally representative surveys of adoption and impact of improved pearl millet and sorghum varieties (Ndjeunga *et al.*, 2011) and modern groundnut cultivars (Ndjeunga *et al.*, 2012b). The cereal survey was conducted in 2009; the groundnut survey was undertaken in 2011.

It is important to point out that several popular improved varieties are not considered as modern varieties for the purpose of this investigation. The groundnut variety 55-347 is the dominant variety in Senegal with an area share of 15%. It is also the leading variety in Nigeria with an area share exceeding 40%. Likewise, the variety 47-10 accounts for over 40% of groundnut growing area in Mali. It was released in Mali in 1957; therefore, it does not qualify on the age criterion of having a release date after 1970. Variety 55-347 and several kindred cultivars do qualify in principle because they were re-released in the late 1980s in several groundnut-growing countries in West Africa. But they do not qualify in practice because they were bred during the colonial era in the 1950s and were initially released during the 1960s. These varieties have been around for a long time; 55-347 is still expanding in area in Nigeria.

The pearl millet open-pollinated variety HKP addresses a different aspect in the definition of a modern variety. It was released in 1977. HKP was derived by selection from a local landrace and is still the most widely multiplied pearl millet in Niger's certified seed programme. Pearl millet is a highly cross-pollinated crop that is very prone to outcrossing so the HKP seed that is marketed now is different from the original. It should, however, still offer some advantage compared to the local landrace from which it was developed because it has a lower frequency of 'shibras', which are weedy intermediates between its cultivated form and its wild progenitor. Nonetheless, HKP was not regarded as an improved variety in this study because it is derived wholly from local landrace materials. Being more inclusive in the definition of a modern variety results in a doubling of the adoption levels of improved varieties in groundnut in Mali, Nigeria and Senegal (Ndjeunga *et al*., 2012a). Including HKP leads to a tripling of the level of pearl millet improved-variety adoption in Niger.

National adoption estimates of improved varieties are presented for the three crops and five countries in Table 7.17. The area weighted mean adoption estimates for improved cultivars of each crop across the five countries varied from about 18% for pearl millet and sorghum to 25% for groundnut. Each crop was characterized by one or more lagging countries where uptake of modern varieties was substantially below this mean level. Niger lagged behind in groundnut. Burkina Faso and Niger were slow to adopt improved varieties of pearl millet. Adoption of modern varieties of sorghum was negligible in Burkina Faso.

Low adoption is partly explained by the slow release of modern varieties, therefore limiting the availability of higher performing varieties that can readily attract smallholder farmers. In effect, countries have historically had weak pearl millet and sorghum breeding programmes. Since 1990, countries in WCA have released on average less than one pearl millet variety per year and less than one sorghum variety per year.

Table 7.17. Adoption of improved varieties of groundnut, pearl millet and sorghum in West and Central Africa, 2009.

Country	National/ agroecology	Area (million ha)	Area MVs (%)
Groundnut			
Burkina Faso	National	0.5	24.8
Mali	National	0.3	19.6
Niger	National	0.6	11.9
Nigeria	National	2.6	19.4
Senegal	National	1.0	47.4
Pearl millet			
Burkina Faso	National	1.2	2.6
Mali	National	1.5	31.1
Niger	National	6.5	11.5
Nigeria	National	3.7	25
Senegal	National	1.0	34.5
Sorghum			
Burkina Faso	National	1.6	3.3
Mali	National	1.0	32.6
Niger	National	2.5	15.1
Nigeria	National	4.7	20
Senegal	National	0.2	41.2

There are, however, disparities between countries. The correlation between the number of releases and adoption is positive and significant. In countries such as Mali, where the number of releases is high, the adoption rate is also relatively high compared to countries like Senegal that have released few if any improved varieties in 20 years. The adoption rate is partly explained by the strength of the breeding programmes.

Low adoption is also attributed to a lack of promotion of released varieties. For example, the hybrid sorghum variety NAD1 developed by both INTSORMIL and the Institut National de la Recherche Agronomique du Niger (INRAN), Niger's national programme, has been largely constrained by incomplete knowledge of hybrid production by 27 seed producers mainly organized in farmer associations. One of their pervasive problems in producing viable hybrid seed is timing the crossing of in-bred lines.

Few if any of the adopted improved groundnut varieties in Table 7.18 could be called dominant or even leading varieties. Only two varieties in Senegal account for more than 10% of cultivated area (Table 7.18). And neither 73-33 or Boulkoss are adopted by other countries in the region. Nevertheless, the incidence of spill-over varieties released and adopted in more than one country in West Africa is quite high. Using an expanded, more inclusive definition of a modern variety, Ndjeunga *et al*. (2012a) found that 12 varieties were sown in two or more countries. Fleur 11, a recent introduction from Asia, is sown in three countries. The old, extensively cultivated bred short-duration groundnut variety 55-437 is released and grown in every West African country included in this study, except Burkina Faso.

In contrast to groundnut, pearl millet is characterized by several recent releases that satisfy the criterion of a leading variety tending towards dominance. SOSAT-C88 in Nigeria and Toronion C1 in Mali are potential members of a set of leading varieties with appreciable levels of adoption (Table 7.19). Similar to groundnut,

Table 7.18. Economically important improved groundnut varieties in West and Central Africa, 2009, by area adopted.

Country	Variety	Area (%)
Burkina Faso	TS32-1	5.98
Burkina Faso	E(104)	5.74
Burkina Faso	CN94_C	4.21
Burkina Faso	SH470-P	3.42
Burkina Faso	QH243-C	2.01
Burkina Faso	SH67-A	0.69
Burkina Faso	RMP12	0.69
Burkina Faso	RMP91	0.69
Burkina Faso	KH149-A	0.69
Burkina Faso	Fleur 11	0.69
Mali	JL 24	4.44
Mali	Fleur 11	3.04
Mali	ICGS(34)E	2.64
Mali	28-206	2.50
Mali	ICG(FRDS)4	2.26
Mali	ICGV 86124	2.01
Mali	CN94C	1.55
Mali	ICGV86015	1.16
Niger	RRB	8.54
Niger	JL 24	1.22
Niger	TS 32-1	1.02
Niger	J11	0.51
Niger	Fleur 11	0.51
Niger	ICG 9346	0.10
Niger	O-20	0.00
Nigeria	SAMNUT 23 (ICGV-IS 96894)	4.21
Nigeria	SAMNUT22 (M572.80I)	3.21
Nigeria	SAMNUT21 (UGA 2)	3.2
Nigeria	RMP 91	2.09
Nigeria	SAMARU	2.09
Nigeria	MK 374	1.24
Nigeria	RRB	1.24
Nigeria	RMP 12	1.14
Nigeria	ICIAR 19bt	0.45
Nigeria	M 25.68	0.28
Nigeria	ICIAR 6at	0.11
Nigeria	F452.2	0.04
Nigeria	M 412.801	0.04
Nigeria	M 318.7	0.02
Nigeria	ICIAR 7b	0.01
Senegal	73-33	12.26
Senegal	Boulkouss	11.31
Senegal	H75-0	6.47
Senegal	28-206	3.93
Senegal	PC7979	3.62
Senegal	Fleur 11	3.55
Senegal	78-936	3.15
Senegal	73-911	3.15

Table 7.19. Economically important improved pearl millet varieties in West and Central Africa, 2009.

Country	Variety	Area (%)
Burkina Faso	IKMP 5	1.11
Burkina Faso	IMKV 8201	0.62
Burkina Faso	IKMP 1	0.60
Burkina Faso	SOSAT-C88	0.27
Mali	Toronion C1	16.61
Mali	SOSAT-C88	5.23
Mali	Sanioba 03	3.15
Mali	Djuiguifa	2.38
Mali	Indiana	1.99
Mali	Benkadinion	1.38
Mali	Sanioteli53	0.35
Mali	Amel.M01	0.00
Mali	IKMV 82-01	0.00
Mali	Pool 9	0.00
Mali	PN4 C1	0.00
Nigeria	SOSAT C88	23.95
Nigeria	GB 8735	0.30
Nigeria	ICMV-IS 89305	0.22
Nigeria	LCIC 9703	0.18
Nigeria	LCIC 9702	0.05
Niger	HKP	5.00
Niger	Moro	2.21
Niger	SOSAT-C88	1.29
Niger	Zatib	1.23
Niger	ANK P1 (Ankoutess)	0.38
Niger	ICMV-IS 89305	0.31
Niger	GB8735	0.26
Niger	H80 10 GR	0.19
Niger	Souna3	0.19
Niger	BAP1	0.16
Niger	ICMV-IS 99001	0.06
Niger	CT 6	0.05
Niger	HKB0P1	0.04
Niger	MTDO	0.04
Niger	CEY	0.04
Niger	Zongo Kollo	0.01
Senegal	Thialack2	16.50
Senegal	Souna3	14.00
Senegal	IBMV8402	4.00

Ndjeunga *et al*. (2012a) also found a high incidence of spill-over varieties in pearl millet. Thirteen cultivars were released and partially adopted in two countries. SOSAT-C88 is released and adopted in four of the five countries included in this study (all except Senegal), and at least three additional countries in the region (Cameroon, Chad and Mauritania). Its cultivated area in West Africa approaches 1 million hectares.

Sorghum seems to be a different case than either groundnut or pearl millet in terms of leading and spill-over varieties. There are no persuasive candidates for leading varieties in Table 7.20. Moreover, only five improved varieties were released and partially adopted in only two countries (Ndjeunga *et al*., 2012a). None was cultivated in more than two countries of the region.

In all the countries, the turn-over of varieties is low. In Niger, the pearl millet variety HKP released in 1975 is still the most popular despite the release of more modern varieties (including ICMV-IS 99001, which is itself a higher-yielding re-selected version of HKP). Similarly the groundnut variety 55-437 released in Senegal some 50 years ago is still the dominant variety in Niger. In Mali, the groundnut variety 47-10 released in the 1950s is still dominant. In Nigeria, the variety 55-437 continues as the leading variety. These varieties are still difficult to replace. Existing groundnut cultivars have staying power in farmers' fields because the crop is highly self-pollinated, the multiplication rate of seed is low, seeding rate is high, and the rate of degeneration from outcrosses, mutation or viruses is negligible.

Table 7.20. Economically important improved sorghum varieties in West and Central Africa, 2009.

Country	Improved variety	Area (%)
Mali	Seguifa	6.97
Mali	Tiandougou coura	4.36
Mali	Grinkan	4.26
Mali	Sewa (hybrid)	4.02
Mali	Jacunbe	2.68
Mali	Unnamed hybrid	2.01
Mali	Darrelken	1.48
Mali	Djiguisene	1.46
Mali	Niatitiama	1.14
Mali	Wassa	1.11
Mali	97-SBF5DT-150	0.79
Mali	Kalaban	0.68
Mali	Marakanio	0.68
Mali	ICSV401	0.65
Mali	Tiandougou	0.12
Mali	98-SB-F2-78	0.11
Mali	97-SB-F5DT-63	0.02
Mali	IS15401	0.00
Niger	Sepon 82	4.95
Niger	MM (Mota Maradi)	3.63
Niger	SSD35	2.91
Niger	IRAT204	2.74
Niger	NAD-1 (hybrid)	0.45
Niger	90SN7	0.14
Niger	S35	0.13
Niger	SRN39	0.07
Niger	MAR	0.02
Niger	90SN1	0.01
Nigeria	ICSV 111	8.65
Nigeria	ICSV 400	8.35
Nigeria	SK 5912	2.76
Nigeria	ICRISAT Hybrid Sorghum	0.27
Senegal	F2-20	12.03
Senegal	CE151	10.57
Senegal	CE145-66	9.30
Senegal	CE181	9.30

On average, during the period 1970–1990 and equating adoption to all released varieties, the age of groundnut varieties is estimated at 20 years, pearl millet at 21 years and sorghum at 19 years (Table 7.21). During the period 1990–2010, the age of varieties was estimated at 12 years for groundnut, 14 years for pearl millet and 12 years for sorghum, signalling low turnover even for the recent time period of the last two decades. There are, however, three cases where varietal age is less than 10 years. In Mali, the turnover for sorghum varieties is relatively higher, i.e. 9 years, and in Niger, the turnover of modern groundnut varieties is fast, estimated at 6 years. In both countries the presence of ICRISAT has played a significant role. Many groundnut varieties released in Niger during the last 10 years are from ICRISAT parents or crosses. Similarly, in Nigeria, pearl millet varieties released during the last 10 years have ICRISAT parents or crosses. In Senegal, the results in Table 7.21 are meaningless because no sorghum or pearl millet varieties were officially released in the recent period.

East and Southern Africa

The three crop estimates for adoption of improved varieties in Tanzania are derived from a nationally representative adoption survey in 2011 (Mausch and Simtowe, 2012). The other eight crop-by-country estimates come from a mixture of expert opinion reinforced by the existing literature on adoption as described earlier in this chapter.

Table 7.21. Average age of varieties (years) released during the entire period 1970–2010 and 1990–2010.

Country	Period	Crop			Total
		Groundnut	Pearl millet	Sorghum	
Burkina Faso	1970–2010	23.25	24.11	17.74	20.04
	1990–2010	16.00	16.00	16.36	16.32
Mali	1970–2010	16.38	17.69	11.61	14.34
	1990–2010	12.05	13.37	9.34	10.79
Niger	1970–2010	19.62	21.75	22.57	21.37
	1990–2010	6.20	15.00	19.33	13.52
Nigeria	1970–2010	25.27	23.5	28.87	27.00
	1990–2010	12.33	7.33	11.00	10.78
Senegal	1970–2010	19.57	28.50	28.00	22.54
	1990–2010	12.5	0.00	0.00	12.50
Total for all five countries	1970–2010	20.36	21.18	18.91	19.98
(weighted average)	1990–2010	11.72	13.53	11.92	12.22

The adoption levels of improved varieties range from 30 to 60% for all 11 of the crop-by-country observations (Table 7.22). In Sudan, the estimates were elicited for the three major sorghum-producing agroecologies. They reflect a wide range in production and economic conditions varying from almost full adoption in irrigated production to very partial adoption of less than 20% in the smallholder rainfed sector that is largely unmechanized.

Adoption estimates by cultivar are presented for groundnut in Table 7.23, for pigeonpea in Table 7.24 and for sorghum in Table 7.25. The rapid uptake of recently released groundnut varieties in Uganda is an emerging success story. The diffusion of these ICRISAT-bred and NARO-selected varieties has been aided and abetted by inputs from USAID's Peanut CRSP (John Williams, 2012, personal communication).

Several of the leading groundnut varieties in Table 7.23 warrant comment. CG 7 (ICGV 83708) was released in Malawi in 1990. CG 7 is a high-yielding, red-seeded Virginia bunch variety that is known for its drought tolerance. In 1997, famine-monitoring survey data suggested that CG7 was planted on about 10% of groundnut area and was replacing Chalimbana, the dominant landrace variety introduced by the EAC (East African Community) in the 1960s (Subrahmanyam *et al.*, 2000). ICGV 83708 is also the leading improved variety in Zambia where it was released in 1990 as MGV 4. ICGV 83708 was released in Uganda as Serenut 1R.

Table 7.22. Adoption of improved varieties of groundnut, pigeonpea and sorghum in East and Southern Africa, 2009.

Country	National/ agroecology	Area (ha)	Area MVs (%)
Groundnut			
Kenya	National	20,640	47
Malawi	National	266,946	58
Tanzania	National	535,000	32
Uganda	National	253,000	55
Zambia	National	204,073	57
Pigeonpea			
Kenya	National	118,167	49.7
Malawi	National	175,734	50
Tanzania	National	72,000	49.8
Sorghum			
Kenya	National	173,172	40
Tanzania	National	874,219	37.7
Sudan	Irrigated	465,675	97.4
Sudan	Mechanized/ rainfed	3,991,500	45.8
Sudan	Traditional/ rainfed	2,195,325	18.5
Sudan	National	6,652,500	40.4

ICGV-SM 90704 is a rosette-resistant cultivar that was released in Malawi in 2000. ICGV-SM 90704 was generated by ICRISAT in 1983 from a cross of two varieties, one of which was developed in Malawi (Chiyembekeza *et al.*, 2000). ICGV-SM 90704 was extensively tested

Table 7.23. Economically important improved groundnut varieties in East and Southern Africa, 2009, by area adopted.

Country	Variety	Area (%)
Kenya	ICGV-SM 90704	22.00
Kenya	ICGV-SM 99568	16.00
Kenya	ICGV-SM 9991	6.00
Kenya	ICGV-SM 12991	3.00
Malawi	ICGV-83708	30.00
Malawi	ICGV-SM 90704	20.00
Malawi	JL 24	7.00
Malawi	ICG 12991	0.50
Malawi	ICGV-SM 99568	0.20
Malawi	C851/7	0.10
Tanzania	Pendo	18.4
Tanzania	Other improved	9.3
Tanzania	Sawia	3.7
Tanzania	Naliendele	0.5
Tanzania	Nachingwea	0.1
Tanzania	Mnanje	0.1
Uganda	Serenut 2T	16.80
Uganda	Serenut 3R	14.20
Uganda	Serenut 1R	12.70
Uganda	Serenut 4T	11.90
Zambia	MGV 4	23.00
Zambia	Chishango	10.00
Zambia	Kadononga	8.00
Zambia	MGV 5	6.00
Zambia	Natal Common	2.00
Zambia	Chipego	2.00
Zambia	Makulu red	2.00
Zambia	Kamulomo	2.00
Zambia	Luena	2.00
Zambia	Katete	0.10

in both on-station and on-farm trials in Malawi. ICGV-SM 90704 is a medium-duration, high-yielding cultivar that gives markedly heavier yields than susceptible varieties in years when rosette epidemics occur. Its incidence of infection with the rosette virus is significantly lower than susceptible varieties. ICGV-SM 90704 was also extensively tested in the region and was released as Serenut 2T in Uganda in 1999 and as Chishango in Zambia in 2004. Although it is not officially released in Kenya, it is believed to be the most widely adopted improved variety (Table 7.23). Among improved varieties of groundnut in ESA, ICGV-SM 90704 ranks first in area in Kenya and Uganda and is second in area in Malawi and Zambia. Consequently, ICGV-SM 90704 scores high marks on wide

Table 7.24. Economically important improved pigeonpea varieties in East and Southern Africa, 2009.

Country	Variety	Area (%)
Kenya	KAT 777	16.00
Kenya	ICEAP 00557	12.00
Kenya	ICPL 87091	10.00
Kenya	KAT 60/8	4.00
Kenya	ICEAP 00554	4.00
Kenya	KAT 81/3/3	0.08
Kenya	ICEAP 00040	0.06
Malawi	ICP 9145	25
Malawi	ICEAP 00040	20
Malawi	ICEAP 00557	5
Tanzania	ICEAP 00040	30.60
Tanzania	ICEAP 00053	12.80
Tanzania	ICEAP 00554	2.20
Tanzania	ICPL 87091	1.60
Tanzania	ICEAP 00557	0.80
Tanzania	ICEAP 00020	0.80
Tanzania	Other improved	0.70
Tanzania	ICEAP 00068	0.30

Table 7.25. Economically important improved sorghum varieties in East and Southern Africa, 2009.

Country	Improved variety	Area (%)
Kenya	Seredo	9.00
Kenya	KARI MTAMA-1	8.00
Kenya	IS21055	6.00
Kenya	KARI MTAMA-3	4.00
Kenya	KARI Mtama 2	4.00
Kenya	Serena	3.00
Kenya	IS8193	3.00
Kenya	GADAM	2.00
Sudan	Wad Ahmed	12.02
Sudan	Tabat	7.82
Sudan	Dabar	7.35
Sudan	Gadam Alhamam	4.45
Sudan	Arfaa gadamak 8	2.41
Sudan	PAN 606	2.05
Sudan	Yarwasha	1.75
Sudan	Arose el rimal	1.30
Sudan	Butana	0.66
Sudan	PAC 501	0.65
Sudan	Ingaz	0.06
Sudan	Hageen Dura 1	0.05
Tanzania	Macia(SDS 3220)	20.8
Tanzania	Tegemeo (ZK×17/B/1)	8.1
Tanzania	Wahi (P9406)	7.1
Tanzania	Hakika (P9405)	6.2

adaptation in ESA and is a prime example of a spill-over variety in the region.

Pendo was released in Tanzania in 1998. It is a short-duration, Spanish-type variety with negligible seed dormancy, has good market acceptance and is easy to hand shell. Pendo is a favourite choice in participatory varietal selection and has received support in seed production from the McKnight Foundation.

ICEAP 00040 is the improved pigeonpea cultivar that has been most widely disseminated in ESA (Table 7.24). It is a long-duration, *Fusarium*-wilt resistant variety with preferred market traits. Its long duration exploits the bimodal rainfall pattern prevailing in large parts of East Africa. The diffusion of ICEAP 00040 in northern and central Tanzania, Kenya and Malawi has resulted in increased grain yields and lowered production costs in comparison to local genotypes. Several medium-duration types, such as ICEAP 00557, are also gaining in popularity (Table 7.24).

According to sorghum experts in the Sudan, three varieties, Wad Ahmed, Tabat and Dabar, account for more than half of the area under improved varieties, which is equivalent to over 1.5 million hectares (Table 7.25). Because of sorghum's economic importance in the Sudan, Wad Ahmed is not only the most widely diffused improved variety in the country, but it is also the leading sorghum variety in sub-Saharan Africa. Wad Ahmed was selected from a NARS cross from NARS parents and was released in 1992. Tabat was selected from an ARC cross with ICRISAT parents and was released in 1996. Dabar was released in 1978 following selection from an introduced landrace. Wad Ahmed is the leading variety in both the mechanized rainfed and irrigated sectors. Tabat, like Wad Ahmed, is produced mainly in the mechanized rainfed and irrigated sectors. Dabar's cultivation is concentrated in the mechanized rainfed sector. None of these commercial varieties that are suitable for large-scale mechanization with an emphasis on grain production are popular in the smallholder traditional rainfed sector. However, with recently enhanced *Striga* resistance through marker-assisted selection, newly released, improved versions of Wad Ahmed and Tabat may become more relevant to small-scale production conditions than the original versions were in the past (ICRISAT, 2013).

Macia is a short-statured, early-maturing, white-grained sorghum line that was selected by breeders in the SADC/ICRISAT Sorghum and Millet Improvement Programme (SMIP) in 1984/85. In 1998, Tanzania became the fifth country in SADC to release this variety.

The 1998 Initiative did contain references to national adoption levels for five crop-by-country observations in ESA that overlap with the present set of observations. The estimates of adoption of improved varieties for sorghum were 20% of area for the Sudan and only 2% in Tanzania (Deb and Bantilan, 2003). Comparable estimates for groundnut in Malawi, Uganda and in Zambia were 10%, 10% and 5% (Bantilan *et al*., 2003). The national adoption estimates in Table 7.22 are substantially higher than these 1998 estimates for all five crop-by-country observations suggesting considerable progress in the diffusion of these improved varieties since 1998.

Slow varietal turnover characterized by old improved varieties in farmers' fields was not a problem in groundnut and pigeonpea in ESA in 2010. High varietal age indicating slow turnover were most evident in sorghum in Kenya and Sudan where the weighted average age of improved varieties was about 19 years. However, recent releases in the 2000s and the early acceptance of those releases suggest that rising varietal age and slowing varietal turnover may not be that problematic in the future, especially in the Sudan.

Summary

Assessing the effectiveness of genetic improvement of the ICRISAT-mandate crops in West and Central Africa and in East and Southern Africa is the focus of this chapter. The assessment centres on three aspects of performance: (i) scientific capacity of NARS; (ii) varietal output in the form of releases; and (iii) adoption of improved varieties and hybrids.

Sorghum, pearl millet and groundnut are the major staples and cash crops for millions of farmers in the Semi-Arid Tropics of West and Central Africa. ICRISAT, the sorghum and millet (INTSORMIL) CRSP, the Peanut CRSP, the University of Georgia, CIRAD (former IRAT and IRHO) and NARS have invested in the development of more than 300 varieties of sorghum, pearl millet and groundnut in West Africa since the 1970s. Results showed that overall more varieties were released prior to the 1990s, less than one quarter of the releases was bred with IARCs' germplasm, and Mali stood out as a high performer in terms of releases after the 1990s. Research intensities (expressed in terms of FTE per million tonnes production) were low. Nigeria stood out as having the lowest apparent research intensity. About 30% of released varieties were bred from direct crosses or from populations; the remaining releases were selected from elite materials in adaptation trials or from the simple purification of local landraces.

The total number of FTE scientists working on sorghum, pearl millet and groundnut crop improvement programmes in five major producing countries was estimated at 60, which is substantially lower than the estimate in Chapter 6 for only one crop improvement programme in one country in the region: maize in Nigeria. In sorghum, pearl millet and groundnut, Mali had more scientists than the other country programmes. About half of the FTE scientists were breeders, and with the exception of IER in Mali, the programmes were not that diversified and supported by research in other relevant disciplines. Half of the scientists had PhDs, but more than two-thirds of the 60 FTE scientists are now more than 50 years old. Estimated research intensities in Nigeria of between 0.3 and 0.5 FTE scientists per million tonnes of production for sorghum, pearl millet and groundnut were among the lowest in the DIIVA Project.

Using a mixture of methods, from expert opinion at the national and regional level to interviews complemented by GIS tools at a higher spatial level of resolution to nationally representative surveys in Nigeria, adoption of improved varieties was estimated for each of the 15 crop-by-country observations. On the basis of a definition of improved varieties as being released in 1985 or later, adoption is estimated to range from 0% to 30% for pearl millet, 0% to 24% for sorghum and from 0% to 27% for groundnut. For groundnut, the dominant varieties in farmers' fields are 55-347 in Nigeria and Senegal and 47-10 in Mali. These varieties were bred during colonial rule and released in the 1950s and 1960s.

Not all is gloom and doom. SOSAT-C88 has emerged as an important cultivar with wide adaptation across several pearl-millet-producing countries in West Africa. Its area approached 1 million hectares in 2009. The high incidence of spill-over varieties in release and adoption from groundnut and pearl millet improvement is also impressive and speaks to the high potential for wide adaptability of these crops in the Sahelian, Sudanian and Guinean agroclimatic zones of West Africa.

In general, the findings support a positive correlation among inputs (FTE scientists), outputs (released varieties) and outcomes (adoption levels). Low numbers of FTE scientists are associated with few if any released varieties, which are associated with low levels of uptake. Relative to the size of its production, Mali has invested more in agricultural research, has released more varieties, and has had more favourable adoption outcomes in these three crops than the other four study countries in West Africa. A viable extension service, such as Nigeria's, and a well-targeted effort, such as ICRISAT's promotion of the diffusion of improved sorghum and pearl millet cultivars in northern Nigeria in the 1990s, can temporarily break these underlying associations, but such one-off initiatives have yet to lead to sustainable outcomes.

The ICRISAT-mandated crops are not nearly as economically important in East and Southern Africa as they are in West and Central Africa; however, groundnut, sorghum and millets still account for about 15% of arable land that is cultivated. Moreover, pigeonpea is an expanding export crop in East Africa.

The assessment in ESA drew on ten crop-by-country observations. They were a mixture of relatively small country programmes in groundnut, pigeonpea and sorghum with one very large country programme, sorghum in the Sudan. The results in ESA contrast sharply with those in West Africa. Releases have increased markedly across almost all programmes since the 2000s, continuing an upward trajectory that became apparent in the 1990s. ICRISAT has contributed to more than 70% of the total of 105 released varieties. With more sorghum-growing area but somewhat less production, sorghum in the Sudan is characterized by an estimated research intensity about 10 times greater than the figure for sorghum in Nigeria.

The adoption estimates for crops and countries in ESA were about twice as large as comparable figures for crops and countries in West Africa.

Similarities in results were not as numerous as contrasts between the two regions. One important similarity was the solid evidence for adaptability across countries in the analysis. In four of the five groundnut study countries, rosette-resistant ICGV-SM 90704 and drought-tolerant ICGV-83708, ranked first or second in the adoption of improved varieties.

Funding in the 1990s and early 2000s drove these regional contrasts. In particular, funding for crop improvement in groundnut, sorghum and pearl millet dried up at both the national and international levels during this period. The key issue has not changed in the recent past: ageing human resources and inability of research managers to replace scientists, as well as ageing research infrastructure and inadequate operational budgets for varietal development and testing. There is an urgent need for governments and donors to renew their investments in strengthening human capacity with adequate funding for operating budgets. Flexibility in varietal release procedures and more operational funding is also needed to stimulate variety release in several countries, such as Nigeria and Senegal, as many varieties are in the pre-release stage. The role of IARCs and CRSPs remains critical in an environment with decreasing human capital and funding, but the role of these international research organizations is largely contingent on the strength of partners. This calls for a collective effort (government and donors) to reinforce national research and extension services as a whole. Thinking outside the box may also be required to break some of the linkages among low input, low output and low adoption characteristics of most groundnut, pearl millet and sorghum improvement programmes in West Africa.

Notes

[1] This chapter is a revised and abridged version of Ndjeunga *et al*. (2012a) and Simtowe and Mausch (2012). It also draws heavily on Zereyesus and Dalton (2012).

[2] The research on and the impact of the hybrid Hageen Dura 1 won the World Food Prize for Gebisa Ejeta in 2009.

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