Impacts of Genetic Improvement in Groundnut 14

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Introduction

This chapter documents groundnut genetic enhancement research conducted by ICRISAT in partnership with NARS in Asia and Africa, and quantifies its impact. Impacts of research in groundnut are measured in terms of variety release, yield gain and reduction in production cost per tonne. Estimates of the impacts are measured at both the farm and aggregate level. This chapter also investigates whether ICRISAT content in improved varieties affects varietal impacts. The extent of adoption of improved groundnut varieties in Africa and Asia is presented. Levels of adoption are high in some countries such as China, South Africa, Swaziland, Mozambique, Argentina and Brazil. There is a notable increase in yield in most of the groundnut growing countries, and per tonne production costs of improved varieties were less than that of local varieties. Increase in yield was associated with uptake of improved groundnut varieties. An important policy implication arising from this study is the need for breeding by ICRISAT in partnership with NARS. For promotion of improved groundnut varieties countries need to ensure the availability of seed and exchange of information.

Groundnut is a major oilseed and food crop worldwide. In 1999, 31.96 million tonnes were produced from 23.57 million ha (Table 14.1). Groundnut is important for its oil and protein, and is a valuable commodity for both human use and livestock feed. The plant originated in South America but is now widely distributed throughout

Table 14.1. Groundnut (in-shell) area, production and yield in different countries, 1979–1999.

	Area ('000 ha)			Yield (t ha^{-1})			Prod ('000 t)		
Country	1979–81	1989–91	1997–99	1979–81	1989–91	1997–99	1979–81	1989–91	1997–99
Africa									
Benin	90	97	122	0.7	0.7	0.8	60	69	102
Botswana	4	1	1	0.3	0.5	0.5	1	1	0
Burkina Faso	129	182	221	0.5	0.7	0.9	70	121	194
Chad	168	186	412	0.6	1.0	1.0	93	164	432
Congo, DRC	477	628	528	0.7	0.8	0.8	334	513	403
Egypt	12	13	49	2.1	2.2	3.0	26	27	146
Gambia	72	85	84	1.1	1.1	1.1	79	96	92
Ghana	98	129	188	1.3	0.9	1.0	125	127	193
Guinea	128	104	166	0.7	0.8	1.0	83	80	168
Kenya	11	20	18	0.6	0.6	0.6	7	12	11
Malawi	250	86	113	0.7	0.7	0.8	176	52	92
Mali	166	188	157	0.9	1.0	0.9	141	174	148
Morocco	28	22	28	1.2	0.9	1.6	34	20	44
Mozambique	350	342	284	0.4	0.3	0.5	131	113	138
Niger	181	86	237	0.6	0.3	0.4	105	30	103
Nigeria	572	878	2,506	0.9	1.4	1.0	503	1,181	2,616
Senegal	1,053	857	722	0.7	0.9	0.9	690	757	651
Sierra Leone	15	23	37	0.8	0.9	0.9	12	20	34
Sudan	960	332	1,461	0.8	0.6	0.7	769	174	976
Swaziland	2	3	7	0.5	1.5	1.4	1	4	9
Tanzania	91	110	116	0.6	0.6	0.6	54	62	73
Uganda	109	185	200	0.7	0.8	0.7	80	149	137
Zambia	28	66	125	0.6	0.4	0.4	18	28	51
Zimbabwe	183	192	207	0.6	0.6	0.5	101	108	109

Asia									
Bangladesh	25	38	35	1.1	1.1	1.1	28	41	40
China	2,346	2,947	4,041	1.5	2.1	2.8	3,501	6,082	11,465
India	7,132	8,562	7,203	0.8	0.9	1.0	5,999	7,570	7,440
Indonesia	496	633	643	1.6	1.8	1.5	806	1,124	968
Malaysia	7	1	1	3.3	3.7	3.8	25	5	6
Myanmar	489	523	472	0.8	0.9	1.2	390	456	554
Pakistan	49	84	101	1.2	1.1	1.1	60	89	107
Philippines	52	45	25	0.9	0.8	1.0	47	35	25
Sri Lanka	12	10	10	0.6	0.6	0.6	7	6	6
Syria	10	11	13	1.8	2.0	2.3	18	22	29
Thailand	103	116	89	1.2	1.4	1.5	128	160	135
Vietnam	106	207	257	0.9	1.1	1.4	94	218	352
Latin America and the Caribbean									
Argentina	289	166	337	1.3	2.1	1.7	403	350	594
Brazil	282	85	95	1.5	1.7	1.8	433	142	168
Haiti	47	42	27	0.7	0.8	0.8	35	34	22
Jamaica	2	2	3	1.2	1.1	1.2	2	2	3
Mexico	67	87	93	1.1	1.3	1.4	73	110	134
Paraguay	29	36	28	1.0	1.1	1.1	28	39	30
Developed countries									
Australia	32	20	25	1.5	1.6	1.6	48	31	39
Greece	4	2	1	2.8	3.9	3.7	11	7	3
Israel	5	3	4	4.4	6.6	6.1	22	20	24
Japan	33	18	12	1.9	2.0	2.3	61	36	27
South Africa	317	129	83	1.0	1.2	1.7	304	150	143
USA	595	739	582	2.6	2.6	2.9	1,550	1,893	1,713
World	18,750	2,0274	23,191	1.0	1.2	1.4	18,546	23,458	31,805

Note: Each figure is a 3-year average for the respective period, e.g. 1979–1981.
Source: Estimated from FAO data.

tropical, subtropical, and warm temperate areas in Asia, Africa, Oceania, North and South America, and Europe. In semi-arid areas, it is largely grown by smallholder farmers under rainfed conditions. Developing countries accounted for over 95% of world groundnut area and about 94% of total production during 1997–1999. Production is concentrated in Asia and Africa, with Asia accounting for about 60% of global area and 70% of production. Major groundnut producers in Asia are India (accounting for 44% of global area and 33% of total output) and China (17% of area and 36% of output). Africa accounts for 35% of global groundnut area and 21% of groundnut production; major producers in Africa are Nigeria, Sudan and Senegal. The USA and Argentina are also major groundnut-growing countries.

Groundnut Genetic Enhancement Research at ICRISAT

Compared to the cereal crops, groundnut has received relatively little research attention. Groundnut research to date has generally been conducted by government or public institutions, apart from some private-sector efforts in the USA (Freeman *et al.*, 1999, p. 30). In general, one or two scientists per country are involved in groundnut research in most of the African countries that produce groundnuts. By comparison, in India, more than 150 scientists are involved in groundnut research. At ICRISAT, five or six breeders and an equal number of other scientists are involved in the improvement of the groundnut crop. Research and development activities carried out by groundnut scientists include collection, evaluation and conservation of germplasm, breeding with specific targets, and distribution of germplasm and enhanced genetic materials to the national programmes. ICRISAT has also collaborated with the national agricultural research systems (NARS) in Africa and Asia and has conducted various international trials and observation nurseries. ICRISAT has also played a major role in training groundnut scientists.

Pre-breeding research

Collection, characterization and maintenance of landraces are essential for crop improvement, and these activities have been a high priority at ICRISAT. As of December 1999, 15,342 groundnut germplasm accessions from 92 countries were conserved in ICRISAT's collections. Forty-eight traits are included in the characterization descriptors.

Once genetic resources have been collected and assembled, ICRISAT and its NARS partners conduct evaluation trials to identify the useful traits available in the germplasm. Economically important traits sought in the evaluation are high oil content, early maturity, large seed and high shelling ratio. So far, researchers have identified sources of resistance for disease (335 accessions), insects (31), drought tolerance (46) and high protein (100). This information has been disseminated to researchers worldwide through reports, journal papers and other fora. In response to requests from users, ICRISAT has distributed 86,088 groundnut germplasm samples to 93 countries up to December 1999. Generally, groundnut germplasm is supplied as pods to scientists in India. It is always supplied as seed to scientists outside India, after complying with all the necessary phytosanitary requirements (Kameswara Rao, 2000).

Breeding research domains

ICRISAT groundnut breeders focus on eight breeding research domains. A 'research domain' is delineated as a homogeneous eco-region defined in terms of soil and climatic conditions, and spreads beyond the geographical boundaries of one country. Table 14.2 summarizes the location and characteristics of each of the eight groundnut research domains identified by groundnut scientists.

Research focus through time

The genetic enhancement approach in groundnut at ICRISAT has differed between subsistence farming systems and high-input farming systems. Resistance breeding was the main focus of the efforts to improve groundnut productivity in subsistence systems, while yield and quality breeding were the targets for high-input farming systems. Breeding methods for both systems have included mass selection, pedigree methods, modified pedigree selection (single seed descent; SSD) and backcross breeding. Backcross breeding is increasing in usefulness as simple traits of economic importance are being discovered. In recent years, molecular genetic research has been adopted and molecular marker technology and genetic transformation work are in use.

The emphasis of groundnut breeding research focus at ICRISAT has changed over time, in keeping with research achievements at ICRISAT and with the increased capability and research infrastructure of NARS. Table 14.3 summarizes the groundnut research portfolio at ICRISAT since 1976. A summary of achievements in different research activities is mentioned below.

Table 14.2. Groundnut research domains.

Domain	Production system characteristics	Major constraints	Locations
GN I	Rainy season, 90–100 days duration, rainfed. Oil and confectionery use	Drought, late leaf spot, rust, rosette, aflatoxin	Mid tier of Sahel (Senegal, Mali, Burkina Faso, Niger), India (Gujarat)
GN II	Rainy season, 100–120 days duration, rainfed. Mostly oil use	Late leaf spot, rust, drought, aflatoxin, rosette	E. Africa (Sudan), India (N. Maharashtra, Madhya Pradesh)
GN III	Rainy season, 90–130 days duration, rainfed. Oil and confectionery use	Late leaf spot, rust, rosette, millipedes, pod rots	Southern tier of Sahel (Nigeria, Gambia, Cameroon, Ghana), India (N. coastal Andhra Pradesh, Orissa, W. Bengal), Bangladesh, N. Vietnam, Indonesia
GN IV	Rainy season, 100–120 days duration, rainfed. Mostly oil use	Late leaf rust, drought, leaf miner, *Spodoptera*	India (S. Maharashtra, Andhra Pradesh, Tamil Nadu, Karnataka), Myanmar, Thailand, S. Vietnam
GN V	Summer season, 110–120 days duration, full irrigation. Mostly oil use	No major constraint, but iron chlorosis and bud necrosis disease could be important	India (Gujarat, N. Maharashtra, Madhya Pradesh)
GN VI	Post-rainy season, 100–120 days duration, full irrigation. Mostly oil use	Late leaf spot, bud necrosis disease, leaf miner, *Spodoptera*, white grubs	India (W. & S. Maharashtra, Andhra Pradesh, Tamil Nadu, Orissa, Karnataka, Kerala), N. India, Pakistan, Nepal (rainy season)
GN VIIa	Rainy season, mostly monocropping, 120–140 days rainfed (generally well distributed). Mostly confectionery use. Large seeded varieties preferred	Early leaf spot, rust, rosette, aphids, jassids	Southern Africa (N. Mozambique, N. Zimbabwe, C. Malawi, E. Zambia, S. Tanzania, Zaire)
GN VIIb	Rainy season, mono- and intercropping, 90–110 days duration, rainfed. Mostly oil use	Late leaf spot, rust, rosette, drought, aflatoxin	Southern Africa (S. Mozambique, S. Zimbabwe)
GN VIII	Rainy season, rainfed (bi-modal rainfall). Mono- and intercropping, 90–120 days duration. Oil and confectionery use. Three-seeded Valencia types preferred	Early leaf spot, late leaf spot, rust, rosette, pod rots	Central Africa (N. Tanzania, N. Zaire, Uganda, Rwanda, Burundi, W. Kenya)

Source: ICRISAT medium term plan, 1994–1998.

Table 14.3. Groundnut research portfolio at ICRISAT (Asia, SEA, WCA).

Research area	1976	1986	1996	2000
Foliar diseases	✓	✓	✓	✓
Rust	✓	✓	✓	✓
Late leaf spot	✓	✓	✓	✓
Early leaf spot	✓	✓	✓	✓
Aflatoxin	✓	✓	✓	✓
Insect pests				
Sucking pests	–	✓	✓	–
Defoliators	–	✓	✓	–
Soil pests	–	✓	✓	–
Virus diseases				
Rosette	–	✓	✓	✓
Bud necrosis	✓	✓	✓	–
Peanut clump	–	✓	✓	✓
Drought	✓	✓	✓	✓
Yield and adaptation	✓	✓	✓	✓
Nitrogen fixation	✓	✓	–	–
Nematode diseases	–	✓	–	–
Nutritional quality	✓	✓	✓	–

Breeding for resistance to foliar diseases

Rust, late leaf spot, and early leaf spots are the major foliar diseases in groundnut. Screening methods for foliar disease resistance have been developed. Resistant sources (*Arachis hypogaea*) have been identified, including 169 lines for resistance to rust, 69 lines to late leaf spot (LLS), 42 lines to rust and late leaf spot, and 32 for early leaf spot. Resistant interspecific derivatives are developed. Through hybridization and selection, scientists have been able to transfer rust and late leaf spot resistance to commercially acceptable and agronomically superior genetic backgrounds. A few resistant cultivars (ICG(FDRS)10, ICGV 86590, ICG(FDRS) 4, Girnar 1, ALR 2) were released but remain largely unadopted due to long-duration, unattractive pod shape and low shelling percentage.

Breeding for resistance to insect pests (foliar and soil)

Achievements in this area include the development of screening methods and the identification of sources of resistance in 15 lines for thrips, 133 lines for jassids, nine lines for termites, four lines for aphids, 14 lines for leaf miner and one for *Spodoptera*. Higher levels of resistance were found in wild *Arachis* species. Elite germplasm (ICGVs 86031, 86252, 86393, 86455, 86462) was developed. Work on pest resistance has been suspended since 1997.

Breeding for resistance to Aspergillus flavus

Aflatoxin contamination is a complex problem and it can occur at preharvest, harvest or postharvest stages in the field as well as during storage at the processor/consumer level. Genetic improvement in the resistance level is considered as one of several approaches to resolving this problem. Genetic resistance, together with better crop management practices and optimal storage conditions, can significantly reduce contamination.

Screening methods and detection tools have been developed. Resistant sources have been identified in 21 lines for preharvest seed infection, 37 lines for *in vitro* seed colonization, and two lines for aflatoxin production. Elite germplasm (ICGVs 88145, 89104, 91278, 91279, 91284) have been developed. Germplasms having resistance to *A. flavus* have been used in the breeding programme. The resulting derivatives have been tested for level and stability of resistance to *A. flavus* and for yield potential in multilocational trials. Scientists have been able to transfer stable resistance into different genetic backgrounds and some of these lines outyield local control varieties at certain trial locations.

Breeding for resistance to viral diseases

Breeding efforts include developing resistant/tolerant varieties to groundnut rosette disease, peanut bud necrosis disease (PBND) and peanut mottle virus (PMV). Scientists have developed diagnostic tools, virus characterization and screening methods, and have identified sources of resistance or tolerance to groundnut rosette disease and peanut bud necrosis disease in 116 and 32 lines, respectively. Bud necrosis disease, caused by tomato spotted wilt virus and transmitted by thrips, occurs in serious proportions in India and is becoming increasingly important in many other countries. By breeding for vector resistance, scientists were able to reduce the incidence of PBND considerably. Both vector-resistant and virus-resistant lines were used to improve the level of PBND resistance. Some of the developed lines having tolerance to bud necrosis, such as ICGV 86032, ICGV 86030, ICGV 86031 and ICGV 86032, have agronomically desirable properties with higher yield potential. Resistance breeding for groundnut rosette disease is in progress in Africa, while resistance breeding for PBND in Asia stopped after 1996.

Breeding for drought tolerance

Achievements include better understanding of the physiology of drought, traits associated with drought resistance and their surrogates, field screening techniques, resistance sources (both to mid-season and end-of-season drought) and resistant varieties. Research activities in this area are in progress. Future work needs to be on trait-based selection procedures for greater efficiency in breeding, knowledge of inheritance of traits associated with drought resistance, and high yielding drought resistant cultivars adapted to different agroecoregions.

Breeding for adaptation to specific environments and requirements

The targets of adaptation breeding were to develop material for varying requirements, from no-stress to multiple-stress situations. After succeeding in developing improved varieties for relatively low-stress conditions by the mid-1980s, breeders then moved to focus on developing breeding lines with resistance/tolerance to multiple-stress factors in different maturity classes – early, medium and late. Achievements include character association and inheritance studies, studies on response to photoperiod in groundnut, enrichment of NARS through improved breeding materials and release of improved varieties jointly by NARS and ICRISAT.

Research Products

Intermediate products

Successful development of new groundnut varieties depends to a large extent on the availability of source germplasm with desirable traits such as high yield, greater oil content, high shelling ratio, disease and insect resistance, drought resistance, improved grain quality for confectionery use, etc. Identification of germplasm with desirable traits and the incorporation of desirable traits to a wide range of germplasm is important for expanding the gene pool. ICRISAT has conducted a massive screening programme to identify germplasm with desirable traits. The team effort of scientists in groundnut breeding, entomology and pathology in screening materials for resistance to various biotic and abiotic stress factors has resulted in the development of elite germplasms. A total of 62 elite lines has been developed. Of these, some display high yield with resistance to one or more stress factors (12 lines); others are noted for high yield (five lines), large seed size (four lines), early maturity (four lines), resistance to foliar diseases (17 lines), resistance to *A. flavus* seed infection (two lines), resistance to insect pests (six lines), seed dormancy (five lines), non-nodulating lines (five lines), and puckered leaves (one line).

Varietal production

A total of 67 improved varieties were released in 22 countries through ICRISAT-NARS partnerships (Table 14.4). Out of the 67 releases, 41 were in nine countries of Asia; 20 varieties were released in ten countries of Africa; and six varieties were released in two other countries. Four released varieties were developed by NARS from ICRISAT germplasm, and seven were released through ICRISAT networks, while all other varieties were bred at ICRISAT and released after adaptive trials by the NARS of the respective countries. Another 40 improved varieties are likely to be released in coming years: 32 varieties in nine African countries, and eight varieties in four Asian countries.

Adoption and Impacts of Improved Groundnut Varieties

Extent of adoption

Table 14.5 reports the level of adoption of improved groundnut varieties in different countries. The level of adoption of improved varieties in South Africa, Mozambique and Swaziland is about 75%. Botswana, Zimbabwe and Zambia have adoption levels of 70, 50 and 20%, respectively. About 10% of the groundnut area of Malawi and Uganda is under improved varieties. Adoption levels in other sub-Saharan African countries are low. Farmers mostly cultivate traditional varieties or some local varieties recommended by researchers. For example, Chalimbana (a local variety recommended for cultivation) is grown in about 80% of the groundnut area in Malawi. In Uganda, three recommended varieties (Red Beauty, Bukene and Roxo) of regional origin have been in cultivation since the 1960s, and they occupied about 80% of the country's groundnut area in 1999.

Technology adoption in some countries is very high – especially in Argentina, Brazil and China (Freeman *et al.*, 1999). Latin America and China have had remarkable success in promoting improved groundnut technology – improved varieties, fertilizer, crop rotation, and chemical control of weeds, pests and diseases. Almost the entire groundnut area in Argentina and Brazil is sown to improved varieties. In China, improved varieties cover more than 90% of the groundnut area.

More than 17% of the groundnut area in Vietnam is under improved varieties. Improved groundnut varieties grown by farmers are: VD-1, VD-2, VD-3, VD-4, VD-5, VD-6, VD-7, VD-8, VD-9, VD-10, HL25, ICGV 87883 and ICGV 90068 (Phan Lieu *et al.*, 1999). On-farm survey results showed that the improved variety VD-1 has started to replace local varieties since its release in 1995. Two other improved varieties belonging to the VD series, VD-3 and VD-4, have also slowly been taken up by farmers.

Table 14.4. Number of ICRISAT-NARS released groundnut varieties in different countries, 1981–1999.

Country	< 1980	1981–1985	1986–1990	1991–1995	1996–1999	Total released	Likely to be released
Africa		(1)	5(1)	7(1)	4(1)	20	32
Burkina Faso	–	–	–	–	–	0	4
Congo	–	–	1 (1)	–	–	2	–
Ethiopia	–	–	1	1	–	2	–
Gambia	–	–	–	–	–	0	3
Ghana	–	–	1	–	–	1	–
Guinea	–	–	–	1	–	1	3
Lesotho	–	–	–	–	–	0	3
Malawi	–	–	1	1 (1)	–	3	3
Mali	–	–	–	–	–	0	7
Namibia	–	–	–	–	–	0	3
Sierra Leone	–	–	–	3	–	3	–
Swaziland	–	–	–	–	–	0	3
Tanzania	–	(1)	–	–	–	1	–
Uganda	–	–	–	–	2	2	–
Zambia	–	–	1	1	(1)	3	–
Zimbabwe	–	–	–	–	2	2	1
Asia		2(1)	13+4*	13(1)	6(1)	41	8
Bangladesh	–	–	–	–	–	0	2
China	–	–	–	–	–	0	1*
Cyprus	–	–	–	3	–	3	–
India	–	1	9 + 4*	4	–	18	–
Indonesia	–	–	–	–	3	3	–
Korea (South)	–	–	1	–	1	2	–

Continued

Table 14.4. *Continued*

Country	< 1980	1981–1985	1986–1990	1991–1995	1996–1999	Total released	Likely to be released
Malaysia	–	–	–	–	–	0	2
Myanmar	–	1 (1)	–	1	1	4	–
Nepal	–	–	–	–	1 (1)	2	3
Pakistan	–	–	1	2	–	3	–
Philippines	–	–	–	(1)	–	1	–
Sri Lanka	–	–	–	2	–	2	–
Vietnam	–	–	2	1	–	3	–
Caribbean	–	–	2	2	2	6	–
Jamaica	–	–	1	–	–	1	–
Mauritius	–	–	1	2	2	5	–
TOTAL	–	2 (2)	20 (1)+4*	22 (2)	12 (2)	67	40

Note: Figures in parentheses indicate number of releases through ICRISAT network while asterisk indicates number of NARS releases from ICRISAT parent. All other releases are ICRISAT-bred varieties released in respective countries after adaptation trial conducted by NARS.

Table 14.5. Level of adoption of improved groundnut varieties in Asia and Africa, 1999.

Country/region	Year (season)	Percentage of area planted to improved varieties				
		ICRISAT bred	ICRISAT parent	ICRISAT network	Other improved	All improved
Africa						
Botswana	1999	–	–	–	70.00	70.00
Malawi	1999	10.00	–	–	–	10.00
Mozambique	1999	0.20	–	–	75.00	75.20
Namibia	1999	–	–	–	50.00	50.00
South Africa	1999	–	–	–	75.00	75.00
Swaziland	1999	5.00	–	–	70.00	75.00
Uganda	1999	–	–	–	10.00	10.00
Zambia	1999	15.00	–	–	5.00	20.00
Zimbabwe	1999	2.00	–	–	50.00	52.00
Asia						
China	1990s					>90.00
India/Maharashtra						
Nasik, Dhule, Kolhapur	1997 (*Kharif*)	–	–	–	25.56	25.56
Nanded, Parbhani, Satara	1997 (*Kharif*)	–	–	–	94.28	94.28
Nanded, Parbhani, Satara	1997 (*Rabi*)	31.71	–	–	48.78	80.49
Nasik, Dhule, Kolhapur	1997 (Summer)	–	–	–	4.49	4.49
Nanded, Parbhani, Satara	1997 (Summer)	18.23	–	–	67.39	85.62
India/Andhra Pradesh						
Guntur, West Godavari	1997 (*Kharif*)	98.00	–	–	–	98.00
Guntur, West Godavari	1997 (*Rabi*)	58.00			–	58.00
Guntur, West Godavari	1997 (Summer)	31.74	–	–	–	31.74
Anantapur, Chitoor, Prakasam	1997 (*Kharif*)	–	–	–	37.00	37.00
Anantapur, Chitoor, Prakasam	1997 (*Rabi*)	39.00	–	–	1.00	40.00
Vietnam/South	1997	0.25	–	–	17.21	17.46

Source: Impact Monitoring Survey 1999–2000. For India, computed from Bantilan *et al.* (1999); and for Vietnam Phan Lieu *et al.* (1999); and for China, Freeman *et al.* (1999).

Uptake of other improved varieties such as HL 25 and ICGV 87391 remained insignificant. HL 25 is suitable only in elevated areas due to its susceptibility to leaf diseases associated with excess moisture. Reasons for low adoption of ICGV 87391 are related to undesirable traits (thick shell, pod reticulation and constriction), high input requirements and its lower market price compared with local varieties. Although five out of six respondents were aware of improved varieties, most did not grow improved varieties. The major reasons cited for not growing improved varieties were: lack of seed availability, lack of elevated land for seed multiplication in the rainy season, some of the improved varieties were not suitable for local conditions, low price (due to low quality) of unsuitable improved varieties, improved varieties with large seed size have varying qualities across seasons (Phan Lieu *et al.*, 1999).

Bantilan *et al.* (1999) reported that in 1997, farmers of Andhra Pradesh (India) grew several improved groundnut varieties (JL 24, Kadiri and ICGS 44), while farmers of Maharashtra (India) adopted JL 24, TAG 24, UF-70-103, TG 26 and Karad 4-11. ICRISAT varieties are popular in the Guntur and West Godavari districts of Andhra Pradesh and in the Nanded, Parbhani and Satara districts of Maharashtra. Two older varieties, TMV2 and SB11, are widely cultivated in Andhra Pradesh and Maharashtra, respectively. The Government of India recommended these two varieties in the early 1940s. Reasons for the wide cultivation of TMV2 and SB11 are seed availability, drought resistance and yield stability. ICGS 11, ICGS 44, ICGS 21 and ICGS 49 were observed on farmers' field in locations where technology was disseminated and seeds were made available. The main reasons given for low adoption of ICRISAT varieties in Maharashtra are non-availability of seed and longer duration. The most preferred traits for rainy season groundnut varieties in Maharashtra are medium duration, high pod yield, greater oil content and higher shelling percentage. On the other hand, Andhra Pradesh farmers want varieties with high pod yield, with pest and disease resistance.

Impacts of improved varieties

The goals of groundnut breeders were to enhance yield and incorporate resistance to biotic and abiotic stresses. ICRISAT-developed varieties were first released for cultivation in farmers' fields in the early 1980s. Therefore, we have computed yield gains in groundnut in 1997–1999 compared with 1979–1981. We have also estimated percentage annual compound rate of growth in yield for the period 1979–1999. If a country has a large area under groundnut cultivation or ICRISAT varieties have been released (or are likely to be released), then we have included that country in our analysis. Results of this exercise are presented in Table 14.6.

Table 14.6. Yield growth for groundnut in different countries.

Country	Growth rates, 1979–99	Country	Growth rates, 1979–99
Africa		Asia	
Benin	1.6	Bangladesh	0.2
Botswana	2.6	China	3.5
Burkina Faso	2.7	India	1.4
Chad	2.7	Indonesia	–0.5
Congo	0.7	Malaysia	0.5
Egypt	2.3	Myanmar	1.2
Gambia	–1.0	Pakistan	–0.7
Ghana	–1.5	Philippines	0.5
Guinea	3.2	Sri Lanka	0.5
Kenya	0.3	Syria	0.9
Malawi	–0.5	Thailand	1.2
Mali	0.5	Vietnam	2.5
Morocco	1.2	Argentina	1.6
Mozambique	1.3	Brazil	1.2
Niger	–1.0	Haiti	0.4
Nigeria	0.8	Jamaica	0.2
Senegal	1.4	Mexico	0.9
Sierra Leone	0.8	Paraguay	0.4
Sudan	–0.1		
Swaziland	7.3	Developed countries	
Tanzania	0.4	Australia	1.5
Uganda	–0.2	Greece	1.6
Zambia	–1.9	Israel	2.1
Zimbabwe	0.6	Japan	1.3
		South Africa	5.1
		USA	0.3
		World	1.9

Note: Growth rates are percentage per annum.
Source: Estimated from FAO data.

Growth in yield

Groundnut yields increased worldwide by 1.9% per year between 1979 and 1999. Yield has increased in most countries, especially in Asia, Latin America and in the developed countries. Yield has increased at the rate of 3.5% per year in China. The adoption of improved varieties in China is more than 90%, and Chinese farmers have also adopted improved management practices such as organic and inorganic fertilizer, crop rotations, plastic film mulch, and pest and disease control. Between 1979–1981 and 1997–1999, groundnut yields in China increased from 1.5 to 2.8 t ha^{-1}. In India, growth in yield was 1.4% per year and average yields increased from 0.8 t ha^{-1} in 1979–1981 to 1 t ha^{-1} in 1997–1999. However, yields in India vary widely depending on the production system. On rainfed groundnut, which occupies about 80% of groundnut area, yields are roughly 0.9 t ha^{-1}, while the irrigated crop yields about 1.6 t ha^{-1}. Yields in Vietnam have increased at the rate of 2.5% per annum. Though the adoption rate of improved groundnut varieties is only about 17%, Vietnamese farmers have widely adopted improved groundnut production technology including alternative coconut ash (ACA). Traditionally Vietnamese farmers used to grow groundnut using coconut ash, but non-availability of natural coconut ash created problems in groundnut cultivation in Vietnam. Then scientists developed ACA, which is a chemical formulation of all the nutrients (chemicals) available in coconut ash. ACA is very popular in Vietnam. Improved management practice, accompanied by improved varieties to a significant extent, has led to the increase of groundnut yield in Vietnam to 1.4 t ha^{-1} in 1997–1999 from 0.9 t ha^{-1} in 1979–1981.

In some countries in sub-Saharan Africa, growth in groundnut yields has been low, but the countries that have high rates of modern variety adoption have experienced high yield growth. For example, Swaziland had 7.3% annual growth in yield and had 75% area under improved varieties. South Africa had 75% adoption and experienced 5.1% annual compound growth rate. Botswana had 70% adoption and enjoyed 2.6% annual growth rate in yield for the period 1979–1999. Mozambique also experienced 1.3% annual growth in yield. Senegal also has high adoption and experienced 1.4% annual growth rate.

By contrast, farmers cultivating under semi-subsistence systems in Africa (Gambia, Ghana, Malawi, Uganda, Zambia) generally grow low-yielding, late-maturing varieties in marginal land without irrigation. They have experienced negative growth in yield, implying that yield declined over time in those countries. Developing countries in Latin America (especially Argentina and Brazil) have experienced positive growth. Argentina and Brazil have also adopted improved varieties and management practices to a large extent.

Between 1979–1981 and 1997–1999, yields in the USA increased from 2.6 to 2.9 t ha^{-1}. This relatively slow growth was due to several reasons. First, technology adoption (e.g. the introduction of runner varieties in the 1970s) and large-scale commercialization had already taken place earlier. Second, weather variability, including drought in some parts, generally reduced yields and increased fluctuations in yield. Third, public concern over the effects of high levels of fertilizer and pesticide use on environmental and human health led to reductions in the use of agro-chemicals during the 1980s, thus slowing down yield growth (Freeman *et al.*, 1999).[1]

[1] It is also true that in the USA, groundnuts tend to be grown on relatively poor farmland, where high input use does not always pay.

Table 14.7 reports data on the adoption and impacts of popular improved groundnut varieties on yield, unit cost of production and per hectare return in Africa and Asia. Adoption levels of some individual varieties are very high. For example, Sellie – a variety from South Africa – covers 70% of the groundnut area in Swaziland, 60% of area in Botswana, 40% of area in Mozambique, 40% of area in South Africa and 10% of area in Zimbabwe. Some are popular in a specific region. For example, ICGS 44 is cultivated in 98% of the rainy season groundnut area of the Guntur and West Godavari districts of Andhra Pradesh in India. CG7 covers 10% of the groundnut area in Malawi. Improved groundnut varieties provided 5–25% higher grain yield in southern and eastern African countries, compared with the best performing local varieties. Yield gain from improved varieties in India was 13–108% in Maharashtra and 27–53% in Andhra Pradesh in the year 1997. Per tonne cost of production was 15–44% lower in Maharashtra except for TMV 10, which had higher per tonne production costs compared with the best performing local variety (SB11). In Andhra Pradesh, per tonne production costs of improved varieties were 11–37% lower, except for ICGS 44, which had slightly higher per tonne production costs. All improved varieties provided a higher net return on a per hectare basis. Compared with the best performing local variety, per hectare net return was 50–594% higher in Maharashtra and 36–191% higher in Andhra Pradesh.

Spillover impacts

An important objective of international agricultural research institutions is to determine the extent to which research undertaken in one location may impact on other regions of interest. This is because research activities are most often planned to target mandate crops and agro-ecological areas found in many parts of the world. ICRISAT has, as a policy, distributed a wide range of groundnut germplasm and elite materials to breeding programmes in NARS throughout the semi-arid tropics. This has contributed to faster and more cost-effective development of useful final products by the receiving parties and thus has generated technology spillover. For example, ICG 221 was developed for India and was also released in Swaziland (Table 14.8). ICGM 286, ICGV-SM 86066, ICGV-SM 85038 and ICGV-SM 86080 were developed for Malawi and are now grown in Rwanda. RMP 12 was originally developed for Burkina Faso but was also released in Uganda and Mozambique.

These examples indicate that the genetic material used in the development of these cultivars has wide adaptation, thus resulting in spillovers from groundnut genetic enhancement research. This indicates the advantages in targeting wide adaptation of the improved varieties.

Table 14.7. Adoption and impacts of popular improved groundnut varieties.

Country (region)	Variety	Year	Adoption (% area)	Impacts of improved varieties on: % yield gain	% reduction in cost per tonne	% increase in net return per ha
Africa						
Botswana	Sellie	1999	60.00	10	–	–
Botswana	55-437	1999	10.00	5	–	–
Malawi	CG7	1999	10.00	50	–	–
Mozambique	Natal Common	1999	30.00	5	–	–
Mozambique	Sellie	1999	40.00	10	–	–
Mozambique	RMP 12	1999	5.00	15	–	–
Namibia	Sellie	1999	50.00	10	–	–
South Africa	Sellie	1999	40.00	10	–	–
South Africa	Anel	1999	15.00	10	–	–
South Africa	Akwa	1999	20.00	20	–	–
Swaziland	Sellie	1999	70.00	10	–	–
Swaziland	ICG 221	1999	5.00	15	–	–
Uganda	Igola-1	1999	10.00	25	–	–
Zambia	MGV4	1999	10.00	25	–	–
Zambia	Luena (JL24)	1999	5.00	15	–	–
Zimbabwe	Falcon	1999	30.00	10	–	–
Zimbabwe	Flamingo	1999	10.00	10	–	–
Zimbabwe	Sellie	1999	10.00	10	–	–
Asia						
India/Maharashtra						
Nasik, Dhule, Kolhapur	JL 24	1997 (*Kharif*)	11.24	31	15	104
Nasik, Dhule, Kolhapur	TMV10	1997 (*Kharif*)	9.08	13	–27	50

Nasik, Dhule, Kolhapur	K2	1997 (*Kharif*)	4.87	66	31	168
Nanded, Parbhani, Satara	JL 24	1997 (*Kharif*)	39.05	24	24	100
Nanded, Parbhani, Satara	Karad4-11	1997 (*Kharif*)	5.71	33	44	254
Nanded, Parbhani, Satara	TAG 24	1997 (*Kharif*)	49.52	–	–	–
Nanded, Parbhani, Satara	ICGS 21	1997 (*Rabi*)	31.71	37	–	–
Nanded, Parbhani, Satara	TAG 24	1997 (*Rabi*)	48.78	86	23	109
Nasik, Dhule, Kolhapur	JL 24	1997 (summer)	4.49	95	27	251
Nanded, Parbhani, Satara	UF-70-103	1997 (summer)	9.94	44	37	133
Nanded, Parbhani, Satara	TAG 24	1997 (summer)	56.35	108	37	445
Nanded, Parbhani, Satara	ICGS 11	1997 (summer)	3.31	19	25	119
Nanded, Parbhani, Satara	ICGS 49	1997 (summer)	14.92	86	24	594
India/Andhra Pradesh						
Guntur, West Godavari	ICGS 44	1997 (*Kharif*)	98.00	50	–	–
Anantapur, Chitoor, Prakasam	JL 24	1997 (*Kharif*)	30.00	57	14	36
Anantapur, Chitoor, Prakasam	Kadiri	1997 (*Kharif*)	7.00	40	37	191
Guntur, West Godavari	ICGS 44	1997 (*Rabi*)	58.00	27	–4	71
Anantapur, Chitoor, Prakasam	JL 24	1997 (*Rabi*)	24.00	53	0	62
Anantapur, Chitoor, Prakasam	Kadiri	1997 (*Rabi*)	15.00	–	–	–
Guntur, West Godavari	ICGS 44	1997 (summer)	31.74	91	11	47
Vietnam	VD-1	1997	12.73	–	–	–

Note: – indicates data not available.
Source: Impact Monitoring Survey 1999–2000. For India, Deb *et al.* (2000) and for Vietnam, Phan Lieu *et al.* (1999).

Table 14.8. Spillover impacts of improved groundnut varieties.

Variety	Production system* and country where originally selected	Spillover into
Chipego	21 Malawi	19, 20, 21 Zambia
ICG 221	9 India	20 Swaziland
ICGM 286	21 Malawi	21, 23 Rwanda
ICGMS 42	21 Malawi	21 Zambia
ICGV-SM 86066	21 Malawi	21, 23 Rwanda
ICGV-SM 85038	21 Malawi	21, 23 Rwanda
ICGV-SM 86080	21 Malawi	21, 23 Rwanda
Johari	9 India	21, 22 Tanzania
RMP 12	15 Burkina Faso	21 Uganda
		21, 22 Mozambique
Roba	8 India	23 Ethiopia
Stella	21 Malawi	22 Mauritius
Veronica	21 Malawi	22 Mauritius

Note:
*Production system 8 (PS 8) is tropical, low rainfall, primarily rainfed, post-rainy season, crops are sorghum/oilseed. Western Deccan Plateau of India is the location included in PS 8. Production system 9 is tropical, intermediate-length rainy season, sorghum/oilseed/pigeonpea interspersed with locally irrigated rice, located in Peninsular India. Production system 15 is intermediate season (125–150 days), rainfed, mixed, sorghum-based, located in Southern Sudanian Zone. Production system 19 (PS 19) covers lowland, rainfed, short-season (less than 100 days) and suitable for sorghum/millet/rangeland, located in Sahelian eastern Africa, and margins of the Kalahari Desert. Production system 20 (PS 20) covers semi-arid, intermediate season (100–125 days) and suitable for sorghum/maize/rangeland, located in eastern Africa and parts of southern Africa.*Production system 21 is intermediate season (125–150 days), sorghum/maize/finger millet/legumes, located in eastern and southern Africa. Production system 22 is lowland, sub-humid, mixed, rice/maize/groundnut/pigeonpea/sorghum, located in coastal areas of eastern and southern Africa. Production system 23 is highland, rainfed, long-season (150–180 days), sorghum/maize/teff, located in highland zones of northeastern and eastern Africa. Agro-ecological details of each production system are given in the ICRISAT *Annual Report, 1993.*
Source: *ICRISAT Southern and Eastern Africa Highlights, 1996* (p. 30).

Conclusions

This chapter documents the evolution of genetic enhancement research in groundnut at ICRISAT and provides an inventory of research products. It also reports the level of adoption and impacts of improved groundnut varieties in Africa and Asia. Only public sector institutions are involved in developing improved groundnut varieties, with the international system playing a central role. There is a notable absence of organized private sector effort in developing and marketing groundnut seed. The groundnut breeding programme at ICRISAT, in partnership with NARS, has released 67 varieties in 22 countries of Africa and

Asia, with as many as 40 more varieties 'in the pipeline' at present in 13 countries of Africa and Asia. Varying rates of adoption are observed in sub-Saharan Africa and Asia. Key factors influencing adoption are availability of seed with high yield potential, more oil content, high shelling ratios, and resistance to insects and pests.

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