Pepper (*Capsicum* spp.) Germplasm Dissemination by AVRDC – The World Vegetable Center: an Overview and Introspection

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Peppers (*Capsicum* spp.) are an important cash crop for smallholder farmers in developing countries. Hot pepper (chili) dominates world spice trade, and sweet pepper has become a popular vegetable and cash crop in the tropics for smallholders. Among the five cultivated species of the genus *Capsicum*, *C. annuum* (both hot and sweet pepper) is the most widely cultivated. According to estimates for 2011, peppers (dry and green) were cultivated on about 3.8 million ha, out of which 3.3 m ha were in developing and less developed countries of Asia (2.5 m ha) and Africa (0.8 m ha) (FAOSTAT, 2013). AVRDC – The World Vegetable Center, plays a major role in the conservation and distribution of vegetable germplasm held in the public domain. Headquartered in Taiwan, the institution initially was set up in 1971 as the Asian Vegetable Research and Development Center (AVRDC). The Center executes long term breeding projects in many vegetables including peppers, which contribute to improving nutritional security and improved income in the developing world. The Center holds a total of 8,165 accessions of *Capsicum*. This is the world's largest collection held by a single institution, comprising about 11% of all accessions held globally (Ebert, 2013). Over the past 25 years, the pepper breeding program at the Center has focused on improving *C. annuum* species (both hot and sweet peppers) by incorporating pest resistance, developing male sterile lines and heat tolerance. A total of 29,980 germplasm materials have been distributed, comprising 6,008 genebank accessions (20%) and 23,972 improved advanced lines (80%). National public and private sector partners have used AVRDC seed materials in various ways. Since 2005, based on AVRDC's germplasm and improved lines, a total of 51 open pollinated and hybrid cultivars of hot and sweet peppers have been released and commercialized by both public and private sectors in countries of South Asia, West Africa, Central Asia and the Caucasus. We have learned from seed distribution experiences that a major multiplying impact of our improved lines can been achieved in developing countries when people working in both public and private sectors have enhanced skills, for example, in India. Hence, capacity building of human resources in less developed and developing countries will remain an integral part of the Center's pepper breeding research cum developmental strategies.

INTRODUCTION

Peppers (*Capsicum* spp.) are an important cash crop for smallholder farmers in developing countries such as Ethiopia, Nigeria, Ghana, China, India, Pakistan, Bhutan, Indonesia, Cambodia, and Thailand. Hot pepper (chili) dominates today's world spice trade, and sweet pepper has become a popular vegetable in the tropics. Among the five cultivated species of the genus *Capsicum* (*C. annuum, C. frutescens, C. chinense, C. baccatum, C. pubescens*), *C. annuum* (both hot and sweet pepper) is the most widely cultivated. According to estimates for 2011, peppers (dry and green) were cultivated on about 3.8 million ha, out of which 3.3 m ha were in developing and less developed countries of Asia (2.5 m ha) and Africa (0.8 m ha) (FAOSTAT, 2013). Based on fruit shape and size, more than 20 market types of hot and sweet peppers are known. These can be grouped into five broad market categories: (i) fresh market (green, red, multi-color whole fruits), (ii) fresh processing (sauce, paste, canning, pickling), (iii) dried spice (whole fruits and powder), (iv) industrial extracts (paprika/oleoresin, capsaicinoids and carotenoids) and (v) ornamental (plants and/or fruits) (Poulos, 1994). These market types reflect that, besides conventional nutritional food uses, there are a number of alternative food (e.g. paprika oleoresin, medicines) and non-food (e.g. defense, spiritual, ethno-botanical) uses for peppers.

AVRDC – The World Vegetable Center plays a major role in the conservation and distribution of vegetable germplasm held in the public domain. Headquartered in Taiwan, the institution initially was set up in 1971 as the Asian Vegetable Research and Development Center (AVRDC). With the geographical expansion of its activities in the 1990s and 2000s, the Center now operates regional offices in Africa (established in 1992 in Tanzania), East and Southeast Asia (established in 1992 in Thailand), South Asia (established in 2004 in India), Central-West Asia and North Africa (established in 2010 in the United Arab Emirates). In addition, the Center has project offices around the developing world (Bangladesh, Cameroon, Mali, Indonesia, Fiji, Solomon Islands and Uzbekistan). The Center executes long term breeding projects in many vegetables including peppers, which contribute to improving nutritional security and improved income in the developing world. The Center makes its germplasm accessions and improved inbred lines derived from its breeding programs available as international public goods for global use (Keatinge et al., 2012) to the world community including public and private sector researchers, most of whom work in developing countries.

This paper focuses on the results of a survey of the Center's *Capsicum* seed distribution during the past decade, as well as information on the uses of peppers in different parts of the world. Some examples of successful use of supplied seed samples and lessons learned are given and future needs concerning ongoing collection of *Capsicum* germplasm and its conservation and utilization are discussed.

CAPSICUM GERMPLASM HOLDINGS AND CHARACTERIZATION

The Center holds more than 67,800 accessions of vegetable germplasm comprising 170 genera and 436 species from 156 countries of origin. With a total of 8,165 accessions, AVRDC's *Capsicum* collection is the world's largest held by a single institution, comprising about 11% of all accessions held globally (Ebert, 2013). These accessions belong to 11 species and the largest number of accessions is available for *C. annuum* (66%), followed by *C. frutescens* (8%), *C. chinense* (6%), *C. baccatum* (5%) and others (Fig. 1). Accessions grown out for regeneration are usually fully characterized with morphological and horticultural descriptors to allow

Figure 1. *Capsicum* species (holdings) and percentage accession characterized.

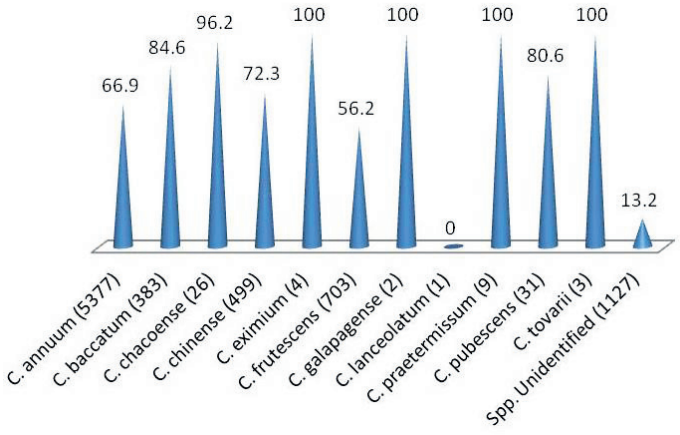


Figure 2. Seed distribution by recipient country during the period 2001 to 2012.

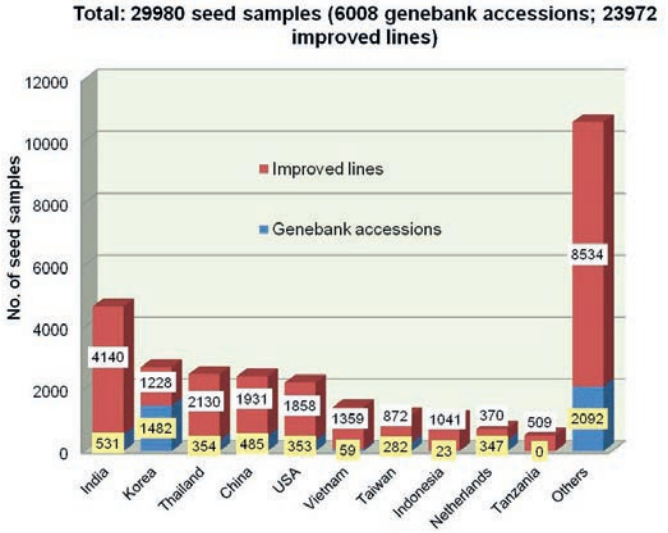
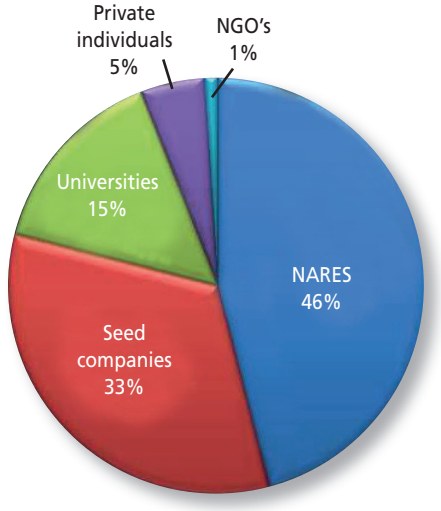


Figure 3. Seed distribution percentage by recipient category.



seed requesters to make an informed choice. The majority of accessions of the different *Capsicum* species have been fully characterized. However, a major effort is needed to regenerate, characterize and determine the taxa of the relatively large group of accessions (13%) without species identification (Fig. 1). Overall, the regeneration and characterization backlog is close to 40%.

SEED DISSEMINATION

Over the past 25 years, the pepper breeding program at the Center has focused on improving *C. annuum* species (both hot and sweet peppers) by incorporating pest resistance, developing male sterile lines and heat tolerance. A detailed search of *Capsicum* germplasm distribution from 2001 to 2012 in our database was conducted and data were analyzed. For this purpose, for each year the shipment lists were revisited and duplicate samples during the same year were ignored in the sample counting process. This analysis did not include seed samples supplied by our regional offices.

A total of 29,980 germplasm materials were distributed, comprising 6,008 genebank accessions (20%) and 23,972 improved advanced lines (80%). The top ten recipient countries of *Capsicum* germplasm were: India (4,671; 15.6%), Republic of Korea (2,710; 9.0%), Thailand (2,484, 8.3%), China (2,416, 8.1%), USA (2,211, 7.4%), Vietnam (1,418; 4.7%), Taiwan (1,154; 3.8%), Indonesia (1,064; 3.5%), The Netherlands (717; 2.4%) and Tanzania (509; 1.7%) (Fig. 2). A total of 10,626 acces-

Table 1. List of additional 113 countries/islands/territories that received pepper seeds from AVRDC – The World Vegetable Center during 2001-2012.

Geographical region	Name of the country (germplasm accessions/breeding lines/total)
East-South Africa	Angola (0/60/60), Botswana (0/129/129), Ethiopia (55/241/296), Kenya (0/190/190), Madagascar (0/9/9), Malawi (0/95/95), Mauritius (1/256/257), Mozambique (0/20/20), Namibia (0/50/50), Reunion (0/18/18), Rwanda (0/20/20), Lesotho (0/95/95), Somalia (0/4/4), Sudan (0/43/43), Uganda (4/288/292), Zambia (3/110/113), Seychelles (0/49/49), South Africa (82/307/389), Suriname (0/12/12), Swaziland (0/20/20), Zimbabwe (0/81/81)
West-Central Africa	Benin (0/31/31), Burkina Faso (0/55/55), Cameroon (0/55/55), Cote d'Ivoire (0/40/40), Democratic Republic of Congo (0/25/25), Gambia (0/15/15), Ghana (13/380/393), Liberia (0/10/10), Mauritania (0/23/23), Niger (0/156/156), Nigeria (11/43/54), Senegal (0/30/30), Sierra Leone (0/10/10), Togo (0/40/40)
Europe	Austria (46/0/46), Belgium (0/10/10), Czech Republic (1/0/1), Denmark (0/5/5), Finland (110/0/110), France (107/55/162), Germany 25/194/219), Greece (0/31/31), Hungary (3/0/3), Italy (163/82/245), Poland (5/0/5), Serbia (48/0/48), Slovenia (15/0/15), Spain (140/3/143), Sweden (60/0/60), Switzerland (0/1/1), Turkey (36/172/208), United Kingdom (20/35/55)
Central-West Asia & North Africa	Armenia (20/83/103), Azerbaijan (0/41/41), Bahrain (0/10/10), Egypt (0/82/82), Georgia (0/23/23), Iran (61/28/89), Israel (1/21/22), Jordan (4/5/9), Kazakhstan (223/18/241), Kyrgyzstan (0/15/15), Oman (0/95/95), Qatar (0/19/19), Saudi Arabia (0/57/57), Tajikistan (0/70/70), Turkmenistan (0/37/37), Tunisia (0/47/47), United Arab Emirates (0/3/3), Uzbekistan (0/56/56)
South-East-Southeast Asia	Afghanistan (0/83/83), Bangladesh (81/270/351), Bhutan (19/84/103), Cambodia (9/349/358), North Korea (0/81/81), Japan (75/281/356), Hong Kong (0/378/378), Indonesia (23/1041/1064), Lao PDR (32/192/224), Myanmar (0/154/154), Malaysia (13/186/199), Mongolia (0/24/24), Nepal (9/34/43), Pakistan (17/433/450), Philippines (129/353/482), Singapore (0/27/27), Sri Lanka (0/373/373)
Australia-Oceania	Australia (118/0/118), Fiji (0/164/164), Guam (0/20/20), Kiribati (0/10/10), Palau (0/8/8), Papua New Guinea (0/26/26), Samoa (0/2/2), Solomon Islands (0/25/25), Tonga (0/6/6), Vanuatu (0/15/15)
North-Central-South America	Belize (0/4/4), Bolivia (0/51/51), Barbados (0/31/31), Canada (19/0/19), El Salvador (0/33/33), Guatemala (219/50/269), Honduras (0/91/91), Mexico (0/52/52), Nicaragua (0/148/148), Panama (0/25/25), Bahamas (0/10/10), Saint Kitts and Nevis (0/25/25), Saint Vincent and the Grenadines (0/20/20), Trinidad and Tobago (4/28/32), Venezuela (0/79/79)

sions (35.4% of total) were shipped to 113 other countries (Table 1). The largest share of germplasm (13,672 samples) went to National Agricultural Research and Extension Systems (NARES), followed by seed companies (9,741), universities (4,558), private individuals (1,611), and non-governmental organizations (NGOs) (398) (Fig. 3).

Given the high consumption of hot pepper in Asian cuisine, high demand for pepper seed owing to the large area under cultivation, and well-developed pepper seed research and development industries, it is understandable why the majority of the top ten recipient countries (7 out of 10) were located in Asia and accounted for about 53% of all *Capsicum* germplasm distributed worldwide. The highest request and supply of seed samples to India (15.6% of the total) can simply be explained by the fact that after liberalization of national seed policy in India during the late 1980s there was a remarkable increase in the number of seed companies (Pray et al., 2001). These seed companies requested and received 64% of the seed samples sent out, which is almost double the average amount of seed samples sent to seed company recipients in other parts of the world (33%; Fig. 3). The presence of Tanzania, the sole country from Africa, among the top ten recipient countries is due to the Center's long presence of more than 20 years in the country.

Most countries preferred to receive AVRDC-developed improved lines. Only the Republic of Korea requested more genebank accessions than improved lines and was the top recipient of genebank accessions (Fig. 2). For The Netherlands, the ratio between the two types of germplasm was almost balanced. A relatively high demand of genebank accessions compared with improved lines in South Korea and The Netherlands may be because both are developed countries with very strong public and/or private pepper breeding programs that can exploit the full potential of germplasm accessions much more effectively than developing countries, which mostly rely on our improved materials. Apart from Korea and The Netherlands, Taiwan (32.3%) and China (25.1%) make relatively large acquisitions of genebank accessions.

USE OF GERMPLASM ACCESSIONS AND IMPROVED LINES

National public and private sector partners have used AVRDC seed materials in various ways. Mostly these lines have been: (i) directly released as open-pollinated varieties through national varietal release procedures, (ii) subjected to selection (in cases of segregating germplasm) according to local trait preferences and subsequently released as new varieties, (iii) used (possibly after further selection) as parental lines in hybrid development, or (iv) used as sources of traits in crosses to develop new breeding lines. Recent attempts to consolidate use of supplied seed samples have revealed that since 2005, 27 germplasm accessions (9) or improved lines (18) supplied by AVRDC have been released as open pollinated varieties for commercial cultivation after further evaluation by the NARES in seven countries. This included 15 hot pepper, 11 sweet pepper and one paprika cultivar (Table 2). In addition, 24 improved lines were used, mostly by private seed companies, as parents in the development of commercial hybrids. All in all, a total of over 51 lines (including several duplicate releases in different countries) were put into commercial use in 12 different countries of Asia and Africa (Fig. 4).

South Asia

In South Asia, the highest number of released and commercialized hybrids (based on AVRDC parents) were in India (13) followed by Sri Lanka and Bangladesh (Tables 2 and 3; Fig. 4). The vegetable breeders of the Indian Council of Agricultural Research (ICAR), New Delhi, have used AVRDC's cytoplasmic male sterility (CMS) hot pepper lines to study genetics and distribution of restoration-of-fertility (*Rf*) locus associated markers, hybrid development (Kumar et al., 2007) and the genetic relationship between two independently isolated commercialized male sterile cytoplasms (Kumar et al., 2009). Kashi Anmol, an open pollinated hot pepper variety, became popular in the Indo-Gangetic Plains for green fruit production because of its earliness, short duration and attractive fruit quality. This success has been attributed mainly to the availability of seed through continuous breeder seed production by the Indian Institute of Vegetable Research, Varanasi and truthfully labeled seeds produced by nascent seed companies and also by farmers themselves. Private seed companies in India use hot pepper CMS lines either for commercial hybrid development and cost-effective seed production, or for converting CMS lines into more desirable and preferred genetic backgrounds. For example, VNR Seeds Ltd., India, started using AVRDC's improved hot pepper lines in early 2000, and the company recently commercialized six hot pepper hybrids that possess parental inbred lines from AVRDC. One of these hybrids, 'Rani' (VNR332), was released in 2012 on the basis of its better performance in multi-location trials (2006-2008) conducted under ICAR's All Indian Coordinated Vegetable Improvement Project. Based on marketed seed of 'Rani' it is estimated that this hybrid variety alone has a cultivated area of about 3,000 hectares in India (Fig. 5). Seed companies use AVRDC's improved lines to develop inbred lines for use in commercial hybrids (Table 3). They have directly used our CMS and restorer lines to produce hybrid seed for commercial hybrids (Fig. 6). It is worthwhile noting that use of CMS lines brings down the cost of hybrid seed production by at least 40% compared with hybrid seed production through manual emasculation and pollination. This cost saving is mainly due to manual emasculation, which requires skilled agricultural laborers. However, skilled labor is more and more difficult to find in India due to migration of laborers to other sectors with higher remuneration like infrastructure development.

Figure 4. Number of open-pollinated released and commercialized hybrids in different countries since 2005.

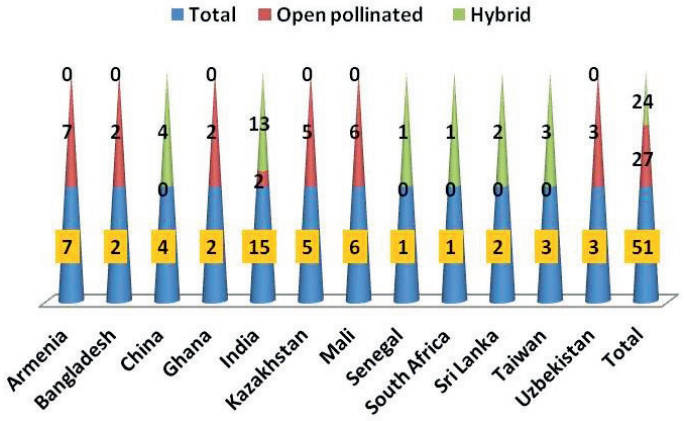


Figure 5. VNR-332 ('Rani'), a notified commercial hot pepper hybrid (3000 ha in 2012) in India developed from male parent from AVRDC.

Table 2. Open pollinated (OP) varieties released based on AVRDC germplasm and improved lines since 2005.

VRDC code for accession / improved lines	Locally released / commercialized name	Country	Year of release	Salient known features recorded in the country, where released
Hot (chili) peppers				
AVPP0305 (0337-7546)	Gita	Armenia	2010	Fruits are elongated (pointed end), green → red, 10.7 x 1.7 cm (size), 10 g average weight. Yield potential 28 t/ha. Appropriate for growing in an open field and greenhouses.
VI014204 (C02408 or PBC203)	Zspanak	Armenia	2010	Average fruit weight 27 g. Yield potential 25-28 t/ha. Good transportability and proceeding quality.
VI037591 (C05670 or PBC613)	Kon	Armenia	2011	Fruits are big elongated, green → red, 6.0 x 0.8 cm (size), 1.6 g average fruit weight, tolerant to anthracnose. Yield potential 24 t/ha.
VI013538 (PI124540 or C01803)	Punj	Armenia	2012	Fruits are elongated (pointed at the distal end), green → red, 12 x 0.8 cm (size), 3 g average fruit weight.
VI046912 (PBC462)	Bangla Lanka-1	Bangladesh	2005	Plants are bushy with profuse fruiting. Fruits are conical (blunt or sunken at distal end), green → red, 7.2 x 1.3 cm (size), 6.5 g average fruit weight.
VI046912 (PBC462)	CRI-Shito-Adope	Ghana	2005	Plants are bushy with profuse fruiting. Fruits are conical (blunt or sunken at distal end), green → red, 7.2 x 1.3 cm (size), 6.5 g average weight.
AVPP9813 (Terry's Joy)	CRI-Mako-Ntoos	Ghana	2005	Heat tolerant with compact plants. Fruits are elongate (pointed end), green → red, 9.0 x 1.7 cm (size), 10 g average weight. Yield potential 25 t/ha. Good transportability and proceeding quality.
VI037808 (PBC460)	Kashi Anmol	India	2005	Bushy plants with profuse fruiting. Fruits are compact, green → red, 6.0 x 1.0 cm (size), average fruit weight 6 g. Yield potential 20 t/ha.
AVPP0105 (PP0107-7058/ ICPN15#09)	Piquant	Kazakhstan	2010	Fruits are elongate (pointed end), green → red, 12 x 2 cm (size), 12 g average weight. Yield potential 14.5 t/ha. Good transportability and proceeding quality; resistant to CVMV and PVY.
AVPP0303 (PP0337-7069)	Erekshe	Kazakhstan	2012	Fruits are elongate (pointed end), green → dark red, 16.8 x 2.4 cm (size), 30 g average weight. Yield potential 21 t/ha.
AVPP0105 (PP9950-5177)	Nafama	Mali	2011	Fruits are elongate (pointed end), green → red, 12 x 2 cm (size), 12 g average weight. Yield potential 14.5 t/ha. Good transportability and proceeding quality; resistant to CVMV and PVY.
AVPP9905 (Susan's Joy)	Nisondia	Mali	2011	Fruits are elongated and mild pungent, yellowish → red, 15.5 x 2.6 cm (size), 29 g average weight. Yield potential 25 t/ha. Resistant to PVY.
AVPP0002 (PP0007-2244)	Bafarima	Mali	2011	Fruits are elongated, 8 x 0.8 cm (size), green dark red, very pungent. Yield potential 10 t/ha. Tolerant to high humidity.
AVPP0303 (PP0337-7069)	Uchkun	Uzbekistan	2009	Fruits are elongate (pointed end), green → dark red, 16.8 x 2.4 cm (size), 30 g average weight. Yield potential 21 t/ha.
AVPP9905 (Susan's Joy)	Tillarang	Uzbekistan	2010	Fruits are elongated and mild pungent, yellowish → red, 15.5 x 2.6 cm (size), 29 g average weight. Yield potential 27 t/ha. Resistant to PVY.
Sweet pepper				
AVPP0112 (0137-7025)	Natali	Armenia	2010	Fruits are conical (pointed end), green → yellow / orange, 7.9 x 5.3 cm (size), 100 g average weight. Yield potential 57 t/ha.
VI046956 (PBC271)	Mili	Armenia	2012	Late ripening (123 days). Fruits are red and rectangular, 9.0 x 7.0 cm (size), 100 g average weight. Yield potential 55 t/ha.
AVPP0114 (0137-7041 or ISPN5#8)	Emili	Armenia	2011	Fruits are blocky (sunken end), green → yellow, 6.7 x 6.5 (size), 160 g average weight. Yield potential 54.6 t/ha.
AVPP0408 (0437-7031 or ISPN9#2)	BARI Misti Mirich 1	Bangladesh	2005	Fruits are blocky (shaken end), yellowish → light yellow, 7 x 2 cm (size), 110 g average weight. Yield potential 25 t /ha.
VI046956 (PBC762 or PI659102)	Kaz-Tai	Kazakhstan	2010	Fruits are conical (blunt end), green → red, 14.0 x 5.5 cm (size), 125 g average weight. Yield potential 22.0 t/ha.
AVPP0119 (PP0037-7645)	Bayan Sulu	Kazakhstan	2010	Fruits are blocky (blunt end), green → yellow, 9 x 9 cm (size), 150 g average weight. Yield potential 30 t/ha.
AVPP0204 (0237-7011)	Kozy-Korpesh	Kazakhstan	2012	Fruits are conical (blunt end), green → red, 12.6 x 6.8 cm (size), 135 g average weight. Yield potential 22.0 t/ha.
AVPP0301 (ISPN6#5 or PP0337-7018)	Wassa	Mali	2011	Fruits are conical (blunt end), green → red, 10.3 x 7.0 cm (size), 140 g average weight. Yield potential 20 t/ha.
AVPP0416 (PP0437-7047)	Seguifa	Mali	2011	Fruits are blocky, green → red, 9.2 x 7.2 cm (size), 140 g average weight. Yield potential 35 t /ha.
AVPP0417 (PP0437-7005)	Poivron Jan	Mali	2011	Fruits are elongated, green → red, 10.3 x 5.6 cm (size), 100 g average weight, yield potential 40 t/ha.
AVPP0408 (0437-7031)	Sabo	Uzbekistan		Fruits are blocky (shaken end), yellowish → light yellow, 7 x 2 cm (size), 110 g average weight. Yield potential 25 t/ha.
Paprika				
VI037556 (PBC535)	Kashi Sinduri	India	2009	Fruits are green-dark red, 12 x 1.5 cm (size), very little pungent (0.002% capsaicin) with high oleoresin. Yield potential 25 t/ha. Resistant to bacterial wilt, CVMV and PVY.

Note: Immature fruit color → mature fruit color; yield potential (fresh ripe fruits); CVMV = *Chili venial mosaic virus*; PVY = *Potato virus Y*.

Central Asia and the Caucasus

Out of 243 samples of pepper genebank accessions and 83 samples of breeding lines distributed to eight countries in Central Asia and the Caucasus, 8 hot pepper and 7 sweet pepper cultivars have been locally released after extensive field trials conducted in Armenia, Kazakhstan and Uzbekistan (Table 2; Fig. 4). Among the released varieties, four hot pepper cultivars and two sweet pepper cultivars were derived from genebank accessions (Table 2). These new varieties possess unique, marketable, valuable traits (high yield, fruit quality and processing quality), and have provided opportunities for farmers to obtain higher farmgate prices. For example, 'Kaz-Tai' and 'Bayan Sulu' are now cultivated successfully in greenhouses in Kazakhstan during the cool autumn, winter and early spring seasons (Fig. 7). In Uzbekistan, farmers have adopted high yielding varieties such as 'Tillarang' (Fig. 8). Seeds of these released varieties are being produced by the Kazakh Research Institute of Potato and Vegetable Growing and the Uzbek Research Institute of Plant Industry and quality seeds are supplied to farmers. These varieties are widely cultivated by farmers and the private sector to meet fresh market demand and to supply the processing industry.

Table 3. Hot pepper hybrids developed and commercialized since 2005 by public institutes and private seed companies*.

Name of hybrid	Developed by	Country of release / commercialization
Kashi Surkh	Indian Institute of Vegetable Research, India	India
Arka Sweta, Arka Hybrid	India Institute of Horticulture Research, India	India
F_1 Hybrid Coral, F_1 Hybrid Dara	Clover Seeds, Hong Kong	China
VNR38, VNR108, VNR174, VNR200, VNR332	VNR Seeds, India	India
F_1 Forever	Tropicasem, Senegal	Many SSA countries
Remington, F_1	Alpha Seeds, South Africa	Many SSA countries
F_1 TSS AVRDC No.4	Suntech Seeds, Taiwan	Taiwan
F_1 TSS AVRDC No.2	Yung Shan Seeds, Taiwan	Taiwan
F_1 Hsing AVRDC No.3 (sweet pepper)	Suntech Seeds, Taiwan	Taiwan
Yun Pepper No.2	Horticulture Research Institute, YAAS, China	China
Yun High Pungency No.1	Horticulture Research Institute, YAAS, China	China
Ulka F_1, Masaya 315, Yuvraj IN	East-West Seeds, India	India
Super F_1, Muria F_1	East-West Seeds, Thailand	Sri Lanka
Hybrid	Indus Seeds, India	India

* Namdhari Seeds in India has used AVRDC lines in four commercial hybrids.
SSA = Sub Saharan Africa.

West Africa

A total of 8 pepper varieties have been catalogued in Mali and one hybrid has been commercialized by a private seed company based in Senegal (Tables 2 and 3; Fig. 4). AVRDC Mali has successfully promoted three hot pepper lines (AVPP9905, AVPP0002, AVPP0105) of *C. annuum* in West Africa, where low productive genotypes of *C. chinense* and *C. frutescens* are also cultivated. The promotion strategy was based on field visits, farmer participatory variety selection, on-farm discussion sessions with producers, sensory quality testing and organization of demand-creation fairs to enhance technology delivery (Fig. 9). The combined efforts successfully raised awareness about high yielding, more nutritious *C. annuum* hot pepper lines among smallholder farmers in Mali, who are requesting additional seed for planting. High quality seed must be available for farmers if these lines are to achieve their full potential for higher incomes and nutrition security (Afari-Sefa et al., 2012). Considering these facts and thanks to the support of the United States Agency for International Development (USAID), AVRDC staff have trained seed producers in the Sikasso region of Mali, who are now multiplying certified seed of released pepper varieties such as Nisonda, Bafarima, Nafama, Poivron and Wassa. In order to develop professional seed businesses, AVRDC has engaged Faso Kaba, a local seed company, to establish seed production contracts with these seed producers.

FEEDBACK & LESSONS LEARNED

The success of any breeding program is highly dependent on continuous operational breeding activities, as well as on receiving continuous performance feedback from different actors in the seed and crop production value chain,

Figure 6. Hot pepper hybrid seed production using AVRDC's CMS line (left) and CMS based hybrid crop (right) at the farmer's field: an example from India.

Figure 7. Commercial production of 'Bayan Sulu' (left) and 'Kaz-Tai' (right) sweet peppers in greenhouse, Kazakhstan.

including seed recipients and end-users. One of our strategies to disseminate improved pepper lines has been through the distribution of sets of the International Chili Pepper Nursery (ICPN) and the International Sweet Pepper Nursery (ISPN). 22 ICPN and 11 ISPN nurseries have been released, which included 142 newly developed improved chili (77) and sweet pepper (65) lines. From 2001 to 2011, a total of 1,039 sets of ICPNs (513) and ISPNs (526) were distributed to cooperators around the world. However, only 12% (127) of the recipients sent AVRDC feedback on field performance, which has been an area of concern. Likewise, lack of either positive or negative feedback on the use of other seed samples such as CMS and resistant breeding/germplasm lines are also of concern because (i) it is difficult to satisfy the need of donor communities on the use of the supplied seed samples and (ii) it might result in failure to appropriately adapt breeding activities to the needs of the collaborators and partners in different countries.

Poor feedback from collaborating partners in most cases is understandable, as often the recipients in developing and less developed countries do not have access to infrastructure and facilities to properly conduct trials. Another reason for limited use of the supplied materials could be attributed to limitations of human resources and the capacity to utilize the full potential of supplied seed. This is in contrast to the Indian seed industry, which was in a better position to exploit the potential of AVRDC's germplasm accessions and improved lines.

FUTURE BREEDING THRUST

We are currently revisiting our anthracnose and begomovirus resistance sources and some of the breeding populations derived from previously identified resistant sources. We have learned from seed distribution experiences that a major multiplying impact of our improved lines can been achieved in developing countries when people working in both public and private sectors have enhanced skills, for example, in India. Capacity building of human resources will remain a cornerstone of our strategy to harness a larger impact for the Center's bred pepper lines.

POTENTIAL *CAPSICUM* EXPLORATION

Out of the five cultivated *Capsicum* species, *C. chinense* and *C. pubescens* are poorly represented in international ex situ collections and require additional collection and conservation efforts. Many wild *Capsicum* species, such as *C. rhomboideum, C. flexuosum*, and *C. lanceolatum*, are hardly found in ex situ collections. This applies also to *C. annuum* var. *glabriusculum*, the putative wild ancestor of *C. annuum* (Kraft et al., 2013). The east Himalayan region (Bhutan, north Bangladesh, northeast India, east Nepal) has long been known as a hot spot of hot pepper biodiversity. This region has received renewed attention in the past decade due to the discovery of the world's hottest pep-

Figure 8. Mr. Vahhobov, an Uzbek farmer with a good crop from hot pepper 'Tillarang'.

Figure 9. Participatory pepper varietal selection by women growers in Mali.

pers and the occurrence of natural inter-specific derivative landraces believed to have originated in the region from sympatric domesticated species (Rai et al., 2013). In the post-Colombian era of *Capsicum* discovery, for the first time, a naturally occurring allotetraploid pepper has been discovered in the region (Jha et al., 2012). It would be worthwhile conducting a regional exploration for *Capsicum*-specific germplasm that recognizes the role of local communities in conserving these genetic resources before they become extinct due to agricultural intensification.

Acknowledgements

The authors thank the international donor community for its continuous support of the Center's research for development. Thanks also to the national public and private partners for sharing information on the use of AVRDC's pepper germplasm.

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