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Review

Overview of pepper (*Capsicum* spp.) breeding in West Africa

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The genus *Capsicum* (sweet and hot pepper) harbors an incredible intra and inter-specific diversity in fruit type, color, shape, taste, and biochemical content. Its potential uses and benefits to mankind cover many areas such as food and nutrition, medicine, cosmetic, plant based insecticides (PBI), and income. The cash income potential combined with the fact that peppers are easy to grow, harvest, and process makes them suitable for use in poverty reduction and food security improvement programs. Efforts were made in West Africa to improve peppers in terms of germplasm collection and conservation, variety introduction and testing, but due to the wide genetic diversity within and between species and inter-specific crossings, there is still room for further improvement of yield and fruit quality. However, to better exploit the various potentials of peppers, there is need to promote improved varieties and improve seed systems through enhanced public/private partnership.

Key words: *Capsicum*, pepper varieties, fruit morphotypes, capsaicin, seed systems.

INTRODUCTION

Peppers (hot and sweet) belong to the Solanaceae family, genus *Capsicum* (Greenleaf, 1986). This genus originated from Central and South America (Grubben and El Tahir, 2004) and comprises about 30 species, of which, five domesticated that comprise *Capsicum annuum L.* (hot and sweet peppers), *Capsicum frutescens* L. or bird pepper, *Capsicum chinense* Jacq. or aromatic chili pepper, *Capsicum baccatum* L. (aji), and *Capsicum pubescens* Ruiz and Pav. (rocoto). The first three species are the most cultivated in both tropical and temperate zones. *C. annuum* often forms a complex with *C. frutescens* and *C. chinense*. In Africa, they are generally considered together as *C. annuum* L (Grubben and El Tahir, 2004).

In this review paper, the morphologic and genetic diversity of *Capsicum* sp. peppers are highlighted as well as their potential uses. Also highlighted are the efforts deployed by the private sector, national and international agricultural research institutions in breeding, germplasm collection and management, and the perspectives for

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further improvement in West Africa.

GERMPLASM COLLECTION AND CHARACTERIZATION

Gene banks of *Capsicum* species are available throughout the world. The USDA has established a pepper gene bank from accessions collected worldwide. AVRDC-The World Vegetable Center has collections in Bamako (Mali), Arusha (Tanzania), and in Shanhua (Taiwan). Gene bank collections available in West Africa also include that of the Nigerian National Horticultural Research Institute in Ibadan. The Brazilian *Capsicum* sp gene bank maintained at the "Universidade Estadual do Norte Fluminense" is a good source of *C. chinense and C. frutescens* accessions. Private seed companies in Asia and North America have developed sets of pepper varieties and may provide small samples for testing. West African agro-dealers and seed companies offer adapted pepper varieties obtained from national and/or international research institutions and from private sector agricultural organizations located in the sub region and abroad. Activities conducted with West African collections include characterization of morphologic diversity and/or genetic diversity using molecular markers and field evaluations to identify gene sources for yield improvement (Adetula, 2006; Adetula and Olakojo, 2006).

USEFULNESS AND DIVERSITY OF MORPHOLOGIC DESCRIPTORS

Numerous identifiable and measurable morphologic descriptors are used for germplasm characterization and/or evaluation (IPGRI, 1995). They are related to the seedling, plant and stem, the inflorescence, the fruits, or to the seeds and are more or less species specific. Some descriptors are often considered as useful for assignment of accessions to species of the genus. Hence, Baral and Bosland (2004) used morphologic descriptors to verify species assignment at the germplasm repository for the *C. chinense* and *C. frutescens* accessions they studied. Using discriminant analysis, their study confirmed the usefulness of morphological descriptors in species classification, though not for all descriptors, but only two (calyx constriction and flower position). Fonseca et al. (2008) also assigned successfully 100% of the *C. chinense* accessions they studied to their corresponding species at the germplasm repository using mainly inflorescence characters. More recently, these results were confirmed by Ortiz et al. (2010) who reported the efficacy of inflorescence descriptors and seed color to reliably distinguish among *Capsicum* species. Using about 90 chili accessions, these authors reported up to three flowers/node and calyx constriction in *C. chinense* accessions, single white flowers/node and white filaments in *C. annuum*, greenish corolla and purple filaments in *C. frutescens*, purple flowers and black seeds in *C. pubescens*, and corolla spots only in *C. baccatum*. Ortiz et al. (2010) highlighted also the usefulness of qualitative descriptors for assessing genetic diversity between species and of quantitative descriptors for assessing genetic diversity within species.

Large variation in the morphological descriptors used for germplasm characterization and evaluation, and assignment of accessions to species of the genus has been reported. Fonseca et al. (2008) evaluated 38 *C. chinense* accessions from Brazil for 51 characters and found significant genetic variation for all characters except only for eight traits (leaf shape, corolla color and shape, calyx pigmentation, annular constriction of the calyx, days to fructification, duration of fructification and seed color). Lannes et al. (2007) highlighted also the large variation of *C. chinense* in fruit color and shape. Large variation in qualitative and quantitative descriptors was reported also by Idowu-Agida et al. (2012). Worth noting is the fact that the subjectivity and difficulty of measurement of qualitative descriptors and the influence of environment on quantitative descriptors are impediments to their use for genetic diversity assessment.

CHARACTERISTICS OF PEPPER FARMS AND PRODUCTION SYSTEMS

The majority of pepper and other vegetable fields in most West African countries (Mali, Burkina Faso, Chad, Guinea, Niger and Senegal) are located in rural areas and exploited mainly by male smallholder farmers (AVRDC, 2008). Women are the main marketers, processers, buyers, and users (Yaméogo et al., 2002). As for other vegetables, farm size ranges from one or more plots of a few squared meters to less than 1 ha (USAID/Guinea, 2006; AVRDC, 2008). The crop may be produced in single stands or intercropped with staple crops or other vegetables, sometimes even with other crops of the Solanaceae family. In urban and periurban settings, peppers and other vegetables are produced to provide nearby city dwellers with fresh produces and growers and marketers with cash income. Farm labor is provided mostly by family members in rural areas, and family members plus paid personnel in the urban and periurban settings. Seed supply is through the private sector, National Agricultural Research and Extension Systems (NARES) or farmers' own saved seeds. The public/private sector partnership involving NARES and/or International Agricultural Research Institutions is very limited. Conventional production methods in open fields are commonly practiced. Although there is an increasing awareness of farmers and consumers in the health and environmental consequences related to the abusive use of chemical inputs, farmers have little interest in organic

Table 1. Profile of a preferred chili pepper variety in Mali according to various stakeholders involved in vegetable value-chain.

	Characters	Most preferred attributes
Standing plant	Number of fruits/plant	Large
	Disease resistance	Viruses Bacterial spot Bacterial wilt
Fresh fruit	Fruit size	Small – big fruits
	Shelf-life	> 3 days
	Firmness	Medium - high
	Wall thickness	Medium - high
Dry fruit	Resistance to breakage	High
	Resistance to transport	High
Fresh and dry fruit	Pungency	Low - high
	Aroma	Low - strong
	Taste	Medium good - very good

Source AVRDC – The World Vegetable Center/Mali, 2010.

farming perhaps due to the lack of resistant varieties to the main biotic constraints, and lack of access to organic markets and regulatory mechanisms.

POPULAR VARIETIES AND CROP PROFILE

There are many local cultivars grown in West Africa. Nigeria alone has more than 200 selections of pepper (Idowu-Agida et al., 2012). The literature regarding other countries is rather limited. However, it is generally recognized that the species *C. annuum sensus stricto* is popular in other West African countries, while almost unknown to Malian consumers who by far preferred the bird pepper *C. frutescens* and the aromatic pepper *C. chinense*. However, since 2008, Malian stakeholders are gaining more and more interest in *C. annuum sensus stricto* as a result of the efforts of the Vegetable Breeding and Seed Systems for the sub-Saharan Africa Project (vBSS) and partners in introducing, testing, promoting, and disseminating this type of pepper (Afari-Sefa et al., 2012). Popular varieties in the sub-region include among others Legon 18, Gbatakin, Bird's eye, Safi, Cayenne, and Jaune du Burkina for hot pepper and Yolo wonder, California wonder, and Morti (Diffa) for sweet pepper.

The pepper crop profile (quality requirements) has been investigated in Mali using participatory variety selection and organoleptic tests, where the quality requirements for chili in that country have been related not only to field appearance of the standing plants and post-harvest quality (Table 1), but also organoleptic quality (data not shown). Further, varieties that have scored high for field appearance may score low for organoleptic quality, indicating the need to select simultaneously for both traits (Dagnoko and Gniffke, unpublished). Another important quality requirement often neglected and none verified is the absence or low content of aflatoxin in the dried whole products and/or powder. Aflatoxin is a pathogenic compound that occurs in the fruits as a result of contamination by the fungus *Aspergillus flavus* Link. However, the extent of pepper contamination in most countries is poorly known and needs exploring for West African pepper products to be competitive in both local and external markets.

MAIN BIOTIC CONSTRAINTS

Peppers are usually considered a robust crop compared with tomatoes and chili pepper is more robust than sweet pepper. However, both peppers are susceptible to a number of pests and pathogens causing considerable economic losses.

The most economically important pests to peppers in West Africa are thrips (*Frankliniella* sp) feeding on the leaves, flowers or fruits; aphids (*Myzus persicae* Sulzer, *Aphis* ssp, and *Macrosiphum euphorbiae* Thomas) feeding on young leaves and shootss; whitefly (*Bemisia tabaci* Gennadius) feeding on the leaves, root knot nematodes (*Meloidogyne* spp) feeding on the roots, the Mediterranean fruit fly [*Ceratitis capitata* (Wiedemann)] feeding on the fruit flesh, red spider mites (*Tetranychus* spp) feeding on the leaves, and fruit borers (*Lepidopterae* spp). In addition to damages caused to the plants by direct feeding, some pests such as nematodes, whiteflies, aphids and thrips are vectors of viruses.

Peppers are susceptible to pathogens such as bacteria, fungi, and viruses. The most economically important pepper bacterial diseases are bacterial wilt [*Ralstonia solanacearum (Smith*)], bacterial leaf spot [*Xanthomonas campestris,* var vesicatoria (Doidge)], and bacterial soft rot [*Erwinia carotovora* (Smith)]. Most threatening fungi for peppers in West Africa are *Phytophthora* root rot, Southern blight [*Sclerotium rolfsii* (Sacc)], and anthracnose [*Colletotrichum capsici* (Syd) E.J. Butler and Bisby)]. About 35 viruses are known to infect peppers worldwide (Green and Kim, 1994). Among viruses, 11 were reported in Africa out of which Pepper Veinal Mottle Virus (PVMV) and Tomato Yellow Leaf Curl Virus (TYLCV) are the most economically important and the most widespread in the Western Africa sub-region (Dafalla, 2001). The latter is restricted to semi-arid and arid zones. Detailed information on economically important biotic stresses of peppers and other vegetables in West Africa, their biological control methods and integrated pest management strategies are provided by James et al. (2010).

ABIOTIC CONSTRAINTS

Abiotic constraints pertaining to the climate (drought, flooding, strong winds, extreme temperature and sun light) and to the soil (moisture and nutrients content) may add up to biotic constraints and lead plants to stress and undergo anatomical and physiological disorders that reduce yield (Jackson, 1986). One of the most common physiological disorders of pepper is blossom-end rot, a calcium deficiency disorder that appears only at the blossom end of the fruit (Hochmuth and Hochmuth, 2009). The threat of abiotic constraints is getting increasingly alarming as a result of population growth and climate change with expected greater adverse effects in vulnerable regions such as semi-arid West and Central Africa. The use of adapted varieties combined with careful crop management practices notably the control of root damaging factors and proper irrigation and nitrogen fertilization help control the effects of abiotic constraints (Hochmuth and Hochmuth, 2009).

YIELD POTENTIAL OF EXOTIC AND LOCAL VARIETIES

Chili pepper may yield up to 18 t/ha and sweet pepper up to 30 t/ha in open-fields (Grubben and El Tahir, 2004).Yields greater than 20 t/ha have been reported for introduced *C. annuum* chili varieties grown on-station in Mali (AVRDC/Mali, unpublished). Identifying varieties with high yield potential is important to breeders, growers, and seed producers in the sub-region. From 2005 through 2010, multi-location trials involving 39 entries of exotic and local varieties were conducted jointly by the National Agricultural Research Systems of six West African countries (Benin, Burkina Faso, Chad, Gambia, Niger, and Togo) and the AVRDC. The World Vegetable Center's sub-regional office in Mali, hence, bringing at seven the number of test countries. Results indicated country yield range of 0.14 to 21.91 t/ha and a mean sub-regional yield of 6.78 t/ha, the highest yield of 14 t/ha being observed in Niger (Table 2). In the FAOStat (2012) estimates, the highest pepper yield of the sub-region was also observed in Niger (9.25 t/ha) followed by Nigeria (8.33 t/ha). Compared to the mean chili and green pepper yield of the world (14.82 t/ha) (FAOStat, 2012) and the yield potentials reported by Grubben and El Tahir (2004) and AVRDC/Mali (unpublished), this regional mean yield is low, suggesting that further improvement of pepper yield in West Africa is needed. Improvement of pepper yield in West Africa can be achieved by introducing and evaluating more exotic varieties in multi-location trials. Since yield is dependent on the genetic background of the plant and the environment, focus should be on varieties with moderate to high tolerance to the prevailing environmental conditions such as high temperatures, viruses, bacterial wilt and *Phytophthora* spp., etc. Also required for reducing the pepper yield gap in West Africa is promotion and adoption of best cultural practices.

CAPSAICIN AND ITS POTENTIAL IN NUTRITION AND HEALTH

Capsaicin (C18H27NO3) is an alkaloid compound believed to be found only in peppers. It is responsible of their characteristic hot taste or pungency. The level of hotness depends on the concentration of capsaicin in the fruit and is variable between species, among varieties within species, among plants within varieties, among fruits of the same plant, and among different parts of the same fruit. *C. chinense* species is traditionally reported to contain the hottest cultivars (Canton-Flick et al., 2008). The placenta tissues and seeds of Habanero pepper (*C. chinense*) are reported to contain most of the capsaicin with 62 and 37%, respectively (González et al., 2004). Sweet pepper has no hot taste as capsaicin is controlled by a single dominant gene and this pepper is recessive for this gene. Capsaicin content is traditionally measured by organoleptic tests involving preferably a panel of non-addicted consumers. Today, high-performance liquid chromatography (HPLC) and enzyme imunoassay (EIA) tests are used to more precisely measure capsaicin content (Guthrie et al., 2004; Canton-Flick et al., 2008). Capsaicin benefits include anti-carcinogenic (American Association for Cancer Research, 2009), anti-oxidant, anti-mutagenic, immunosuppressive, hypocholesterolaemic, and bacterial growth inhibition effects (Grubben and El Tahir, 2004). In traditional medicine, chili pepper is used to ease digestion, stimulate the gut, combat constipation, and relieve pain. Capsaicin may have also a potential role in the development of pain-killing agents (Patwardhan et al., 2010).

Table 2. Minimum, maximum and average yield [t/ha] of chili pepper evaluated in seven countries of West Africa from 2005 through 2010.

Country	Trial period RS (rainy season) DS (dry season)	# Entries	Chili pepper total yield [t/ha]			
			Minimum	Maximum	Average	Coefficient of variation %
Benin	RS 2005	8	1.08	20	10.1	20.6
Burkina Faso	RS 2005	9	5.08	14.61	9.59	15.9
	DS 2005-2006	11	2.13	11.67	5.49	31.1
Chad	RS 2005	6	1.75	3.87	2.95	31.2
Gambia	RS 2005	7	1.46	6.52	3.67	56.8
Niger	DS 2005 - 2006	3	9.17	19.53	14	34.2
Togo	RS 2005	8	1.08	11.8	5.35	41
	DS 2005 -2006	8	3.81	9.93	6.8	27.4
Mali	RS 2005 DS 2006	15	2.43	11.36	5.3	32
	RS 2008	20	6.9	9.88	7.9	39.4
	RS 2009	8	2.42	5.02	4.12	19.7
	DS 2009-2010	10	8.69	21.91	12.43	13.01
	DS 2009-2010	10	0.14	0.73	0.38	38.2
Across all countries [t/ha]						
Minimum			0.14	0.73	0.38	
Maximum			9.17	21.91	14	
Mean			3.55	11.29	6.78	

Data source: AVRDC – The World Vegetable Center.

Peppers are also good sources of nutrients - Vitamins A, C, K, and B6, calcium, iron, zinc, and fiber. The nutrient and other phytochemical composition of peppers vary with color and/or maturity stage (Deepa et al., 2007). Given the wide variability in capsaicin and nutrient content of peppers, more breeding can be undertaken for improvement. Since peppers are easy to grow, harvest, process and utilize, efforts should be undertaken by extension workers, nutrition and health promoting specialists to disseminate and promote improved varieties.

BIOPESTICIDE POTENTIAL OF *CAPSICUM* SPECIES

Although the use of plant based insecticides (PBI) to control insect pests prior to and after harvest has been practiced for many centuries (Jacobson, 1958, 1975), it was rather limited in potential and ignored (Oparaeke et al., 2005). Nowadays, PBIs are gaining more and more interest in IPM strategies worldwide as a means to promote agricultural production, environment sustainability, and human health. In this regard, the biopesticide potential of *Capsicum* spp. to control insects feeding on diverse parts of various plants has been widely explored. Bouchelta et al. (2003, 2005) reported a toxic effect of pepper extracts on eggs and adults of the *tabaci* whitefly infesting solanaceous crops. Oparaeke et al. (2005) reported a reduced number of thrips, pod borers, and pod suckers on cowpea after treatment with chili pepper based extracts. Prior to these studies, other authors have reported a repellent effect of pepper extracts on the grain borer *Rhyzopertha dominica* (L.) (El-Lakwah et al., 1997) and the cowpea bruchids *Callosobruchus maculatus* (F.) (Onu and Aliyu, 1995). The toxicity of *Capsicum* spp on insects is thought to be the effects of secondary metabolites including alkaloids, saponins and flavonoid compounds of this plant (Bouchelta et al., 2005). The efficacy of these toxic compounds may be enhanced by combining chili pepper extracts with extracts from other plants such as cashew nutshell and garlic bulb to create a synergistic effect between their respective toxic compounds (Oparaeke et al., 2005). Worth mentioning is that chili extracts have been used by some authors in small quantity (2% compared with 10% for other botanical species) perhaps due to its potential phytotoxicity. Yepsen (1976) suggested a rate of only two teaspoonfuls per 4 L of water. Adding a small level of soap to a solution of PBI may help it adhere to the plant upon spraying. Advantages of using chili pepper extract in pest control in West Africa encompass availability and affordability in most local markets, environmental safety, safety on human health, and ease of use. However, more research is needed before the commercial use of chili extracts as bio-pesticides can be feasible. Such studies should focus on the development of synergistic combinations of PBIs with chili extracts, identification of susceptible insects, and quantification of the toxicity levels, and efficient spray time and frequency, etc.

ECONOMIC IMPORTANCE AND POTENTIAL IN POVERTY REDUCTION

The world fresh chili and sweet pepper production was 27.6 million tons in 2010, to which West Africa contributed 888,400 tons or 3.2%. The biggest West African contributors are Nigeria and Ghana that ranked 8th and 13th, respectively (FAOStat, 2012). The vast majority of West Africa's pepper is sold in local or regional (Senegal, Gambia, Liberia, Sierra Leone and Mali), and international markets (Europe and North America). The crop therefore constitutes a source of income for resource poor households in rural, periurban and urban areas. Women are the main processors, traders, buyers, and users in West African cuisine. They can benefits from the cash income potential of chili pepper. There are some *C. annuum* chili varieties that have high fruit yield, many fruits/plants, and attractive fruit color and shape, and that are easy to grow and harvest. They are suitable for use in poverty reduction programs targeting resource poor households, including women in developing countries.

CONCLUSIONS AND PERSPECTIVES FOR FURTHER IMPROVEMENT

Breeding programs in West Africa have focused on pungent types of the *C. annuum* - *C. chinense* -*C. frutescens* complex, perhaps due to their large adaptation as compared with *C. annuum* sweet pepper. Both types of peppers hold tremendous potential in the sub-region in terms of health and nutrition improvement and poverty reduction. Although progress has been made in terms of germplasm collection and characterization, variety introduction and testing, there is still room for further fruit yield and quality improvement of both chili and sweet pepper especially in the face of climate change. The great genetic diversity in the *C. annum* - *C. frutescens* - *C. chinense* complex and possibilities of inter-crossing between species of this complex offer potential for genetic improvement of the crop. Such improvement should focus on agronomically important traits such as disease resistance, yield, persistence of the mature fruits on the pedicel (it determines fruit resistance to winds under open field cultivation), and heat tolerance for sweet pepper. Other characters to consider in breeding programs would be fruit market value adding traits such as longer shelf-life and wall thickness (both desirable for transport over long distances and storage of fresh and dried fruits, respectively). Taste and visual appeal are important issues to consider as preferences vary among consumers between and within communities. Fortunately, the great diversity in fruit characters offers opportunity for breeders to collect, characterize, evaluate, and to select *Capsicum* spp. varieties with different fruit characters. Another area for pepper improvement in West Africa is large-scale dissemination and promotion of improved varieties. To that end, efforts are needed from extension workers, National and non-government organizations, nutrition and health promoting specialists and agro-dealers for seed availability to growers through a dynamic public/private sector partnership.

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