Morphologic Variation for Fruit Characteristics in the USDA/ARS *Capsicum baccatum* L. Germplasm Collection

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Abstract. Mature fruit of 295 accessions of *Capsicum baccatum* from the USDA/ARS *Capsicum* germplasm collection were characterized for fruit length, width, weight, and color. Mean fruit weight was determined to be 5.91 g with a range of 0.15 to 22.8 g. Mean fruit length was 6.01 cm with a range of 0.8 to 16.0 cm. Mean fruit width was 1.86 cm and a range of 0.5 to 4.75 cm. Distributions of all characteristics were positively skewed and failed the Kolmogorov-Smirnov test for normality. The distribution of fruit weight values was the most highly skewed, possibly reflecting a more intense human selection pressure for this characteristic. Distributions of fruit width, length, weight, and length:width were leptokurtic (long-tailed). Ninety-three percent of accessions were elongate. Mature fruit colors included red (73.6%), orange (19.7%), yellow (3%), green (0.3%), and mixed (3%). These data suggest that variability for mature fruit characteristics within this germplasm collection is considerable and that variability for fruit length, width, weight, and color is sufficient to provide the basis for the improvement of the aji crop.

Capsicum baccatum var. *pendulum* (Willd.) Eshbaugh, commonly referred to as “aji,” is one of the five cultivated species in this genus (Eshbaugh, 1968, 1970; Pickersgill, 1969). Archeological and other evidence suggests that the cultivated ajis (var. *pendulum*) were derived from the wild *C. baccatum* var. *baccatum* L. that are known as “arivivi” in Bolivia (Eshbaugh, 1976; McLeod et al., 1983; Pickersgill et al., 1979). Domestication of *C. baccatum* var. *baccatum* is believed to have occurred in Peru approximately 2500 BC (DeWitt and Bosland, 1996; Pickersgill, 1969), and the crop subsequently improved by pre-Incan civilizations. That is, selection occurred then for both fruit size and persistence. Today, the domesticated ajis are quite diverse in the size, shape, and color of their fruits (DeWitt and Bosland, 1996), whereas those of the wild form are considered less so (Eshbaugh, 1970). The pods of the cultivated ajis have a distinctive fruity flavor and they are widely used in salsas, ceviches, and as dried powders (DeWitt and Bosland, 1996).

Although both the cultivated and the wild forms of *C. baccatum* are indigenous to South America, the distribution of *C. baccatum* var. *baccatum* has been reported as more restricted than that of its cultivated counterpart, being limited primarily to northern Argentina, Bolivia, southwestern Brazil, western Paraguay, and central Peru with a center of diversity/origin in Bolivia/Peru

(D’Arcy and Eshbaugh, 1974; Eshbaugh, 1970; Hunziker, 1950). The cultivated *C. baccatum* var. *pendulum* is native from the lowlands to the middle elevations in the previously noted countries in addition to parts of Ecuador, Colombia, Chile, and a larger area within Brazil. *Capsicum baccatum* var. *pendulum* has been introduced to Central America, Hawaii, the mainland United States, and elsewhere (Smith and Heiser, 1957). A third variety *C. baccatum* var. *praetermissum* (Heiser & P.G. Sm.) Hunz. (Hunziker, 1971) is believed to have arisen from isolated populations of *C. baccatum* var. *baccatum*. Its distribution appears to be restricted to southern Brazil (McLeod et al., 1983).

Morphologic differences within and between the cultivated ajis (var. *pendulum*) and the wild *C. baccatum* var. *baccatum* were discussed by D’Arcy and Eshbaugh (1974), who described both varieties as having off-white corollas with a pair of yellowish, greenish, or tan markings at the base of each lobe, a calyx with five distinct teeth, and yellow anthers. The fruit of *C. baccatum* var. *pendulum* can be brown, red, orange, or lemon yellow. Its fruit are pendant (very rarely erect), persistent, firm-fleshed, and variously shaped—usually elongate and very rarely globose (D’Arcy and Eshbaugh, 1974). In contrast, fruit of *C. baccatum* var. *baccatum* typically have red fruit that are erect (very rarely pendant), deciduous, globose to oblong in shape, and 4 to 13 mm long and 3 to 7 mm wide. Although some authors have noted the ease with which these two varieties can be separated from another based on

morphologic characteristics (Eshbaugh, 1970; Jensen et al., 1979), others have observed that *C. baccatum* var. *baccatum* intergrades into domesticated *C. baccatum* (Eshbaugh, 1980; Pickersgill et al., 1979).

Fruit color, size, shape, and so on, contribute to the quality of the aji crop. Manipulation of or selection for one or more morphologic characteristics can result in improved phenotypes. To date, relatively limited information is available on the extent of variability present for fruit characteristics of accessions within existing germplasm collections of *C. baccatum*. This study was conducted to examine the variability for mature fruit morphologic characteristics [length, width, length:weight (L:W), weight, and color] among 295 accessions of *C. baccatum* (vars. *baccatum* and *pendulum*) in the USDA/ARS *Capsicum* germplasm collection (Jarret et al., 1990).

Materials and Methods

Seed of a total of 295 accessions of *Capsicum baccatum* were obtained from the USDA/ARS genebank in Griffin, Ga., and sown in the greenhouse in Mar. 2004. These materials represent the total of all accessions of this species currently in the USDA/ARS germplasm collection whose taxonomic identification has been verified. Individual accessions were acquired from a variety of countries, including Argentina (9), Bolivia (39), Brazil (72), Bulgaria (2), Chile (5), Colombia (5), Costa Rica (24), Ecuador (22), Guatemala (2), Guyana (1), Hungary (1), India (3), Mexico (4), Paraguay (21), Peru (65), Philippines (1), Russian Federation (2), the United States (12), Uruguay (4), and Venezuela (1). Twenty to 25 seedlings/genotype were transplanted to the field in May into rows $\approx$ 2 m apart (0.25 m between plants within rows). Plants received fertilization, irrigation, and weed and pest control measures as required.

Descriptive data were recorded using an in-house descriptor list. Information on individual descriptors and their states can be viewed at www.ars-grin.gov/cgi-bin/npgs/html/desclist.pl?116. One hundred fully mature fruit of each genotype were harvested at random from 20 plants/genotype (five fruit/plant), weighed, measured, L:W ratios calculated, and photographed. Values for each characteristic were averaged within accessions and these means further analyzed using SigmaStat (ver. 3.1). Digital images of the fruit of the accessions used in this study can be viewed at www.ars-grin.gov/npgs/acc/acc_queries.html.

Results and Discussion

The statistics for fruit width, length, weight, and L:W for the 295 accessions of *C. baccatum* examined are presented in Table 1. Fruit width averaged 1.86 cm and ranged from 0.5 cm (PI 238061, 439384, and 639129) to 4.75 cm (PI 441551). Fruit length averaged 6.01 cm with a range of 0.8 cm

Table 1. General statistics on four fruit parameters among 295 accessions of *Capsicum baccatum*.

Statistic	Fruit width (cm)	Fruit length (cm)	Fruit wt (g)	Fruit length: width
Mean	1.863	6.012	5.912	4.07
SD	0.816	3.227	4.705	2.188
SE	0.048	0.188	0.274	0.127
Confidence interval of mean	0.094	0.370	0.539	0.251
Range	4.250	15.20	22.65	11.50
Maximum	4.750	16.00	22.80	12.00
Minimum	0.500	0.800	0.150	0.500
Median	1.750	5.500	4.800	4.000
Skewness	1.007	0.766	1.290	0.439
Kurtosis	1.089	0.056	1.351	0.018
Kolmogorov-Smirnov distribution	0.160*	0.108*	0.131*	0.090*

*Nonsignificant.

(PI 439380 and 633751) to 16.0 cm (PI 260585). Average fruit weight was 5.9 g with a range of 0.15 g (PI 639129) to 22.8 g (Grif 9210). Fruit L:W averaged 4.08 with a range of 0.50 (PI 439368) to 12.00 (PI 260535). Fruit shapes were similar to those described by DeWitt and Bosland (1996). Ninety-three percent of accessions were elongate with a L:W greater than 1.0. These and other data presented in Table 1 provide a profile of the fruit characteristics of this species.

As indicated in Table 1 and Figure 1, the distributions of the values for mature fruit length, width, weight, and L:W were positively skewed. Assuming that selection for fruit size occurred over the course of the domestication of this species, as seems relatively certain (Eshbaugh, 1980; McLeod et al., 1982; Pickersgill, 1971), positively skewed distributions for these characteristics would be expected because major genes conditioning these traits were rapidly pyramided. All distributions failed the Kolmogorov-Smirnov test (Stuart and Ord, 1987), indicating nonnormality. The distributions of fruit weight and fruit width values were more

positively skewed (1.29 and 1.00, respectively) than distributions for fruit length (0.76) or L:W (0.044). Distributions for fruit length, width, weight, and L:W were leptokurtic (Table 1; Fig. 1), having longer-than-expected tails. Observed ranges for fruit length and width were in relative agreement with those of Eshbaugh (1970), who noted ranges of 0.4 to 17.2 cm in fruit length and 0.3 to 2.6 cm in fruit width among 36 accessions of the species examined.

A variety of mature fruit colors were recorded among the 295 accessions of *C. baccatum*. These included red [217 (73.6%)], orange [58 (19.7%)], yellow [9 (3%)], and green [1 (0.3%)]. Ten accessions (3.4%) yielded mixtures of red and yellow or red and orange mature fruit. Although the occurrence of brown- (or chocolate) colored mature fruit was reported in this species by Eshbaugh (1970), brown fruit were not observed in this study, suggesting the absence of the full range of variability for this characteristic. Some accessions yielded fruit of more than a single color. This can be attributed to the occurrence of accessions that

were segregating for fruit color and also accessions that were likely originally obtained as mixtures of two or more distinct forms.

Previous investigators (Eshbaugh, 1970; Pickersgill et al., 1979) examined the morphologic variation present in this species to assess the validity of its division into the two currently recognized varieties, var. *baccatum* and var. *pendulum*. Before 1961, *C. baccatum* var. *baccatum* and *C. baccatum* var. *pendulum* were recognized as *C. microcarpum* Cav. and *C. pendulum* Willd., respectively. Hunziker (1961) suggested uniting these into a single species, *C. baccatum*. Eshbaugh (1970) subsequently provided justification for their classification as varieties. Although defining the validity of the two varieties is tangential to the purposes of the present study, it is of interest to note that the bimodal distributions for mature fruit length and width that were reported and used by Eshbaugh (1970) to separate the species into two varieties were not observed (Figs. 1). It seems likely that the bimodal distributions previously reported may have been the result of the relatively small sample size used. However, the absence of bimodal distributions for these or other fruit characteristics neither supports nor disproves the validity of the current two-varietal classification system. Such a division should be based on a broader range of characteristics than those reported here (Pickersgill et al., 1979). More or less continuous distributions for the characters analyzed would appear to support the evolution of the large-fruited domesticated types from the smaller-fruited form.

As noted by Pickersgill et al. (1979), the distinction between wild peppers with small red deciduous erect fruits and domesticated peppers with large pendant nondeciduous fruit of various colors is not clearcut. Many of the characters initially used to define the two varieties do not appear to be unique to either. For example, although data on fruit persistence were not recorded, deciduous large-fruited accessions were observed as were upright, persistent small-fruited forms. The occurrence of nondeciduous upright fruit in an accession of the nondomesticated *Capsicum cardenasii* Heiser & P.G. Sm. (PI 590507) has also been observed. Although fruit of *C. baccatum* var. *baccatum* are typically red (Eshbaugh, 1970), accessions of *C. baccatum* with orange or yellow fruit that were both small and upright and that otherwise shared many of the characteristics of var. *baccatum* have been reported (DeWitt and Bosland, 1996). Among the materials examined in the present study, pedicels of most accessions were erect, or nearly so, at anthesis. Pendant small-fruited accessions of *C. baccatum* were not observed. Large-fruited accessions with upright fruit were not observed and were not expected. As fruit size increased as the result of human selection, the relatively long pedicel characteristic of *C. baccatum* could no longer support the fruit in an upright position, and the fruit became pendant. Thus, pendant fruit are a manifestation of human selection for fruit

Fig. 1. Frequency distribution of 295 accessions of *Capsicum baccatum* for (A) fruit weight, (B) length, (C) width, and (D) length:width.

size in the absence of selection for enhanced pedicel strength (or perhaps in the absence of genetic variability within *C. baccatum* for this characteristic) and not necessarily a reflection of any inherent difference in the initial orientation of the fruit. Numerous transitional forms with smallish to moderately sized semipendulous fruit were observed (for example, PI 188481, 215739, 260564, 281313, and 439409).

Efforts to use biochemical/molecular methods to differentiate var. *baccatum* from var. *pendulum* have met with limited success. For example, Ballard et al. (1970) noted that the flavonoid profiles of both varieties were identical. Jensen et al. (1979) reported that *C. baccatum* var. *pendulum* and *C. baccatum* var. *baccatum* could not be differentiated from each other based on isozymes (23 loci, 63 alleles), although *C. baccatum* var. *praetermissum* was distinct from both of these. Walsh and Hoot (2001) separated the two varieties from one another using sequence data obtained from *waxy* introns and *atpB-rbcL* noncoding spacer regions. However, because only a single accession of each variety was included in the study, the possibility that those differences reflected only intraspecific variability cannot be discounted. Additional or more recent studies either did not include both varieties or did not identify them as such (Buso et al., 2003; Prince et al., 1995; Rodriguez et al., 1999; Toquica et al., 2003). From a practical standpoint, the absence of a single defining characteristic that might be used to differentiate semidomesticated forms from either the wild (var. *baccatum*) or domesticated (var. *pendulum*) forms precludes the unequivocal identification of these forms.

Crop germplasm collecting/acquisition frequently occurs as opportunity permits and not always in a systematic or comprehensive manner. A collector's perception of what constitutes unique or potentially valuable material may be influenced (biased) by the extent of the collector's previous exposure to the diversity already characterized within the taxa being collected. Hence, a thorough and random sampling of the gene pool of many crop plants and their wild relatives has not always been accomplished. The accessions evaluated in the present study, although substantially greater in number than in previous studies (DeWitt and Bosland 1996; Eshbaugh, 1970) represent

only a portion of the phenotypic diversity present in the *C. baccatum* gene pool. For example, the orange- or yellow-fruited forms of *C. baccatum* var. *baccatum* described by DeWitt and Bosland (1996) and the chocolate-colored forms of var. *pendulum* noted by Eshbaugh (1970) were not observed. Several fruit shapes reported by DeWitt and Bosland (1996) were also not observed.

The data presented suggest that variability for mature fruit characteristics within the USDA/ARS *C. baccatum* germplasm collection is somewhat representative of the diversity within this species, and that variability for fruit morphologic characteristics is likely sufficient to provide the basis for the improvement of the aji crop. Incongruities in the distributions for the fruit characteristics that were observed can almost certainly be attributed in part to inadequate sampling of the gene pool.

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