Archeological Evidence for Selection in Avocado

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Seeds of avocado, *Persea americana* Mill. var. *drymifolia* (Schlecht. & Cham.) Blake, were abundant among the remains of many species of cultivated plants discovered in cave deposits in the Tehuacán Valley, Puebla, Mexico. The pits seemed to increase in size toward the top of the deposits, and it was desirable to substantiate this with measurements of the intact pieces.

The Proyecto Arqueologico-Botánico "Tehuacán" of the R. S. Peabody Foundation under the directorship of R. S. MacNeish (1964) undertook the excavation of the deposits. Plant fragments of many kinds were found in five cave deposits, but avocado remains were recovered from only three of the caves. These have been designated TC 35, El Riego Cave, TC 50, Coxcatlán Cave and TC 272, Purrón Cave, by the archeologists. Dependent upon archeological interpretation of artifacts, a number of levels of each cave have been assigned to cultural horizons (summarized in Table 1). All of the recovered fragments will be discussed in relation to cultural horizons which have been dated by a series of C^{14} determinations.

I compared the avocado fragments of a group found within an excavated meter square (Fig. 1). Obviously matching cotyledons, orginally one seed, were paired, and only one cotyledon of each seed was measured. It is possible that fragments found at the extreme margin of a square are matched by a cotyledon from the adjacent square, but it is impossible to determine which fragments came from the margins of the excavated area. Therefore, no attempt was made to match cotyledons from adjacent meter squares. All intact cotyledons were measured from the base to the apex (l.) and across the widest part (w.). An additional measurement was made from the base of the plumule to the margin of the base of the cotyledon (pl.) if the embryo remained attached to the cotyledon. Finally, each cotyledon was scored for the depth or absence of a basal depression. A total of 148 cotyledons were measured (Table 1).

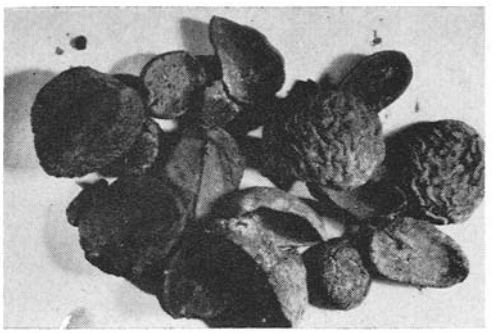

Fig. 1. Avocado cotyledons from the Venta Salada cultural horizon of Coxcatlán Cave.

Analysis of Archeological Avocado Fragments

The oldest cotyledon came from Coxcatlán Cave, Zone XXIV, assigned to the Ajuereado cultural horizon dated 10,000 B. C. (Fig. 2). Because Zone XXIV is nearly central in the horizon, I estimate that the avocado pit may have been discarded as early as 8000 B. C. or as recently as 7000 B. C. Orginally, the seed was nearly spherical with a concave base. In its present dry state, it measures 2.1 cm. long $\times$ 2.2 cm. wide. The embryo has eroded away. It is not significantly different morphologically from more recent avocado pits.

The second earliest avocado pit, also from Coxcatlán Cave, was found in Zone XVIII dated ca. 6600 B. C. Proportionately thicker than the earliest cotyledon, it is 2.4 cm.

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Table 1 - Avocado Remains from the Tehuacán Valley

Venta Salada Cultural Horizon

Largest cotyledon measured - 3.2 X 3.1 cm. Smallest measured - 1.7 X 1.5 cm. Total measured - 26. l X w = 9.92

TC 35e	l.	2.9	3.3	2.7	1.7			
Zone A	w.	2.5	2.1	2.1	1.5			
ca. 1500	pl.	--	0.5	--	--			
A. D.	base	svx	svx	svx	vx			
TC 35e	l.	2.2	2.7	1.8	3.0	2.8	2.7	
Zone B	w.	1.4	2.4	1.2	2.3	2.0	1.4	
ca. 1300	pl.	--	--	0.3	0.4	0.4	0.4	
A. D.	base	vx	ve	vx	fl	vx	vx	
TC 50	l.	3.8	1.7					
Zone I	w.	1.7	1.8					
ca. 1300	pl.	0.9	0.3					
A. D.	base	vx	vx					

TC 50	l.	2.8	1.9	2.0	1.9	2.5	1.9	1.9
Zone II	w.	2.6	2.1	2.3	1.8	1.7	1.7	2.2
ca. 1000	pl.	0.8	0.5	0.3	0.2	0.4	0.3	--
A. D.	base	ve	sve	ve	fl	vx	vx	ve
TC 50	l.	3.2	3.0	2.1	2.4	2.0	3.2	1.9
Zone III	w.	3.1	2.8	1.9	2.5	1.3	1.8	1.9
ca. 800	pl.	0.7	0.5	0.4	0.3	0.3	0.4	0.3
A. D.	base	ve	fl	sve	fl	vx	vx	sve

Aver. l. 2.5+
Aver. w. 2.0
Aver. pl. 0.4+
vx>ve

Palo Blanco Cultural Horizon

Largest cotyledon measured - 3.0 X 3.5 cm. Smallest measured - 1.3 X 1.8 cm. Total measured - 97. l X w = 10.50

TC 35e	l.	3.5	2.8	2.4	2.3	2.3	1.8																	
Zone C	w.	2.0	2.0	1.8	1.5	1.9	1.4																	
ca. 600	pl.	0.6	--	--	0.2	0.4	0.2																	
A. D.	base	vx	vx	vx	vx	svx	fl																	
TC 35e	l.	2.8	2.2	2.9	2.6																			
Zone D	w.	1.8	2.1	1.5	1.7																			
ca. 200	pl.	--	--	0.3	0.5																			
A. D.	base	fl	vx	svx	svx																			
TC 50	l.	1.8	2.0	2.2	3.4	1.6	3.0	1.3	1.4	1.6														
Zone IV	w.	1.8	1.6	1.7	1.8	1.8	2.7	1.8	1.6	1.8														
ca. 300	pl.	0.3	0.5	0.4	--	0.3	0.9	0.2	--	0.3														
A. D.	base	ve	vx	vx	sve	vx	fl	sve	sve	fl														
TC 50	l.	1.6	1.5	2.2	2.1	2.3	2.3	2.2	2.5	1.9	2.1	1.8	1.8	1.7	2.5	2.1	1.7	1.9	2.5	2.1	2.4	1.9	2.8	1.7	1.8	2.4
Zone VI	w.	1.5	1.4	1.1	1.3	1.4	1.5	2.3	2.2	2.6	1.7	1.2	1.4	1.5	1.5	1.8	1.4	1.6	1.8	1.8	2.3	1.6	1.4	1.4	1.6	1.1
(Cont.)	pl.	0.2	--	0.4	0.3	0.4	0.5	--	0.3	--	0.3	0.3	0.2	0.2	0.4	0.4	0.3	0.4	--	--	0.3	0.3	0.4	0.3	--	0.3
	base	vx	sve	vx	svx	svx	sve	sve	ve	ve	vx	vx	sve	fl	vx	vx	sve	vx	ve	sve	ve	sve	sve	vx	vx	vx

TC 50	l.	2.0	2.4	2.1	2.2	1.6	2.1	1.4	2.1	2.0	1.9													
Zone V	w.	1.6	1.9	2.1	2.5	2.1	3.0	1.6	1.7	1.5	2.1													
ca. 200	pl.	0.4	0.4	--	0.6	0.3	--	0.2	0.3	0.4	--													
A. D.	base	vx	vx	sve	ve	ve	ve	sve	vx	sve	sve													
TC 272	l.	2.5	2.0	2.5	1.9																			
Zone D	w.	2.4	1.4	1.6	1.6																			
ca. 200	pl.	--	--	0.4	--																			
A. D.	base	sve	vx	vx	svx																			
TC 50	l.	1.8	1.8	2.0	1.6	2.1	2.6	3.2	1.6	1.9	2.3	2.2												
Zone VI	w.	1.2	1.1	1.3	1.3	1.3	2.3	2.3	2.2	2.2	1.8	1.4												
ca. 0	pl.	--	0.2	0.2	--	0.3	--	--	--	--	0.4	0.4												
	base	fl	vx	vx	vx	vx	ve	ve	ve	ve	vx	vx												

vx = convex, ve = concave, svx = slightly convex, sve = slightly concave, fl = flat

TC 50	l.	3.0	2.7	2.7	2.4	2.1	1.6	2.2	2.2	1.8	2.4	2.1	1.6	2.3	2.1	2.9	1.7	2.1	2.4	2.0	1.8	1.7	2.4	2.0	1.8	2.0
Zone VI	w.	3.5	2.8	3.5	3.2	1.4	1.4	1.2	1.4	1.4	1.2	1.1	1.2	2.6	2.6	2.5	2.7	1.6	2.3	1.9	2.6	2.1	1.7	1.9	2.7	1.5
(Cont.)	pl.	--	0.4	0.5	--	0.4	--	0.3	0.3	0.2	--	0.3	0.3	0.6	--	--	--	--	0.2	0.4	--	0.4	0.4	0.3	0.3	0.3
	base	sve	sve	ve	ve	vx	vx	vx	vx	vx	vx	vx	fl	ve	ve	sve	ve	sve	ve	sve	ve	sve	vx	ve	ve	fl
	l.	2.0	1.8	1.6																						
	w.	1.6	1.7	1.1																						
	pl.	0.2	0.3	0.2																						
	base	vx	vx	vx																						

Aver. l. 2.1
Aver. w. 1.8
Aver. pl. 0.35
vx > ve

Santa María Cultural Horizon

Largest cotyledon measured - 2.6 X 3.0 cm. Smallest measured - 1.4 X 1.5 cm. Total measured - 19. l X w = 7.80

TC 35e	l.	1.6	3.0	
Zone E	w.	1.6	1.9	
ca. 300	pl.	0.2	0.6	
B. C.	base	fl	svx	
TC 272	l.	3.1	2.1	2.6
Zone G	w.	1.5	1.7	3.0
ca. 400	pl.	--	0.3	0.3
B. C.	base	vx	svx	ve

TC 50	l.	2.6	2.0	2.4	2.2	1.7	2.5	2.4	2.0	1.4	2.4	2.1	2.5	2.8	1.9
Zone VII	w.	1.9	2.0	2.8	1.2	1.6	2.4	2.5	1.7	1.5	2.6	2.0	1.9	2.4	1.5
ca. 500	pl.	0.4	--	--	0.3	--	0.4	--	0.4	0.3	0.3	--	0.3	0.5	0.4
B. C.	base	ve	svx	ve	vx	vx	ve	ve	vx	vx	ve	ve	vx	vx	vx

Aver. l. 2.3
Aver. w. 1.98
Aver. pl. 0.36
vx > ve

Abejas Cultural Horizon

Total measured - 2. l X w = 3.78

TC 50	l.	1.8	TC 50	l.	2.1	Aver. l.	1.95
Zone VIII	w.	2.1	Zone IX	w.	1.4	Aver. w.	1.75
ca. 2900	pl.	0.2	ca. 3200	pl.	0.5	Aver. pl.	0.35
B. C.	base	ve	B. C.	base	vx	vx = ve	

Coxcatlán Cultural Horizon

Total measured - 2. l X w = 3.40

TC 50	l.	2.0	1.9	Aver. l.	1.9+
Zone XI	w.	1.7	1.6	Aver. w.	1.6+
ca. 4000	pl.	--	0.4	Aver. pl.	0.4
B. C.	base	svx	vx	vx	

El Riego Cultural Horizon

Total measured - 1. l X w = 6.48

TC 50	l.	2.4
Zone XVIII	w.	2.7
ca. 6600	pl.	--
B. C	base	sve

Ajuereado Cultural Horizon

Total measured - 1. l X w = 4.62

TC 50	l.	2.1
Zone XXIV	w.	2.2
ca. 8000	pl.	--
B. C	base	ve

vx = convex, ve = concave, svx = slightly convex, sve = slightly concave, fl = flat

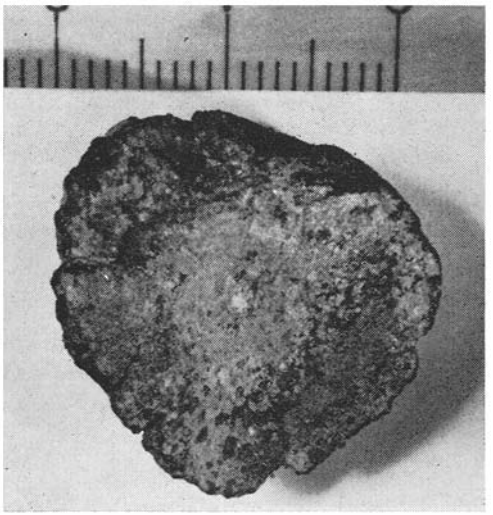

Fig. 2. The oldest avocado cotyledon found in Coxcatlán Cave came from the Ajuereado cultural horizon. By carbon 14 dating, it is estimated to have been deposited between 8000 and 7000-6500 B.C.

long × 2.7 cm. wide and has a slightly concave base.

Two measurable cotyledons were found in Coxcatlán Cave, Zone XI, in the Coxcatlán cultural horizon dated 4000 B.C. Both are slightly longer than wide: one is 2.0 × 1.7 cm., the other is 1.9 × 1.6 cm. Their bases are convex.

In the Abejas cultural horizon, two more measurable cotyledons were recovered. The more elongate was from Coxcatlán Cave Zone IX, dated ca. 3200 B. C., and was 2.1 × 1.4 cm. The other cotyledon was from Zone VIII, dated about 2800 B. C., and is 1.8 cm. long × 2.1 cm. wide.

A total of 19 measurable avocado pits from the Santa María cultural horizon were found in all three of the caves from which avocado pits were recovered. The earliest were 14 cotyledons from Coxcatlán Cave, Zone VII, dated ca. 500 B. C. Three others were from Purrón Cave, Zone G, dated ca. 400 B. C. The last two were from El Riego Cave, Zone E, dated ca. 300 B. C. The largest cotyledon in this series is 3.0 × 1.9 cm.; the smallest is 1.4 cm. long × 1.5 cm. wide. More seeds have convex than concave bases. The average size of avocado seeds in the Santa María horizon is 2.3 × 1.98 cm.

A total of 97 measurable cotyledons came from the Palo Blanco cultural horizon. Sixty-four measurable cotyledons came from Coxcatlán Cave, Zone VI, four from Purrón Cave, Zone D, ten from Coxcatlán Cave, Zone V, nine from Coxcatlán Cave, Zone IV, four from El Riego Cave, Zone D, and six from El Riego Cave, Zone C. Dates for these levels range from 200 B. C. to 700 A. D. The largest cotyledon measures 3.5 × 2.0 cm. and the smallest 1.3 × 1.8 cm. More of the seeds have convex than concave bases.

Finally, 26 measurable avocado pits were found in the Venta Salada cultural horizon. Dates for these range from ca. A. D. 700 to 1540. From the oldest to the youngest, they are as follows: From Coxcatlán Cave, Zone III, seven, Zone II, seven, and Zone I, two; from El Riego Cave, Zone B, six, and Zone A, four. The largest cotyledon measured is 3.3 × 2.1 cm. and the smallest 1.7 × 1.5 cm. As in the next lower horizon, more seeds had convex than concave bases.

Comparison of the figures shows little difference from horizon to horizon because of the wide variability of the seeds (Table 1). The smallest seeds from the upper levels are smaller than the oldest seeds. The shape of the seeds ranges from oblate to nearly spherical to nearly conical. From the seeds, it is impossible to determine the thickness of the flesh of the whole fruit. However, the shape of the fruit probably followed the shape of the seed, as it does in the cultivated varieties of recent avocados.

Although the average length and width of the seeds changes little from the oldest to the youngest archeological horizons, there is a gradual increase upward from the Coxcatlán horizon (only one seed was recovered from the Ajuereado and El Riego horizons). The average length and width in the Coxcatlán horizon is 1.9 × 1.6 cm.; in the Venta Salada horizon, the average length and width is 2.5 × 2.0 cm. An even more dramatic change in over-all size is shown by the figures resulting from the multiplication of the length by the width of the largest seeds from each horizon. This parameter is more nearly proportional to the change in volume of the fruit. For the

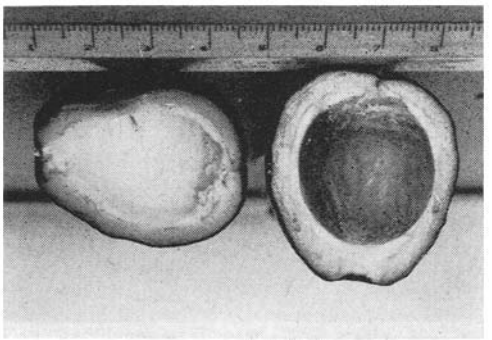

Fig. 3. Fruit of *Persea americana* var. *drymifolia* purchased in the market at Tehuacán, Puebla.

largest seed from the Coxcatlán horizon, this value is 3.40. In the Abejas horizon, it increases to 3.78, but in the Santa María horizon it jumps sharply to 7.80. The figure 10.50 for the largest seed of the Palo Blanco horizon is the largest for the whole group. In the top-most Venta Salada horizon, the figure falls slightly to 9.92.

The average distance of the end of the plumule from the base of the seed does not change significantly from the oldest to the youngest seeds. The shape of the base of the seeds is concave in the two oldest seeds examined, but both seeds found in the Coxcatlán horizon had convex bases. Upward in the deposits, convex bases are far more frequent than concave bases; for the most part, the length of the seeds is greater than the width, indicating that the shape of the fruit changed from nearly spherical or oblate spherical to ovoid or ellipsoid.

Thus, significant changes occur in the avocado seeds from the oldest to the youngest archeological horizons in the Tehuacán Valley. The Tehuacán people apparently actively selected seed for planting. This selection led to an increase in the size of avocados and to a change in shape of the fruit from nearly spherical to ovoidal or ellipsoidal.

Past and Present Ecology of the Tehuacán Area

At present, in the Tehuacán Valley, the greater part of the precipitation falls from May to September, with peaks in June and at the end of the rainy season. At Tehuacán, the annual average precipitation is 478 mm. (Contreras, 1942) and the highest monthly average is 119 mm. for September.

The Tehuacán area is seasonally very dry, and this is reflected in the natural vegetation. Over the central and eastern part of the area, thorn-scrub-cactus forest predominates. Canopy height is low, trees are generally widely spaced, and the near-desert aspect is emphasized by many species of columnar arboreal cacti. Along the western margins of the area, the underlying limestone rocks provide increased drainage in an area which receives even less precipitation than Tehuacán. Here the vegetational cover consists mainly of spiny shrubs and cacti with scattered trees (Smith, 1965).

Many fragments of native plants were recovered from the cave deposits during the archeological excavations. The earliest of these came from the Ajuereado horizon, and such fragments were increasingly abundant upward in the deposits. In no way do the earlier native plants differ in species composition from the present vegetation of the area. It therefore appears that there has been no significant change in the rainfall pattern in the Tehuacán area for 12,000 years.

Biology of the Avocado

The recovered fragments of avocado are referable to *Persea americana* Mill. var. *drymifolia* (Schlecht. & Cham.) Blake. Dried seeds of this variety purchased in the Tehuacán market in 1961 averaged 2.1 $\times$ 1.65 cm., with the plumule 0.35 cm. from the convex base. The whole fruit averaged 4.65 $\times$ 3.2 cm. The skin was thin, tough, and dark purple outside. The flesh was whitish, changing to greenish near the skin, and had a strong odor and flavor of anise (Fig. 3).

Dooryard trees in the Tehuacán area are often about 10 m. and rarely more than 15 m. tall. They tend to branch near the base, but they are frequently planted in close association with other fruit trees that soon shade out lower branches. I have never seen them standing very far from other trees, nor do they grow in the area without irrigation. The leaves are thin and considerably larger than those of the na-

tive trees of the area. Avocados, trees of mesic forest associations, are not native to the semi-desert Tehuacán Valley floor.

The nearest environment in which avocados might be expected to grow as native trees is found in the barrancas cutting deeply into the Sierra de Zongolica on the eastern side of the Tehuacán Valley. In the barrancas that have a permanent stream, the mountain forest vegetation comes downward toward the valley. The oldest avocado seeds were probably brought into the valley from the forest in one of these barrancas.

By the middle of the El Riego horizon, a number of plants were coming into cultivation in the Tehuacán Valley area. These include both annual and perennial species native to the valley floor, but that chili (*Capsicum annuum*) and ciruela (*Spondias mombin*) are indigenous is doubtful. Altogether, eight avocado seeds are represented by fragments from Zone XVIII of Coxcatlán Cave, although only one was sufficiently intact for accurate measurements. The fruit from which these seeds came were probably grown on a tree planted on a streamside near the Cave. All of the agricultural techniques needed for the successful cultivation of avocados in the semi-desert valley were practiced at this time.

Persea americana var. *drymifolia* may once have been restricted in distribution to the moist montane forests of eastern and southern Mexico, but it is no longer possible to determine this accurately. It is now widely scattered in cultivation throughout Mexico from Tamaulipas and Nuevo León to Chiapas (Fig. 4). In recent years, Mexican avocados have been intensively sampled by botanists working for the California Avocado Society (see references), but even this has failed to delimit the native area of this tree.

Summary

A series of avocado seeds recovered from the deposits in El Riego, Purrón and Coxcatlán Caves of the Tehuacán area show gradual increase in size and a change in shape from oldest to youngest. The oldest cotyledon from Zone XXIV of the Coxcatlán Cave deposit is dated at least 7000 B. C.

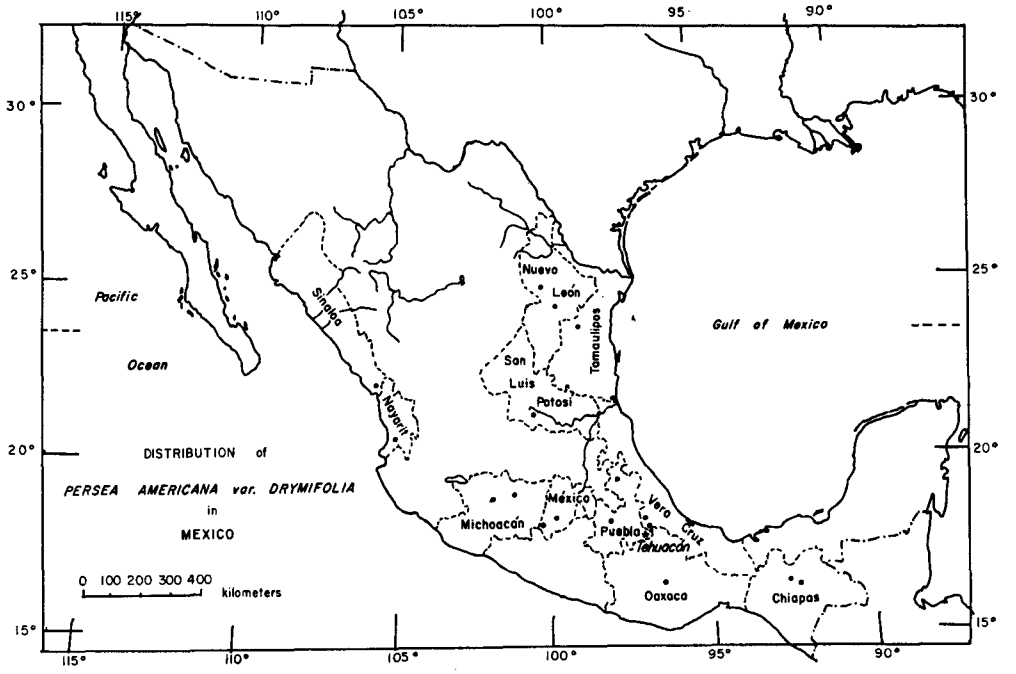

Fig. 4. The geographical range of *Persea americana* var. *drymifolia*, plotted from herbarium records, is largely in the eastern and central highlands of Mexico with a few stations on the Pacific side of the country in Nayarit and Sinaloa.

It was probably brought into the Cave from a native tree growing in mesic forest in one of the barrancas in the mountainside to the east. The quantity of avocado seeds and the presence of other undoubtedly cultivated plants indicates that avocados probably were being planted on nearby streamsides by 6500 B. C. The dramatic increase in the figure obtained by multiplying the length by the width of the largest avocado cotyledons proves that selection for larger fruit was markedly effective by 900 B. C. Since avocados are a long-lived tree crop and the results of selection are not readily apparent, the increase in size is particularly significant.

While the average size of the avocado cotyledons increases from older to younger cultural horizons, the smaller seeds remain abundant. Evidently trees that bore small or poor fruit were not eliminated and they probably slowed the process of selection materially for trees that bore larger and better fruit.

Acknowledgment

My sincere thanks go to Caroline K. Allen and Lucille Kopp for their assistance. Locality data from the forthcoming monograph of *Persea* by Kopp (1966) are the basis for the distribution map. I wish also to thank R. S. MacNeish, Director of the Tehuacán project, who made every effort to ensure that I received all of the valuable material on which this report is based.

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