Investigating Native Californian Tobacco Use at Mission Santa Clara, California, through
Morphometric Analysis of Tobacco (*Nicotiana* spp.) Seeds

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Abstract

Excavations in the Native ranchería at Mission Santa Clara, California, recovered a large assemblage of predominantly uncharred archaeological tobacco seeds, including many morphologically intact specimens, associated with deposits from ca. 1790-1840 C.E. This assemblage, estimated to contain over 4600 tobacco seeds, provided an unprecedented opportunity to explore tobacco use by Native people living at a California mission. Morphometric and linear discriminant analysis of modern comparative tobacco species was used to identify archaeological tobacco seeds at the species or species-group level. Analysis revealed the presence of domesticated tobacco (*Nicotiana tabacum*), tree tobacco (*Nicotiana glauca*), and at least one other kind of tobacco (either *Nicotiana attenuata*, *N. quadrivalvis*, and/or *N. acuminata*) at Mission Santa Clara during the period of occupation. This evidence suggests that domesticated tobacco and tree tobacco were cultivated and processed at Mission Santa Clara. Domesticated tobacco cultivation and processing reflects hybrid cultural practice, with traditional indigenous methods applied to a novel plant. Tobacco representation in a pit feature associated with mourning ceremony materials indicates an association between ceremonial contexts and intentional tobacco burning, as well as a possible association between native tobacco species and ceremonial practices.

1. Introduction

1 Many archaeologists have examined the Spanish missions of California as loci of cultural
2 hybridity and colonial entanglement (Allen 1998; Arkush 2011; Lightfoot 2005; Panich and
3 Schneider 2015; Robinson 2013). Archaeology provides multiple avenues to explore these
4 relationships by documenting changes in contextual use of material culture. However, there has
5 been little published research about how Native people responded to colonial entanglements
6 through ethnobotanical practice (but see Allen 1998; Reddy 2015).

8 Recent archaeological excavations in the Native American ranchería, or neighborhood, at
9 Mission Santa Clara de Asís (ca. 1777-1840s) in central California produced a large assemblage
10 of uncharred and charred tobacco (*Nicotiana* spp.) seeds, with a substantial proportion of
11 apparently morphologically intact uncharred seeds. It is rare to recover uncharred archaeological
12 (vs. modern contaminant) plant remains in California, and unprecedented to recover tobacco
13 seeds in quantities approaching those reported in this study. This unique assemblage of
14 archaeological tobacco makes it possible for the first time to explore what kinds of tobacco were
15 used at the mission and to relate tobacco use to the topics of Native social autonomy,
16 ethnobotanical practices, and economic production.

18 In this paper, we summarize ethnographic information about Native uses of tobacco in Central
19 California and present background information about excavations in and around a Mission Santa
20 Clara adobe structure. Using digital image analysis to record information on 15 shape
21 parameters, we applied linear discriminant analysis to seven species of tobacco to document
22 shape variability within and between taxa. We used the results of discriminant analysis to
23 taxonomically classify archaeological tobacco seeds and to provide a quantitative measure of
24 classification certainty. We interpret results of archaeological tobacco identification in the
25 broader context of the archaeological study and consider implications of this analysis for future
26 research.

28 **1.1. Tobacco use by Native people in central California**

30 Tobacco was an important plant for most Native peoples in central California, including Ohlone
31 (formerly called Costanoan), Yokuts, and interior Miwok groups who became associated with
32 Mission Santa Clara. Throughout California, tobacco was involved in a wide range of cultural
33 practices including social gatherings, ceremonies, medicine, economic transactions, story-telling,
34 resource tending, and recreation (Anderson 2005; Gayton 1948a, 1948b; Harrington 1932;
35 Kroeber 1941; Timbrook 2008; Zigmond 1981).

37 Native species of tobacco in central California include “Indian tobacco” (*Nicotiana quadrivalvis*,
38 with two varieties, see Hammett 2000) and “coyote tobacco” (*N. attenuata*). Both native tobacco
39 species are associated with gravelly, well-drained slopes (Baldwin et al. 2012), thus neither is
40 likely to have grown naturally in the seasonally wet alluvial plains around Mission Santa Clara.
41 There are also two exotic tobacco species that now grow outside of cultivation, “manyflower
42 tobacco” (*N. acuminata*) and “tree tobacco” (*N. glauca*) (Baldwin et al. 2012). Tree tobacco was
43 reportedly introduced to southern California “during mission times” (Timbrook 2008:156), and
44 the earliest botanical records in the San Francisco Bay Area date to the 1890s (Consortium of
45 California Herbaria 2015). It should be noted that while tree tobacco has become naturalized and
46 commonly grows outside of cultivation in southern California, it rarely grows outside of

1 cultivation in the San Francisco Bay Area (Calflora 2015). Documentary information about the
2 date of introduction of manyflower tobacco is lacking. The earliest vouchered specimen in
3 California was collected in the 1880s (Consortium of California Herbaria 2015; Hammett 2000).

4
5 Ethnographic information from A. Solorsano (Mutsun) in 1929 suggests tree tobacco was a
6 relatively recent introduction in the region to the south of Mission Santa Clara, and was not used
7 by Native people associated with Mission San Juan Bautista. Solorsano reported "Here they call
8 this kind of tobacco 'Chinese tobacco' ... [it] is not very old here, it grows tall like a tree, it has
9 many very green and smooth leaves, it was not used for anything" (translated by R. Cuthrell;
10 Harrington n.d., microfilm Series 2 Reel 61). Likewise, I. Meadows (Rumsen), associated with
11 Mission Carmel near Monterey, reported that she did not know of tree tobacco (*ibid.*).

12
13 Traditional tobacco tending, cultivation, preparation, and consumption practices were sometimes
14 variable even between closely related Native groups (e.g., Gayton 1948a, 1948b). Across
15 California, tobacco acquisition and production practices among Native groups ranged from
16 collection of untended wild tobacco to formal cultivation that included bed preparation, seed
17 sowing, soil tillage, and watering (Anderson 2005:173-4; Harrington 1932; Kroeber 1941:13-7;
18 Strike 1994:95-7). Burning was one of the most common tobacco tending practices in California,
19 and many Native groups reported that tobacco grew better in burned places (Anderson 2005;
20 Hammett 2000). In a controlled study, Baldwin et al. (1994) found that *N. attenuata* germinates
21 more successfully when exposed to the chemical byproducts of fire. Winter (2000, see p. 140
22 note #3) reported anecdotally that *N. attenuata* may require exposure to fire to germinate
23 successfully, while *N. quadrivalvis* apparently does not.

24
25 Most Yokuts groups reported pruning tobacco by removing the tops of the plants or buds to
26 encourage larger leaf growth (Driver 1937:84; Gayton 1948a:92, 1948b:228), and a minority of
27 Yokuts groups reported sowing tobacco seed or burning patches of tobacco to encourage growth
28 (Driver 1937:84). In contrast, patch burning and seed sowing was nearly universal among
29 interior Miwok groups (Aginsky 1943:425). Ohlone informants reported gathering wild tobacco,
30 but not tobacco tending or sowing (Harrington 1942:28). However, in the case of Ohlone groups,
31 lack of ethnographic attestation of these practices does not necessarily rule them out. Due to
32 earlier and more substantial disruption of Ohlone lifeways by Spanish colonization, some
33 traditional practices, such as historically attested landscape burning, were not reported during
34 ethnographic work in the early 20th century (see Cuthrell 2013; Harrington 1942:9; Milliken
35 1995).

36
37 During a reconnaissance expedition led by Juan Bautista de Anza in 1776, Fr. Pedro Font
38 reported "a good deal" of native tobacco growing at an unoccupied Native settlement on the
39 plains of the eastern San Francisco Bay shore (Brown 2011:292), a location where it probably
40 would not grow naturally. While Native people may have sown and cultivated tobacco around
41 settlements, it is also possible that tobacco became established around settlements due to the
42 creation of anthropogenic ecological niches in the form of soils enriched in the chemical
43 byproducts of burning.

44
45 Tobacco preparation practices of Yokuts living in the central and southern portion of the San
46 Joaquin Valley and Sierra Nevada foothills are described in detail by Gayton

(1948a:22,50,52,92-3; 1948b:155,161,191,228-9). The following description summarizes preparation and use methods. Tobacco leaves were harvested in summer and cured by wetting and allowing them to ferment for several days. Leaves were then dried, ground finely, and water was added to make a paste that was formed into cakes, which were dried. To use tobacco, a small portion of the cake was scraped off and eaten or ground into a mixture of water and calcium hydroxide derived from burned freshwater invertebrate shells. Tobacco was used in this way as an emetic to clean the stomach and to assist in dreaming. Tobacco was also smoked in small quantities from pipes made of cane or wood. Gendered use of tobacco varied between groups, but it was common for public tobacco use to be associated with men and for private use to be associated with both women and men.

Interior Miwok groups smoked tobacco in a manner similar to Yokuts groups, but use as an emetic appears to have been less common, particularly in the northern portion of Miwok territory (Aginsky 1943:425; Barrett and Gifford 1933:195). Rather than forming tobacco into cakes, Miwok groups harvested green tobacco plants whole, dried them in the shade, and then shred the leaves into small pieces for smoking (Barrett and Gifford 1943:193).

There is little ethnographic information about tobacco use by Ohlone groups. Tobacco leaves were smoked and tobacco/shell mixtures were consumed as an emetic; tobacco was used for medicinal, ceremonial, and recreational purposes; and tobacco was included in traditional stories (Bocek 1984; Harrington 1942:28; n.d., mf. Vol. 2 Reel 61). Two stone pipes, recovered archaeologically from precontact Ohlone burials dating to between 1305-1415 C.E. tested positive for the alkaloid nicotine, indicating tobacco use at that time (Eerkens et al. 2012). Charred tobacco also comprised 0.5% (n=240) of the identified seed assemblage at site CA-SMA-113 near Año Nuevo Point, dated ca. 1000-1300 C.E. (Cuthrell 2013:328).

1.2. Tobacco trade, production, and use in Spanish missions

Franciscan missionaries entered Alta California in 1769 with the goal of converting Native hunter-gatherers to a Catholic, agrarian lifestyle. To establish relationships with Native people, missionaries offered goods that had analogs in Native societies. European glass beads were accepted by indigenous people, who used shell beads as a status symbol and for currency (O'Neil 1992; Panich 2014). Tobacco similarly interested California's Native peoples and was traded by many Spanish explorers and missionaries. Writing in 1774, Junípero Serra, Father President of the Alta California missions, remarked that Native Californians around the future site of Mission Soledad initially sought beads, but increasingly requested tobacco as time went on (Tibesar 1956:141). Serra described appeals for along the coast from San Diego to Monterey, with unmissionized Native people calling out for "*Tabaco, Padre!*" (Tibesar 1956:146-147).

The recovery of large quantities of tobacco seeds from Mission Santa Clara raises several questions about the origins, identity, and context of tobacco use by Native people in mission settings. We identify three possible modes of tobacco acquisition, which are not mutually exclusive: 1) mission neophytes, as baptized indigenous people were known, grew native tobacco at Mission Santa Clara and/or obtained it outside of the missions through direct acquisition or trade; 2) Franciscan missionaries encouraged or tolerated the cultivation of domesticated tobacco; and 3) neophytes consumed domesticated tobacco imported from

1 mainland Mexico. We briefly review the ethnohistorical record in relation to each of these
2 scenarios.

3
4 Although Native people have long been characterized as passive victims in California mission
5 settings, contemporary scholarship shows they maintained a degree of autonomy from colonial
6 systems (Panich and Schneider 2015). At Mission Santa Clara, archaeological evidence
7 demonstrates that some neophytes had access to exotic goods, including obsidian, shell beads,
8 and certain wild animals (Panich et al. 2014). This suggests Native people could have obtained
9 wild tobacco from plants growing outside of the mission estate. Alternatively, ethnohistorical
10 information states that Santa Clara neophytes were encouraged to plant their own gardens
11 (Geiger and Meighan 1976:111), offering opportunities for small-scale cultivation of tobacco in
12 the Native *ranchería*.

13
14 It is also possible that Franciscan missionaries grew domesticated tobacco or instructed Native
15 people in its cultivation. In a 1774 letter to the Viceroy of New Spain, Serra wrote that he had set
16 aside a corner of the garden at Mission Carmel for tobacco cultivation. Citing strong Native
17 demand for the plant and the lack of imported tobacco, he wrote, “And so, from a sprig that we
18 had here, we started to plant it” (Tibesar 1956:147). There is little other information on the
19 cultivation of tobacco at California missions. Two entries in a notebook kept by missionaries at
20 Santa Clara describe the management and curing of tobacco (Viader n.d.), however the
21 descriptions are not necessarily specific to that mission. Tobacco was also cultivated at ranches
22 established as part of the Russian colony of Ross north of San Francisco Bay (Essig et al. 1933).
23 During his visit to Alta California in the early 1840s, Duflot de Mofras (1937:252, 258) observed
24 that the previously successful cultivation of tobacco was generally “neglected” across the
25 province. Only at Mission San Rafael did he witness tobacco plants worthy of mention (Duflot
26 de Mofras 1937:237). Later in the nineteenth century, Guadalupe Vallejo (1890:189), who grew
27 up in Mexican California, recalled the mission gardens in which “a fine quality of tobacco was
28 cultivated and cured by the Indians.”

29
30 A final possibility is that the archaeological tobacco seeds originate from domesticated tobacco
31 imported from colonial New Spain. Account books detailing supplies sent to Mission Santa Clara
32 from the colonial port of San Blas list almost annual shipments of tobacco and tobacco products
33 during the period for which records are available (1776-1810). In addition to quantities of *puros*
34 (cigars) and *cigarros* (cigarettes), these documents list leaf tobacco in the form of *manojos*, a
35 bundle weighing about two pounds; almost 200 *manojos* of tobacco were sent to Mission Santa
36 Clara (Skowronek et al. n.d.). In contrast, the account books for the military presidio of Santa
37 Barbara contained no listings for *manojos* (Perisinnotto 1998), suggesting that the leaf tobacco
38 shipped to Santa Clara was specifically intended for Native Californians (see also Archibald
39 1978:57).

40
41 In the years that Mission Santa Clara imported tobacco, the crop was under a state-controlled
42 monopoly. The state relied on two main production areas in southern Mexico, and the output was
43 heavily regulated and graded according to quality. The inclusion of shoots and suckers with the
44 leaf was explicitly prohibited, and certain wage categories were established for topping and
45 suckering (Deans-Smith 1992:74-75, 120), suggesting that imported leaf tobacco probably
46 contained few or no seeds.

2. Archaeological Research at Mission Santa Clara

2.1 Mission Santa Clara and its Native Inhabitants

Mission Santa Clara de Asis was founded in 1777 just south of the San Francisco Bay. The region was in the ancestral homeland of the Tamien Ohlone, but the mission eventually attracted other Ohlone people from the greater San Francisco Bay area. After 1810, recruitment shifted eastward to Yokuts-speaking groups of the San Joaquin Valley and perhaps to interior Miwok groups of the Sierra Nevada foothills (Milliken 2002). The mission's Native population was one of the largest in Alta California, with roughly 1400 indigenous neophytes during much of its existence. Mission Santa Clara was officially secularized in the mid-1830s, but continued to house a significant Native population until the 1840s.

2.2 Archaeological Context of Botanical Materials

Archaeological tobacco seeds examined in this study were recovered from the Native American *ranchería*, at Mission Santa Clara. The mission itself was moved several times over the course of the colonial period (Skowronek and Wizorek 1997), but the *ranchería* remained in the same general area from the early 1780s through the end of the mission's occupation in the late 1840s. The samples were drawn from multiple contexts associated with an adobe apartment row, or barracks, intended for married neophytes and their families. The structure was constructed in the 1790s and was likely occupied by native people until the 1840s. The barracks from which the samples were recovered was one of several such structures within the *ranchería*.

In the California mission system, adobe barracks are commonly assumed to have housed Native people of relatively high status within the mission estate. This hypothesis was recently tested by comparing the assemblage recovered from the barracks site to materials excavated from a Native-style thatched dwelling in the *ranchería* (Panich et al. 2014). Materials from the adobe barracks did include more introduced items such as ceramic wares and metal implements than those from the Native-style dwelling. But it also appears that the occupants of the barracks enjoyed preferential access to exotic goods traditionally valued in Native societies, such as obsidian and shell beads. Thus, Native people who lived in the adobe barracks may have outwardly accepted aspects of the mission program while maintaining important cultural traditions within their own neighborhood (Lightfoot 2005:98-99).

Soils samples for flotation were collected from four distinct depositional contexts at the barracks site: ash lenses from interior domestic space; ash lenses from exterior sheet midden; four discrete strata within a large pit feature directly outside of the structure; and from soils below midden deposits (Figure 1). The pit feature contained two major burning episodes but otherwise appears to have been filled rapidly, as evidenced by extant voids between large fragments of ceramic roof tile. About 25% of the pit feature was excavated. Artifacts included approximately 1900 burned shell beads and 30 glass beads. Among other possible functions, the pit was likely filled with materials burned after the death of an individual or during an annual mourning ceremony (Panich 2014, 2015). Based on diagnostic shell bead types, the pit feature dates to the

1 1810s or later. Dates for other contexts cannot be refined beyond the documented period of
2 occupation, ca. 1790s-1840s.

3
4 Although we cannot rule out all forms of post-depositional contamination, we note several
5 factors that argue against it. After the closure of the mission in the 1840s, the excavation area
6 was incorporated into the growing city of Santa Clara. By 1892, it comprised the backyard of a
7 residential lot in which several outbuilding structures were constructed and razed during the
8 subsequent 100 years. These activities led to approximately 50-60 cm of American-period
9 deposits that effectively capped the mission period materials from which our flotation samples
10 were collected. By the late 1990s, the entire excavation area was paved for a parking lot.

11
12 Despite the large number of mitigation projects that have affected the native *ranchería* at
13 Mission Santa Clara, few comparable archaeobotanical datasets are currently available. Of note
14 are three uncharred tobacco (*Nicotiana* sp.) seeds that were recovered from the floor of the
15 Native-style dwelling mentioned above (Cummings et al. 2010).

16 17 **3. Materials and methods**

18 19 **3.1. Archaeological materials**

20
21 Twelve flotation samples totaling 217.5 liters in volume (range 3-119 liters) were analyzed in
22 this study. Samples were processed at the Archaeological Research Facility, UC Berkeley, using
23 a modified SMAP-type tank constructed by R. Cuthrell (Pearsall 2000), with 1 mm heavy
24 fraction mesh and ca. 0.2 mm light fraction mesh. After drying, light fractions were sieved into
25 the following size fractions for analysis: >4.0 mm, 2.0-4.0 mm, 1.0-2.0 mm, 0.5-1.0 mm, 0.3-0.5
26 mm, and <0.3 mm. Materials <0.3 mm were not analyzed. Light fractions were sorted under a
27 stereoscopic microscope with 5-50x magnification range. To expedite analysis, size fractions of
28 flotation samples were sometimes sub-sampled using a riffle splitter to 6.25-50.00% of size
29 fraction totals.

30
31 Tobacco seeds were present in 0.3-0.5 mm and 0.5-1.0 mm size fractions of flotation samples.
32 Due to morphological alteration, charred tobacco seeds were not included in this study. Whole,
33 uncharred tobacco seeds with high morphological integrity were selected for morphometric
34 analysis, encapsulated in 0.2 ml tubes, and assigned unique specimen numbers. Tobacco seeds
35 with minor fissures or indentations that appeared to retain their original shape were included in
36 analysis, while seeds exhibiting morphological alterations impacting seed shape were excluded.

37 38 **3.2. Comparative tobacco seed materials**

39
40 The tobacco comparative data set consisted of eleven samples representing seven tobacco species
41 (Table 1). These included two species native to California (*N. attenuata* and *N. quadrivalvis*),
42 two exotic species that may have been present in California during the early 1800s (*N. acuminata*
43 and *N. glauca*), four varieties of domesticated tobacco (*N. tabacum*), and two species originating
44 from South America (*N. rustica* and *N. sylvestris*). Tobacco seed comparative materials were
45 acquired from the USDA Germplasm Resources Information Network (USDA GRIN), the UC
46 Berkeley Botanical Garden, and field collections by R. Cuthrell and L. Panich. Specimens

collected in the field (*N. quadrivalvis* and *N. sylvestris*) were identified using the Jepson Manual (Baldwin et al. 2012).

The four varieties of *N. tabacum* chosen for inclusion in this study were collected from Mexico and Central America in the 1930s. We reasoned that these local cultivars may be closely related to domesticated tobacco shipped to the California missions in prior centuries. *N. rustica* was selected for inclusion because it was used by indigenous people of Mexico and North America before European colonization, and colonists from Mexico may have brought this species with them. The specimen of *N. sylvestris* analyzed was discovered growing in a garden less than 300 m from the Mission Santa Clara excavations. Although we have been unable to locate information about the antiquity of *N. sylvestris* in California, the earliest botanical records of this plant date to the 1940s, suggesting a 20th century introduction date (Consortium of California Herbaria 2015). We included this sample in the comparative collection to explore whether the modern plants growing in close proximity to Mission Santa Clara could be descended from tobacco grown there during the 19th century.

3.3. Morphometric analysis

Preliminary research on morphological features of tobacco seeds (e.g., shape, hilum configuration, surface reticulations, and others) conducted in preparation for this study suggested that the taxa of interest could not be differentiated using morphological feature analysis. Furthermore, we found it difficult to consistently apply morphological feature terminology, and this approach provides no measure of classification confidence. For these reasons, we chose to use an exclusively morphometric approach to tobacco seed classification.

To create digital images, tobacco seeds were placed laterally in a salt bath with a scale and photographed through an Olympus SZ61 microscope equipped with an Olympus DP72 camera. Morphometric data was collected using analytical tools to trace seed outlines in Olympus Microsuite software. Morphometric data was recorded using 15 shape parameters (Table 2).

From each modern comparative tobacco sample, the first 50 morphologically intact seeds encountered in a sorting tray were selected for morphometric analysis. Since the appearance of comparative specimens was not typically altered by adherent foreign bodies or taphonomic impacts, outlines of these specimens were often recorded by applying a threshold filter to binarize the image and using a “magic wand” tool to trace the outline (smoothing = 15).

When flotation samples contained less than 50 morphologically intact specimens in a size fraction, all specimens were analyzed. When more than 50 intact specimens were present in a size fraction (i.e., Flot #3, 0.3-0.5 mm; Flot #5, 0.5-1.0 mm), only the first 40 specimens encountered were included in morphometric analysis. Since foreign particles were sometimes present on the surface of archaeological tobacco seeds, and in some cases seeds displayed small fissures or other minor morphological irregularities, outlines of archaeological seeds were traced manually. A total of 323 archaeological specimens were analyzed.

3.4. Statistical analysis

Linear discriminant analysis (LDA) was used to identify morphometrically distinct taxon groups and to identify archaeological tobacco seeds. Morphometric data from modern comparative materials were imported into JMP software (statistics package, SAS Institute, Inc.) and LDA was performed using sample number (Table 1) as the dependent variable and all morphometric parameters (Table 2) as independent variables. Formulas for sample assignment were applied to archaeological specimens in a preliminary evaluation of group identity. Modern groups unlikely to contain members from the archaeological tobacco seed assemblage were excluded from the data set to improve the accuracy of discriminant analysis. Among the remaining sample groups, morphometrically distinct taxonomic groups were identified, creating new categories containing one or more comparative samples.

A second LDA was then performed using morphometrically distinct taxonomic group as the dependent variable and all morphometric parameters as independent variables. Formulas predicting group membership were applied to archaeological tobacco specimens. Specimens with >90% probability of membership in one group were identified as group members, while specimens with <90% probability of membership were designated as “indeterminate” in identity.

Based on subsample proportions, numbers of specimens in each size fraction were scaled to estimate total number of specimens per group and proportional representation of groups in each flotation sample. Due to potential complications from taphonomic effects, counts of charred and altered tobacco seeds were not included in these estimates, such that calculated counts and proportions represent only intact, uncharred tobacco seeds in each sample.

4. Results

4.1. Results of Macrobotanical Analysis

Results of tobacco seed macrobotanical analysis are presented in Table 3. Density of uncharred tobacco seeds ranged from 0.8-75.2 n/l (specimens per liter). Excluding sub-midden soils, eight of ten samples analyzed contained >10 n/l uncharred tobacco seeds. Densities of charred tobacco seeds were generally much lower, ranging from 0.0-0.2 specimens per liter outside of the pit feature. In the pit feature, charred tobacco seed density ranged from 0.8-7.8 n/liter, with an average density of 3.3 n/liter. Charred tobacco seeds represented 0.0-1.3% (average = 0.4%) of tobacco seeds per sample outside of the pit feature, and 2.7-22.1% (average = 11.5%) of tobacco seeds in the pit feature. These contrasting patterns suggest that most pit feature ash layers may represent contexts in which tobacco was intentionally burned, while tobacco seeds in other ash layers were incorporated after ash deposit formation.

4.2. Results of Morphometric Analysis.

Means and standard deviations of comparative sample morphometric parameters are presented in Tables 4 and 5. Figure 2 illustrates morphological variability of seeds within and between tobacco species. Specimens in the left column of the figure represent relatively common seed morphology for each species, while specimens in the middle and right columns illustrate the range of variability in seed size and shape. While some species can be consistently distinguished from one another on the basis of size alone (e.g., *N. rustica* is consistently larger than *N.*

1 *tabacum*, *glauca*, and *sylvestris*), in there is often considerable overlap between seed sizes and
2 shapes of seeds between species (e.g., between *N. acuminata*, *attenuata*, and *quadrivalvis*).
3 Surface reticulations are also variable within species and, due to their complex morphology, the
4 surface texture is difficult to consistently and meaningfully classify using morphological
5 terminology.

6 7 **4.3. Results of First Linear Discriminant Analysis** 8

9 The first linear discriminant analysis (LDA #1) was performed on all modern comparative
10 samples to determine which samples represented morphometrically distinct taxonomic groups
11 and to evaluate which of these groups were likely to contain representatives among the
12 archaeological assemblage (Figure 3). Assignment of specimens to sample groups was relatively
13 inaccurate in the overall analysis, with 34.0% of specimens miscategorized (Table 6). Along with
14 interpretation of results presented in Figure 3, this indicated that several sample groups in the
15 analysis were not morphologically distinct from one another.

16
17 Based on interpretation of Figure 3B, *N. sylvestris* and *N. rustica* were excluded from further
18 analysis because a) these groups appeared to contain few or no (respectively) potential members
19 from the archaeological assemblage that could not plausibly be members of other groups and b)
20 there are no historical or botanical records indicating their presence in 19th century California.
21 Among the remaining sample groups, three relatively morphometrically distinct taxonomic
22 groups were apparent: a group containing *N. glauca*, a group containing four samples of *N.*
23 *tabacum*, and a group containing two samples of *N. quadrivalvis* and one sample each of *N.*
24 *attenuata* and *N. acuminata* (designated “N. qu-at-ac”; Figure 3B).

25 26 **4.4. Results of Second Linear Discriminant Analysis** 27

28 The second linear discriminant analysis (LDA #2) was performed on morphometrically distinct
29 taxon groups identified through interpretation of LDA #1 results (Figure 4). Identification
30 accuracy in LDA #2 was much higher than LDA #1, with only 4.2% of comparative specimens
31 miscategorized (Table 7), indicating that the designated groups are relatively morphometrically
32 distinct from one another. Identification formulas from LDA #2 were applied to archaeological
33 tobacco seeds (n=323), resulting in positive identifications (>90% probability) of 76.2% of
34 specimens. Figure 5 presents examples of identified seeds in each of the three taxonomic groups.
35 Based on subsample proportions, estimated total numbers of specimens in each identification
36 category (Table 7) and proportions of categories were calculated for each sample (Figure 6).

37
38 About 60 of the 323 (18.6%) archaeological specimens analyzed in the second LDA lie outside
39 of the density ellipses representing comparative sample morphometric variation presented in
40 Figure 4B. Since the density ellipses represent 90% of sample variation, we would expect about
41 10% of specimens (ca. n = 32 archaeological specimens) to lie outside ellipse boundaries. Two
42 other factors may explain why there are additional specimens outside ellipse boundaries. First,
43 minor taphonomic alterations to archaeological specimens would be expected to shift a subset of
44 specimens outside the range of variation of comparative specimens. Second, the comparative
45 data set used in this analysis may not represent the entire range of morphometric variation
46 present in the archaeological assemblage.

1
2 In the overall archaeological assemblage, 49.8% of specimens were identified as *N. glauca*,
3 19.2% were identified as *N. tabacum*, and 10.9% were identified as *N. acuminata*, *N. attenuata*,
4 or *N. quadrivalvis* (Table 8). Among identified specimens (calculated total n = 1253.3), 86.3% of
5 specimens were identified as exotic species, and 13.7% could be native tobaccos or the exotic
6 species *N. acuminata*.

7
8 Among flotation samples from deposits outside of the pit feature, proportional taxonomic
9 representation of tobacco is similar between samples, with *N. glauca* comprising 60.6-79.5% and
10 *N. tabacum* 10.3-27.3% of specimens (Figure 6). *N. qu-at-ac* is generally absent, with only 5%
11 representation in a single sample from an interior context (Flot #8). Within the pit feature, two
12 samples from context 10025 (Flots #10 and #12) display composition similar to samples outside
13 of the pit feature. Three other samples from the pit feature (Flots #1, #2, and #5), each
14 representing a distinct context, contain higher proportions of tobacco seeds in the *N. qu-at-ac*
15 group, ranging from 19.8-36.4% of specimens per sample.

16 17 **5. Discussion**

18
19 Consistently moderate to high densities of uncharred tobacco seeds in nearly all flotation
20 samples suggest Native people cultivated, processed, and/or used tobacco in the excavation area.
21 Moderate density of tobacco seeds in one sub-midden context (3.3 seeds per liter) indicates that
22 bioturbation has altered the distribution of tobacco seeds in the midden to some extent, and thus
23 some proportion of tobacco seeds in exterior contexts could represent seeds incorporated after
24 the mid-1800s. By the late 1800s, the area had become densely populated, and it is less likely
25 that rodent bioturbation played a major role in site taphonomy afterwards. Interior and feature
26 contexts were relatively intact, and we think these accurately represent cultural uses during the
27 first half of the 19th century.

28
29 If tobacco plants were collected entire and hung to dry around the time of seed maturation, fruit
30 capsules would have opened and dispersed numerous seeds during the drying process. If plants
31 were not harvested entire, the viscid leaves of *N. tabacum* or “*N. qu-at-ac*” group plants with
32 adhering seeds could also have spread seeds into the area. Plants growing near the excavation
33 area could also have dispersed seeds naturally into the excavated contexts. Since tree tobacco (*N.*
34 *glauca*) does not have viscid leaves, these seeds could originate from branches with nearly
35 mature inflorescences hung to dry, or from natural dispersal of seeds from nearby plants. Very
36 high densities of uncharred tree tobacco seeds in one of the interior contexts (Flot #11, >20 n/l,
37 Figure 6), suggests tree tobacco may have been hung or stored inside the building. The low
38 density or absence of these seeds in the other two interior contexts (0.0 and 1.4 seeds/liter, Flots
39 #8 and 9) indicates seed distribution in this location is highly heterogeneous, and thus probably
40 not due to natural seed dispersal.

41
42 The consistent presence of domesticated tobacco (*N. tabacum*) seeds in the assemblage, with
43 densities up to ca. 5 n/l, indicates that domesticated tobacco was cultivated at Mission Santa
44 Clara, and was not exclusively imported. These data also suggest that topping of domesticated
45 tobacco was not a universal practice, if it was employed at all. Domesticated tobacco cultivation
46 after 1810 could have been spurred by cessation of shipments from San Blas. We have not

1 encountered documentary records reporting import of processed tree tobacco (*N. glauca*) to the
2 California missions. The high proportional representation of tree tobacco seeds in the assemblage
3 suggests that it was also cultivated at Mission Santa Clara.

4
5 Tobacco seeds in the “N. qu-at-ac” group could represent native tobaccos and/or the exotic
6 manyflower tobacco (*N. acuminata*). Comparison of Figures 2A and 2B suggests that of all
7 modern comparative samples in this group, archaeological specimens are most similar in shape
8 to native coyote tobacco (*N. attenuata*). However, because of the substantial overlap among seed
9 shapes in these samples, identification remains uncertain. Since seeds would be expected to
10 adhere to leaves of these plants, seeds in the N. qu-at-ac group may have been cultivated or
11 harvested from volunteer stands at Mission Santa Clara, collected from outside of the mission, or
12 acquired through trade.

13
14 Each flotation sample recovered from the pit feature contains higher percentages of charred
15 tobacco seeds (range=2.7-22.1% of seeds) than any sample from outside of the pit feature
16 (range=0.0-1.3%). A chi-square analysis indicates this difference in proportional representation
17 is highly statistically significant (Table 9). This pattern may be associated with use of the pit as a
18 depositional location for mourning ceremony materials. Higher proportional representation of
19 potentially native tobaccos among uncharred assemblages of tobacco seeds in the pit feature
20 (Figure 6) suggests Native people may have preferred native tobacco for ceremonial uses, if
21 these seeds do represent native tobacco deposited intentionally with mourning ceremony
22 materials. Lack of identification of charred specimens due to taphonomic alteration prevents
23 evaluation of whether native tobacco was more strongly associated with intentional burning.

24
25 Representing nearly half of the uncharred tobacco seed assemblage, the high proportion of tree
26 tobacco was unexpected. Because there is so little historical information about the use of tree
27 tobacco in the California missions, these data are difficult to interpret. As noted above,
28 informants associated with two missions south of Santa Clara reported that they did not know of
29 the plant or that it was a recent introduction not used by Native people. The high density of tree
30 tobacco seeds in an interior context (20.7 n/l; Flot #11) suggests that it was stored, processed, or
31 used indoors by Native people at Mission Santa Clara. Very high density of tree tobacco seeds in
32 an exterior midden context (32.6 n/l; Flot #3) could also represent a tree tobacco processing
33 location, or an area in proximity to a tree tobacco plant.

34 35 **6. Conclusions**

36
37 By applying morphometric analysis and linear discriminant analysis to an assemblage of tobacco
38 seeds unprecedented in quantity and preservation quality among California archaeological sites,
39 this study has revealed new information about indigenous tobacco use in an early 19th century
40 California mission setting. By the 1810s, Native people cultivated domesticated tobacco and
41 possibly tree tobacco at Mission Santa Clara. At least some portion of domesticated tobacco was
42 processed using traditional methods adapted from native tobacco processing, rather than using
43 the Spanish colonial method which involved topping the plants to remove inflorescences.
44 Domesticated tobacco use thus provides an example of a hybrid practice in which Native people
45 applied traditional uses to a novel organism. Details about tree tobacco use are unclear, however
46 its high density in an interior context suggests intentional storage or processing.

1
2 While incorporating domesticated tobacco and tree tobacco into ethnobotanical practice, Native
3 people at Mission Santa Clara probably continued to use native tobacco as well. However, this
4 interpretation is complicated by an inability to distinguish native tobacco seeds from the exotic
5 manyflower tobacco. Acquisition routes of this third tobacco group are unclear. This group is
6 more strongly associated with a pit feature containing materials probably associated with
7 mourning ceremony, which also contained higher proportions of burned tobacco seeds than other
8 contexts. If this group of tobacco seeds originates from native plants, it suggests that native
9 tobaccos may have retained an association with traditional ceremonies among Native people at
10 Mission Santa Clara in the early 19th century.

11
12 Future research could clarify some of the interpretive challenges identified in this study. Using
13 ancient DNA analysis, it may be possible to identify many of the uncharred tobacco seeds to
14 species level. However, these techniques are still in an early stage of development (Kistler 2012),
15 and analyses are expensive, destructive, and uncertain to yield results from materials as small as
16 tobacco seeds. Conducting morphometric analysis of charred seeds, although potentially much
17 more widely applicable in archaeobotanical research, also presents a new set of challenges
18 because the range of taphonomic effects from different charring conditions would need to be
19 replicated using modern materials. For seeds as similar in shape as tobacco seeds, we expect
20 charring substantially reduces the potential to identify seeds to low taxonomic levels. A final
21 possibility for clarifying or confirming tobacco seed identity, though perhaps unlikely to
22 succeed, is to attempt to germinate intact archaeological tobacco seeds. In collaboration with
23 botanists, we intend to pursue this possibility during the next phase of research.

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27
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34 **Figures**

35

Figure 1. Map of 2012 excavations at Mission Santa Clara showing flotation sample locations.

Figure 2. Examples of tobacco seeds from comparative samples. The three examples presented for each species were selected to illustrate the range of intraspecific morphological variability. row A = *Nicotiana acuminata* (A-1 = specimen N-03-47, A-2 = N-03-17, and A-3 = N-03-43); row B = *N. attenuata* (B-1 = N-02-28, B-2 = N-02-04, and B-3 = N-02-27); row C = *N. quadrivalvis* (C-1 = N-01-19, C-2 = N-01-39, and C-3 = N-01-38); row D = *N. rustica* (D-1 = N-04-25, D-2 = N-04-20, and D-3 = N-04-39); row E = *N. tabacum* (E-1 = N-08-30, E-2 = N-05-41, and E-3 = N-08-20); row F = *N. glauca* (F-1 = N-09-05, F-2 = N-09-37, and F-3 = N-09-38), and row G = *N. sylvestris* (G-1 = N-10-42, G-2 = N-10-19, and G-3 = N-10-43).

Figure 3. Plots of first and second canonical discriminant functions from first linear discriminant analysis on all comparative samples (LDA #1; see Table 1 and Table 6). **A** – Comparative collection specimen data grouped by sample with 50% density ellipses. Marker color assigned by sample and marker shape assigned according to morphometrically distinct taxon groups. **B** – Archaeological specimen data overlaid on comparative sample density ellipses. *N. sylvestris* and *N. rustica* excluded due to unlikelihood of representation among archaeological specimens. Remaining sample groups were categorized into three relatively morphometrically distinct taxon groups: the *N. glauca* group (containing one sample of *N. glauca*); the *N. tabacum* group (containing four samples of *N. tabacum*), and the *N. qu-at-ac* group (containing two samples of *N. quadrivalvis* and one sample each of *N. attenuata* and *N. acuminata*).

Figure 4. Plots of first and second canonical discriminant functions from second linear discriminant analysis on morphometrically distinct taxon groups (LDA #2; see Table 1 and Table 7). **A** – Comparative collection specimen data categorized by morphometrically distinct taxon groups with 90% density ellipses. Marker colors and shapes assigned according to taxon group. **B** - Archaeological specimen data overlaid on comparative sample density ellipses. Marker shape assigned according to identification from LDA #2 analysis. Samples with less than 90% probability of identification as a single taxon were designated “indeterminate.”

Figure 5. Examples of archaeological tobacco seeds from each of the three taxonomic groups used in LDA #2 (>90% category membership probability). Note that among uncharred archaeological seeds, surface texture is often degraded and/or obscured by adhering sediment. Row A = “*N. qu-at-ac*” group (A-1 = specimen F01-A009, A-2 = F02-B003, and A-3 = F02-A001), row B = *N. tabacum* (B-1 = F05-B031, B-2 = F04-B030, and B-3 = F05-A037), and row C = *N. glauca* (C-1 = F04-B009, C-2 = F03-B016, and C-3 = F03-B038).

Figure 6. Pie charts of tobacco taxonomic composition in flotation samples based on discriminant analysis assignment to morphologically distinct taxon groups. Flotation samples with less than 10 analyzed specimens are not presented (Flots #6 and #9). “N. qu-at-ac” designates the taxonomic group containing *N. quadrivalvis*, *N. attenuata*, and *N. acuminata*; “nr” = raw count of specimens; “nc” = calculated counts of intact tobacco specimens after scaling raw counts based on subsample proportions; “Ctx” = context number. Pie charts are based on proportions derived from calculated counts. Bar charts to the left of each pie chart present total density (specimens per liter) of uncharred and charred tobacco seeds in each flotation sample (uncharred density values include both intact and altered specimens).

Table 1

Sample #	LDA #2 Taxon Group	Specimens Analyzed	Accession #	Species	Area of Origin	Source	Collection Year
N-01	N. qu-at-ac	50	W6-46891	<i>Nicotiana quadrivalvis</i>	San Luis Obispo County, California, USA	USDA GRIN	2013
N-02	N. qu-at-ac	50	W6-43858	<i>Nicotiana attenuata</i>	California, USA	USDA GRIN	2012
N-03	N. qu-at-ac	50	W6-37495	<i>Nicotiana acuminata</i>	Nevada, USA	USDA GRIN	2010
N-04	n/a	50	PI-555555	<i>Nicotiana rustica</i>	Unknown	USDA GRIN	1962
N-05	N. tabacum	50	PI-114012	<i>Nicotiana tabacum</i>	Palmares, El General, Costa Rica	USDA GRIN	1936
N-06*	n/a	50	PI-555564	<i>Nicotiana suaveolens</i>	Australia	USDA GRIN	1961
N-07	N. qu-at-ac	50	None	<i>Nicotiana quadrivalvis</i>	San Benito County, California, USA	Field collection, R. Cuthrell	2014
N-08	N. tabacum	50	PI-116183	<i>Nicotiana tabacum</i>	Yerbanis, Durango, Mexico	USDA GRIN	1936
N-09	N. glauca	50	37.0012	<i>Nicotiana glauca</i>	Berkeley, California, USA	UCB Botanical Garden	2014
N-10	n/a	50	None	<i>Nicotiana sylvestris</i>	Santa Clara, California, USA	Field collection, L. Panich	2015
N-11	N. tabacum	50	PI-114574	<i>Nicotiana tabacum</i>	Encarnacion, Jalisco, Mexico	USDA GRIN	1935
N-12	N. tabacum	50	PI-114551	<i>Nicotiana tabacum</i>	Tuxtepec, Oaxaca, Mexico	USDA GRIN	1935

Table 1. Origin and accession information for modern comparative tobacco samples included in this study. “LDA Taxon Group” identifies membership in morphometrically distinct taxon categories identified through linear discriminant analysis. *Sample N-06 was originally labeled as *N. quadrivalvis* in the GRIN database. After analysis showed these seeds to be highly morphologically distinct from other *N. quadrivalvis*, additional research into the origin of these specimens determined that they were actually Australian *N. suaveolens* that had been relabeled after collection. This sample was excluded from analysis.

Table 2

Shape Parameter	Description
Area	Two dimensional extent of the object in mm ² .
Aspect Ratio	Ratio of maximum length to orthogonal width.
Central Distance Maximum	Maximum distance between object centroid and boundary in mm.
Central Distance Mean	Mean distance between object centroid and boundary in mm.
Central Distance Minimum	Minimum distance between object centroid and boundary in mm.
Convex Area	Area of convex hull bounding the object in mm ² .
Convex Perimeter	Length of convex hull bounding the object in mm.
Convexity	Ratio of object area to area of convex hull bounding object.
Elongation	A measure of lack of object roundness, related to sphericity.
Feret Diameter Maximum	Maximum distance between two parallel lines bounding object in mm.
Feret Diameter Mean	Mean distance between two parallel lines bounding object in mm.
Feret Diameter Minimum	Minimum distance between two parallel lines bounding object in mm.
Perimeter	Length of object boundary in mm.
Shape Factor	A measure of object compactness.
Sphericity	A measure of object roundness using central moments.

Table 2. Shape parameters used in morphometric analysis.

Table 3

Context	10017	10017	10019	10019	10019	10021	10021	10025	10025	10026	10027	10028	TOTAL
Flotation Sample #	3	4	8	9	11	6	7	10	12	1	5	2	
Context Group	Midden	Midden	Interior	Interior	Interior	Sub-Mid.	Sub-Mid.	Pit	Pit	Pit	Pit	Pit	
Volume (liters)	17.5	8.5	8.5	6.0	3.0	10.0	10.0	5.0	3.0	119.0	9.5	17.5	217.5
0.5-1.0 mm Subsample %	25	50	100	100	50	100	100	100	100	6.25	100	25	
0.3-0.5 mm Subsample %	25	50	50	100	50	100	100	50	50	6.25	100	12.5	
Raw Counts													
0.5-1.0 mm Uncharred	0	1	5	2	0	2	4	20	7	32	213	10	296
<i>Intact</i>	0	0	3	1	0	1	2	3	5	12	*77	7	34
<i>Altered</i>	0	1	2	1	0	1	2	17	2	20	136	3	185
0.5-1.0 mm Charred	0	0	0	0	0	0	0	4	3	5	27	0	39
0.3-0.5 mm Uncharred	329	75	15	7	86	6	80	62	23	72	248	21	1024
<i>Intact</i>	*190	42	8	2	39	2	31	16	11	10	45	3	209
<i>Altered</i>	139	33	7	5	47	4	49	46	12	62	203	18	625
0.3-0.5mm Charred	0	1	0	0	0	0	1	0	6	9	47	2	66
Sample Total	329	77	20	9	86	8	85	86	39	118	535	33	1425
Calculated Counts													
0.5-1.0 mm Uncharred	0	2	5	2	0	2	4	20	7	512	213	40	807
<i>Intact</i>	0	0	3	1	0	1	2	3	5	192	77	28	312
<i>Altered</i>	0	2	2	1	0	1	2	17	2	320	136	12	495
0.5-1.0 mm Charred	0	0	0	0	0	0	0	4	3	80	27	0	114
0.3-0.5 mm Uncharred	1316	150	30	7	172	6	80	124	46	1152	248	168	3499
<i>Intact</i>	760	84	16	2	78	2	31	32	22	160	45	24	1256
<i>Altered</i>	556	66	14	5	94	4	49	92	24	992	203	144	2243
0.3-0.5mm Charred	0	2	0	0	0	0	1	0	12	144	47	16	222
Total Uncharred Calc. Count	1316	152	35	9	172	8	84	144	53	1664	461	208	4306
Total Charred Calc. Count	0	2	0	0	0	0	1	4	15	224	74	16	336
Total Intact Calc. Count	760	84	19	3	78	3	33	35	27	352	122	52	1568
Total Altered Calc. Count	556	68	16	6	94	5	51	109	26	1312	339	156	2738
Total Sample Calc. Count	1316	154	35	9	172	8	86	148	68	1888	535	224	4643
Percent Charred	0.0	1.3	0.0	0.0	0.0	0.0	1.2	2.7	22.1	11.9	13.8	7.1	7.2
Densities (n/liter)													
0.5-1.0 mm Uncharred	0.0	0.2	0.6	0.3	0.0	0.2	0.4	4.0	2.3	4.3	22.4	2.3	3.7
<i>Intact</i>	0.0	0.0	0.4	0.2	0.0	0.1	0.2	0.6	1.7	1.6	8.1	1.6	1.4
<i>Altered</i>	0.0	0.2	0.2	0.2	0.0	0.1	0.2	3.4	0.7	2.7	14.3	0.7	2.3
0.5-1.0 mm Charred	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	1.0	0.7	2.8	0.0	0.5
0.3-0.5 mm Uncharred	75.2	17.6	3.5	1.2	57.3	0.6	8.0	24.8	15.3	9.7	26.1	9.6	16.1
<i>Intact</i>	43.4	9.9	1.9	0.3	26.0	0.2	3.1	6.4	7.3	1.3	4.7	1.4	5.8
<i>Altered</i>	31.8	7.8	1.6	0.8	31.3	0.4	4.9	18.4	8.0	8.3	21.4	8.2	10.3
0.3-0.5mm Charred	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.0	4.0	1.2	4.9	0.9	1.0
Total Uncharred Density	75.2	17.9	4.1	1.5	57.3	0.8	8.4	28.8	17.7	14.0	48.5	11.9	19.8
Total Charred Density	0.0	0.2	0.0	0.0	0.0	0.0	0.1	0.8	5.0	1.9	7.8	0.9	1.5
Total Sample Density	75.2	18.1	4.1	1.5	57.3	0.8	8.6	29.6	22.7	15.9	56.3	12.8	21.3

Table 3. Summary data on archaeological tobacco seeds. “Intact” seeds are those that appeared to be morphologically intact, while “altered” seeds displayed indentations, cracking, splitting, or other features that made them inappropriate for morphometric analysis. “Sub-Mid.” designates samples collected from soil layers below midden deposits. *These samples contained more than 50 seeds per size fraction, and only the first 40 seeds encountered were included in morphometric analysis.

Table 4

Sample #	Species	n	Area (mm ²)		Perimeter (mm)		Aspect Ratio		Ferret Max (mm)		Ferret Mean (mm)		Ferret Min (mm)		Central Distance Max (mm)		Central Distance Mean (mm)		Central Distance Min (mm)	
			mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
N-01	N. quadrivalvis	50	0.432	0.047	2.596	0.149	1.287	0.090	0.850	0.053	0.771	0.042	0.654	0.045	0.441	0.028	0.371	0.020	0.260	0.023
N-02	N. attenuata	50	0.400	0.057	2.518	0.174	1.287	0.134	0.822	0.065	0.747	0.050	0.627	0.051	0.430	0.031	0.358	0.025	0.260	0.026
N-03	N. acuminata	50	0.452	0.048	2.678	0.140	1.283	0.134	0.873	0.058	0.794	0.041	0.671	0.053	0.456	0.028	0.381	0.020	0.271	0.030
N-04	N. rustica	50	0.643	0.105	3.108	0.252	1.294	0.105	1.031	0.098	0.930	0.076	0.792	0.069	0.535	0.048	0.453	0.037	0.354	0.037
N-05	N. tabacum	50	0.291	0.023	2.147	0.096	1.419	0.112	0.725	0.038	0.639	0.027	0.506	0.031	0.375	0.024	0.307	0.013	0.235	0.015
N-07	N. quadrivalvis	50	0.464	0.042	2.731	0.114	1.277	0.103	0.883	0.042	0.807	0.034	0.681	0.038	0.464	0.019	0.386	0.017	0.265	0.018
N-08	N. tabacum	50	0.362	0.035	2.341	0.107	1.318	0.094	0.784	0.033	0.701	0.031	0.594	0.050	0.402	0.017	0.340	0.016	0.278	0.024
N-09	N. glauca	50	0.230	0.027	1.921	0.108	1.441	0.136	0.658	0.045	0.574	0.032	0.451	0.038	0.345	0.021	0.273	0.016	0.198	0.020
N-10	N. sylvestris	50	0.188	0.024	1.722	0.115	1.509	0.140	0.598	0.044	0.518	0.035	0.393	0.028	0.310	0.022	0.248	0.016	0.181	0.013
N-11	N. tabacum	50	0.356	0.028	2.337	0.091	1.343	0.084	0.785	0.037	0.698	0.027	0.581	0.030	0.400	0.019	0.338	0.013	0.269	0.016
N-12	N. tabacum	50	0.313	0.031	2.200	0.112	1.336	0.119	0.737	0.048	0.659	0.034	0.544	0.035	0.392	0.026	0.318	0.016	0.252	0.019

Table 4. Summary of morphometric data by sample for the following morphometric parameters: area, perimeter, aspect ratio, feret diameter maximum, feret diameter mean, feret diameter minimum, central distance maximum, central distance mean, and central distance minimum. See Table 2 for morphometric parameter descriptions. s.d. = standard deviation.

Table 5

Sample #	Species	n	Elongation		Shape Factor		Sphericity		Convex Perimeter (mm)		Convex Area (mm ²)		Convexity	
			mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.	mean	s.d.
N-01	N. quadrivalvis	50	1.315	0.092	0.804	0.027	0.587	0.083	2.548	0.142	0.444	0.048	0.974	0.009
N-02	N. attenuata	50	1.311	0.136	0.790	0.023	0.599	0.115	2.472	0.166	0.412	0.058	0.972	0.013
N-03	N. acuminata	50	1.316	0.148	0.791	0.029	0.596	0.115	2.627	0.141	0.466	0.048	0.971	0.012
N-04	N. rustica	50	1.302	0.111	0.832	0.018	0.603	0.100	3.075	0.252	0.651	0.106	0.988	0.004
N-05	N. tabacum	50	1.425	0.113	0.792	0.026	0.502	0.078	2.112	0.093	0.296	0.023	0.982	0.006
N-07	N. quadrivalvis	50	1.317	0.107	0.781	0.022	0.588	0.097	2.663	0.116	0.481	0.043	0.965	0.009
N-08	N. tabacum	50	1.318	0.098	0.827	0.016	0.585	0.088	2.317	0.104	0.368	0.036	0.984	0.004
N-09	N. glauca	50	1.455	0.137	0.780	0.029	0.484	0.091	1.898	0.108	0.236	0.027	0.974	0.013
N-10	N. sylvestris	50	1.522	0.149	0.796	0.024	0.444	0.088	1.711	0.115	0.191	0.024	0.986	0.005
N-11	N. tabacum	50	1.351	0.083	0.818	0.019	0.554	0.066	2.305	0.088	0.363	0.028	0.980	0.006
N-12	N. tabacum	50	1.337	0.118	0.812	0.019	0.571	0.091	2.178	0.111	0.319	0.032	0.982	0.004

Table 5. Summary of morphometric data by sample for the following morphometric parameters: elongation, shape factor, sphericity, convex perimeter, convex area, and convexity. See Table 2 for morphometric parameter descriptions. s.d. = standard deviation.

Table 6

Categories		Comparative Samples
# of Categories		11
Total Specimens		550
Specimens Misclassified		187
% Misclassified		34.0
Canonical Discriminant Functions	Eigenvalue	Cumulative %
Canonical 1	12.24	68.4
Canonical 2	2.55	82.6
Canonical 3	1.91	93.3
Canonical 4	0.43	95.7
Canonical 5	0.32	97.5
Canonical 6	0.23	98.8

Table 6. Details of first linear discriminant analysis (LDA #1).

Table 7

Categories	Morphometrically Distinct Taxon Groups	
# of Categories	3	
Total Specimens	450	
Specimens Misclassified	19	
% Misclassified	4.2	
Canonical Discriminant Functions	Eigenvalue	Cumulative %
Canonical 1	5.63	78.3
Canonical 2	1.56	100.0

Table 7. Details of second linear discriminant analysis (LDA #2).

Table 8

Context	10017	10017	10019	10019	10019	10021	10021	10025	10025	10026	10027	10028	TOTAL
Flotation Sample #	3	4	8	9	11	6	7	10	12	1	5	2	
Context Group	Midden	Midden	Interior	Interior	Interior	Sub-Mid.	Sub-Mid.	Pit	Pit	Pit	Pit	Pit	
Volume (liters)	17.5	8.5	8.5	6.0	3.0	10.0	10.0	5.0	3.0	119.0	9.5	17.5	217.5
0.5-1.0 mm Subsample %	25	50	100	100	50	100	100	100	100	6.25	100	25	
0.3-0.5 mm Subsample %	25	50	50	100	50	100	100	50	50	6.25	100	12.5	
LDA #2 Raw Count Data													
0.5-1.0 mm													
<i>N. glauca</i>	0	0	0	0	0	0	0	0	1	0	0	0	1
<i>N. qu-at-ac</i>	0	0	1	0	0	0	0	1	1	7	12	2	24
<i>N. tabacum</i>	0	0	0	0	0	1	2	2	3	2	11	5	26
<i>Indeterminate</i>	0	0	2	1	0	0	0	0	0	3	17	0	23
0.3-0.5 mm													
<i>N. glauca</i>	30	27	6	0	31	0	20	10	6	1	6	1	138
<i>N. qu-at-ac</i>	0	0	0	0	0	0	0	0	0	1	1	1	3
<i>N. tabacum</i>	5	6	1	2	4	1	7	3	2	4	19	0	54
<i>Indeterminate</i>	5	9	1	0	4	1	4	3	3	4	19	1	54
0.5-1.0 mm Total Analyzed	0	0	3	1	0	1	2	3	5	12	40	7	74
0.3-0.5 mm Total Analyzed	40	42	8	2	39	2	31	16	11	10	45	3	249
Total Specimens Analyzed	40	42	11	3	39	3	33	19	16	22	85	10	323
LDA #2 Calculated Count Data													
0.5-1.0 mm													
<i>N. glauca</i>	0	0	0	0	0	0	0	0	1	0	*0	0	1
<i>N. qu-at-ac</i>	0	0	1	0	0	0	0	1	1	112	*23.1	8	146.1
<i>N. tabacum</i>	0	0	0	0	0	1	2	2	3	32	*21.2	20	81.2
<i>Indeterminate</i>	0	0	2	1	0	0	0	0	0	48	*32.7	0	83.7
0.3-0.5 mm													
<i>N. glauca</i>	*570	54	12	0	62	0	20	20	12	16	6	8	780
<i>N. qu-at-ac</i>	*0	0	0	0	0	0	0	0	0	16	1	8	25
<i>N. tabacum</i>	*95	12	2	2	8	1	7	6	4	64	19	0	220
<i>Indeterminate</i>	*95	18	2	0	8	1	4	6	6	64	19	8	231
0.5-1.0 mm Calculated Total	0	0	3	1	0	1	2	3	5	192	77	28	312
0.3-0.5 mm Calculated Total	760	84	16	2	78	2	31	32	22	160	45	24	1256
Calculated Total Count	760	84	19	3	78	3	33	35	27	352	122	52	1568
Calculated Density													
<i>N. glauca</i>	32.6	6.4	1.4	0.0	20.7	0.0	2.0	4.0	4.3	0.1	0.6	0.5	3.6
<i>N. qu-at-ac</i>	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.2	0.3	1.1	2.5	0.9	0.8
<i>N. tabacum</i>	5.4	1.4	0.2	0.3	2.7	0.2	0.9	1.6	2.3	0.8	4.2	1.1	1.4
<i>Indeterminate</i>	5.4	2.1	0.5	0.2	2.7	0.1	0.4	1.2	2.0	0.9	5.4	0.5	1.4
Calculated Total Density	43.4	9.9	2.2	0.5	26.0	0.3	3.3	7.0	9.0	3.0	12.8	3.0	7.2

Table 8. Results of linear discriminant analysis identification of archaeological tobacco seeds using a 90% probability threshold for identification (LDA #2). "Sub-Mid." = sub-midden contexts. *In order to estimate size fraction totals per identification category, these numbers were calculated by multiplying the number of seeds in each identification category by the ratio of total seeds in the size fraction to seeds analyzed (see Table 3).

Table 9

	Pit Feature	Other Contexts
Uncharred seeds	2530	1776
Charred seeds	333	3
$\chi^2 = 214.7$		
df = 1		
p < 0.0001		

Table 9. Chi-square analysis of calculated totals of charred and uncharred tobacco seeds in the pit feature and in all other excavated contexts.