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Shaping wood in the Canary Islands: First experimental dataset focused on tool marks of Prehispanic wooden artifacts

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ABSTRACT

The first settlers of the Canary Islands arrived at this archipelago from northern Africa between the 2nd and 5th centuries CE. These communities probably knew metallurgy in their area of origin, although an adaptation process must have taken place for the successful development of woodworking strategies based on stone/bone technologies in a volcanic archipelago. In this paper, the first experimental program focusing on Prehispanic indigenous woodworking activities is presented. Conducted in 2022 in Tenerife, 41 experiments explored technological traces of specific woodworking actions and techniques, using replicas of tools made from obsidian, coarse-grained volcanic and pumice rocks, as well as transformed ovicaprid bones serving as bone chisels, wooden wedges and hammers. The experimentation addressed some of the woodworking *chaîne opératoire* stages, generating a reference collection of tool marks produced under controlled variables. The obtained experimental dataset enabled statistical comparisons with diverse archaeological artifacts in terms of typology and origin. Our results provide preliminary observations regarding actions, types of tools and techniques. In addition, this data suggests that the technological adaptation of aboriginal societies to woodworking with non-metal tools produced similar results on different islands.

1. Introduction

The volcanic archipelago of the Canary Islands is located in north-west Africa, ~100 km off the Saharan coast. It is made up of eight islands with great environmental diversity and a unique set of native vegetation types (Del Arco et al., 2010, 2006; Fernandopullé, 1976). Human colonization of this archipelago is relatively recent, occurring between the 2nd and 5th centuries (c.) CE by Amazigh communities from northern Africa (Fregel et al., 2020; Serrano et al., 2023). To date, there is no clear archaeological evidence of contact between islands or with the mainland until the arrival of European explorers in the 14th-15th c. CE. However, there is evidence of Romanized people visiting the Archipelago, exchanging some goods, as it is documented in Lanzarote Island (Atoche Peña et al., 2023) and even exploiting some raw materials, as can be seen in the remains of a purple dye workshop from the Early Roman Empire period (1st c. BCE) on the Islet of Lobos, although it represents a relatively short occupation (Núñez-Lahuerta et al., 2023).

The indigenous people of the Canary Islands were agropastoral groups whose economy was based on the introduction of crops and domesticated animals, the gathering of wild plants, shellfish, and fishing. Isolation, the different environmental conditions of each island, time, as well as cultural or demographic particularities, determined the

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progressive diversification of habitats and the material culture. Consequently, lithic and ceramic productions exhibit distinct typologies and unique traits specific to each island, influenced by the availability and characteristics of raw material (e.g., obsidian is only documented on three of the seven inhabited islands). Regarding woodworking activities, artifacts in the archipelago were crafted with tools made of stone, wood, bone and other plant or animal materials. Therefore, even if the initial settlers possessed metallurgical knowledge in their region of origin, an adaptation process would have been necessary for the successful evolution of woodworking techniques rooted in stone and bone technologies. In this sense, although traceological analyses in the Canary Islands are still scarce, there is evidence of obsidian flakes, rarely retouched, serving for scraping or splitting wood (Naranjo-Mayor and Rodríguez Rodríguez, 2015; Rodríguez-Rodríguez, 1998a) and larger unifacial/bifacial examples or larger retouched and non-retouched flakes serving for chopping, sawing and scraping wood (Rodríguez-Rodríguez, 1998b, 1993).

1.1. The Canary Islands: A necessary plant technology approach

Technological aspects in past societies are mostly studied through durable materials frequently preserved in the archaeological record such as stone, pottery, or metal. Past woodworking activities are poorly represented in the archaeological record due to the perishable nature of wooden artifacts (Blanchette, 2000; Moskal del Hoyo et al., 2010; Toriti et al., 2021). This leads to a bias in our understanding of wood processing that can be partially rectified by indirect studies such as functional analyses of stone tools (Bencomo Viala et al., 2020; Domínguez-Rodrigo et al., 2001; Hardy and Garufi, 1998). Waterlogged or arid contexts with exceptional preservation of organic matter highlight the importance of perishable organic materials in the past (Hurcombe, 2014). These contexts have provided direct woodworking evidence by applying a plant-based technological approach through tool-mark and wear analyses on wooden objects (López-Bultó et al., 2020a, 2020b; Milks et al., 2023; Pillonel, 2007; Piqué et al., 2015; Rios-Garaizar et al., 2018; Sands, 1997; Vidal-Matutano et al., 2021b). The gradual adoption of this analytical approach is key to deepening our understanding about wood procurement strategies shaped by cultural choices, traditional crafts, and technological constraints (woodworking with lithic tools vs. metal tools).

The Canary Islands present an exceptional desiccated wooden assemblage from the Prehispanic period including containers, construction timber, funerary objects, a coffin and wooden sticks from domestic and funerary contexts (Vidal-Matutano et al., 2020, 2021a). Some specific issues of ancient indigenous lifeways can be gleaned from historical written sources produced by the European explorers arriving in the archipelago in the 15th c. (Torriani, 1978, [1592]: 99; Abreu Galindo, 1977, [1632]: 159). However, these documents essentially provide data as to the indigenous population living in the moment of contact and cannot be extrapolated to previous chronological periods. Furthermore, data related to wood manufacturing processes are absent in these texts. According to this, the outstanding preservation of desiccated wooden objects from the Prehispanic period constitutes an excellent opportunity to approach past indigenous woodworking activities in these oceanic islands.

Tool-mark analyses on Prehispanic wooden artifacts were recently applied to several wooden remains from aboriginal communal granaries of Gran Canaria (Vidal-Matutano et al., 2020, 2021b). In parallel, technological analyses of Prehispanic wooden artifacts from different islands of the archipelago have been carried out since 2022. This previous archaeological research has motivated the development of the first experimental program focused on woodworking activities among the aboriginal groups of the Canary Islands.

1.2. Questions and aims

In this study, we aimed to test the reproduction of archaeological tool marks through the implementation of a specific experimental program considering different variables. In this sense, the primary goal of our experimental program was not to reproduce specific artifacts but to produce and document tool marks during some of the actions of the *chaîne opératoire.* Therefore, the experimentation aimed to relate stop marks, striations and facets to specific woodworking actions and techniques. The new experimental dataset presented here could contribute significantly to archaeological data relevant to the Island Archaeology, mainly in the case of the Canarian archipelago but also in the context of other islands where the inhabitants had to develop woodworking activities with volcanic tools (Ayers and Mauricio, 1987; Collerson and Weisler, 2007). These new data will also be of interest to researchers focused on the Palaeolithic-Mesolithic-Neolithic periods where woodworking activities were developed with lithic/bone/shell tools (López-Bultó et al., 2020a; Milks et al., 2023; Palomo et al., 2013; Rios-Garaizar et al., 2018).

Our experimental data will serve to compare tool marks on wooden objects from different islands of the archipelago, ultimately assessing whether the woodworking techniques were convergent or divergent after the arrival of the first settlers in each island. Our research questions are:

1.- Can we relate stop marks with specific woodworking actions and tools?

2.- Can we establish a relationship between striations and specific woodworking actions and tools?

3.- Can we associate facet marks to a specific type of tool (stone vs. bone)?

4.- Can we identify the woodworking knapping technique (direct/indirect percussion) through tool marks?

2. Material and methods

2.1. Experimental activities and material

Experimental work took place in Tenerife in 2022 with a total of 41 experiments and the participation of 8 contributors. For each experiment, the wood raw material, the woodworking action, the knapping technique, the tools used, the number of people involved, and the duration were documented (Table 1). Some experiments were superimposed on another action (e.g., roughing over debarking) to obtain a set of work marks closer to the archaeological record with the overlapping of technological traces produced in different phases of the *chaîne opératoire*. As this was the first experimental program on woodworking by the aboriginal groups of the Canary Islands, the combinations between actions, knapping techniques, and tools were randomized to obtain tool marks that could be compared with the archaeological record. All experiments were documented by photographs and video.

Wood raw material for the experiments was collected in Tenerife (Anaga Rural Park) and Gran Canaria (Finca Osorio) with the corresponding environmental permits. The raw material was green wood collected 3 months prior to the experimentation and the selected taxa corresponded to some of the most common species archaeologically documented during the analysis of aboriginal wooden objects: *Pinus canariensis* (Canary Island pine), *Salix canariensis* (Canary Island willow), *Morella faya* (Firetree), *Erica arborea* (Tree heath) and *Erica platycodon* (Canarian Heather) (Vidal-Matutano et al., 2021a, 2021b).

Tool replicas were made from stone (Fig. 1 a-e), bone (Fig. 1 f) and wood (Fig. 1 g-h). Stone tools were configurated according to previous lithic and functional analyses from Prehispanic contexts (Rodríguez-Rodríguez 1993; Galván and Hernández, 1996; Rodríguez-Rodríguez 1998a; 1998b). Obsidian, coarse-grained volcanic rocks, and pumice rocks were collected from different locations of Tenerife and La Gomera. Some lithic tools were also made with basaltic material of columnar

Table 1
Experimental data.

Experiment	Wood raw material	Burnt surface	Woodworking action	Previous woodworking action	Knapping technique	Tool	Nb. of people involved	Duration
1	*Pinus canariensis*	No	Debarking	No	Direct	Coarse-grained volcanic rock flake	1	15′ 38′′
2	*Pinus canariensis*	No	Debarking	No	Direct	Coarse-grained volcanic rock flake	1	4′ 45′′
3	*Pinus canariensis*	No	Debarking	No	Direct	Coarse-grained volcanic rock pick	1	7′ 28′′
4	*Pinus canariensis*	Yes	Debarking	No	Direct	Coarse-grained volcanic rock flake	1	18′ 14′′
5	*Pinus canariensis*	Yes	Debarking	No	Direct	Coarse-grained volcanic rock pick	1	4′ 15′′
6	*Pinus canariensis*	Yes	Debarking	No	Indirect	Basalt pick and wooden hammer	1	9′ 42′′
7	*Pinus canariensis*	No	Debarking	No	Direct	Coarse-grained volcanic rock pick	4	43′ 14′′
8	*Pinus canariensis*	No	Longitudinal splitting	No	Indirect	Coarse-grained volcanic rock flake, wooden wedges and wooden hammer	1	8′ 43′′
9	*Salix canariensis*	No	Roughing	No	Direct	Coarse-grained volcanic rock pick	1	63′ 18′′
10	*Pinus canariensis*	No	Roughing	Debarking	Indirect	Coarse-grained volcanic rock flake and wooden hammer	1	30′ 00′′
11	*Pinus canariensis*	No	Roughing	No	Indirect	Bone chisel and wooden hammer	1	23′ 32′′
12	*Salix canariensis*	No	Roughing	No	Indirect	Basalt flake and wooden hammer	1	20′ 00′′
13	*Salix canariensis*	No	Longitudinal splitting	Roughing	Indirect	Coarse-grained volcanic rock flake, wooden wedge and wooden hammer	2	6′ 00′′
14	*Morella faya*	No	Debarking	No	Indirect	Coarse-grained volcanic rock flake and wooden hammer	2	15′ 57′′
15	*Morella faya*	No	Debarking	No	Direct	Coarse-grained volcanic rock pick	1	10′ 54′′
16	*Morella faya*	No	Debarking	No	Indirect	Coarse-grained volcanic rock pick and wooden hammer	1	21′ 26′′
17	*Pinus canariensis*	No	Debarking	No	Indirect	Coarse-grained volcanic rock flake and wooden hammer	1	14′ 38′′
21	*Pinus canariensis*	No	Roughing	Debarking	Indirect	Coarse-grained volcanic rock flake and wooden hammer	1	10′ 08′′
22	*Pinus canariensis*	Yes	Roughing	No	Indirect	Coarse-grained volcanic rock flake and wooden hammer	1	47′ 19′′
23	*Pinus canariensis*	Yes	Roughing	No	Direct	Coarse-grained volcanic rock pick	1	50′ 24′′
24	*Pinus canariensis*	Yes	Roughing	No	Direct	Coarse-grained volcanic rock pick	1	58′ 31′′
25	*Pinus canariensis*	No	Roughing	Debarking	Indirect	Columnar disjunction flake and wooden hammer	1	8′ 02′′
26	*Pinus canariensis*	No	Roughing	Debarking	Indirect	Columnar disjunction flake + coarse-grained volcanic rock flake + wooden hammer	1	10′ 01′′
27	*Pinus canariensis*	No	Regularization	No	Indirect	Bone chisel and wooden hammer	1	21′ 26′′
28	*Pinus canariensis*	No	Regularization	No	Indirect	Bone chisel and wooden hammer	1	8′ 02′′
29	*Pinus canariensis*	No	Regularization	No	Indirect	Bone chisel and wooden hammer	1	21′ 26′′
30	*Pinus canariensis*	No	Regularization	No	Indirect	Hafted obsidian flake and wooden hammer	1	39′ 55′′
31	*Salix canariensis*	No	Debarking	No	Direct	Obsidian flake	2	43′ 00′′
32	*Salix canariensis*	No	Debarking	No	Direct	Coarse-grained volcanic rock flake	2	50′ 00′′
33	*Salix canariensis*	No	Regularization	Debarking	Indirect	Bone chisel and wooden hammer	1	18′ 00′′
34	*Erica platycodon*	No	Debarking	No	Direct	Hafted columnar disjunction flake	5	51′ 00′′
35	*Erica platycodon*	No	Regularization	Debarking	Indirect	Bone chisel and wooden hammer	3	38′ 00′′
36	*Erica platycodon*	No	Debarking	No	Indirect	Coarse-grained volcanic rock flake and wooden hammer	2	15′ 00′′
37	*Erica platycodon*	No	Regularization	Debarking	Indirect	Bone chisel and wooden hammer	1	12′ 00′′
38	*Erica arborea*	No	Debarking	No	Indirect	Coarse-grained volcanic rock flake and wooden hammer	1	19′ 41′′

(*continued on next page*)

Table 1 (*continued*)

Experiment	Wood raw material	Burnt surface	Woodworking action	Previous woodworking action	Knapping technique	Tool	Nb. of people involved	Duration
39	*Erica arborea*	No	Debarking	No	Direct	Coarse-grained volcanic rock pick	3	40′ 00′’
40	*Erica arborea*	No	Regularization	Debarking	Indirect	Bone chisel and wooden hammer	2	27′ 56′’
41	*Erica arborea*	No	Polishing	Regularization	Direct	Pumice rock	2	41′ 00′’

Fig. 1. Examples of experimental tool replicas and the woodworking actions developed during the experimental program: a) coarse-grained volcanic rock flake; b) obsidian flake; c) coarse-grained volcanic rock pick; d) columnar disjunction fragment; e) pumice rock; f) bone chisel; g) wooden hammer; h) wooden wedge; i) debarking; j) longitudinal splitting; k) roughing; l) planing/regularization; m) abrasion/polish.

disjunctions from Tenerife targeting the creation of edges that were straight and less than 45° to replicate observed technological traces. Regarding bone tools, several bone chisels were manufactured although the role that bone tools may have played in aboriginal woodworking activities remains unknown. Even if Prehispanic bone industries have been developed very little since Galván's typological classification (Galván, 1979), use-wear traces visible on some bone chisels from Gran Canaria indicate plant processing activities. Replicas of wooden wedges and hammers were also produced despite these tool types not yet being identified in the archaeological record.

2.2. Woodworking actions

The main goal of the experimental program was not the reproduction of a specific artifact but the production and recording of tool marks during some of the actions of the *chaîne opératoire* (Fig. 1 i-m). The experimentation revolved around the following actions/phases which have been defined in Vidal-Matutano et al. (under review).

2.2.1. Debarking

A total of 17 debarking experiments were performed (Table 1). Three experiments used a pine trunk with charred bark from a natural fire to assess the ease of performing this action. Direct and indirect percussion were carried out using coarse-grained volcanic rock /obsidian flakes, coarse-grained picks, and a hafted columnar disjunction fragment. Chopping and scraping activities were frequently undertaken during the experiments.

2.2.2. Longitudinal splitting

Two experiments focused on this action through indirect percussion using coarse-grained volcanic rock flakes, wooden wedges, and a wooden hammer (Table 1).

2.2.3. Roughing

Ten experiments were devoted to this action using both direct (picks) and indirect (coarse-grained volcanic rock flakes, bone chisels and columnar disjunction fragments) percussion (Table 1). The controlled use of fire was applied in three experiments focused on shaping the tangential section of the wood. Bidirectional work, chopping, variation of the working angle (90°/30-40° tool angle) and tool dragging were documented.

2.2.4. Regularization/planing

Eight planing experiments were performed by indirect percussion using bone chisels, a hafted obsidian flake and a wooden hammer (Table 1). Variation of the working angle (90°/30-40° tool angle), direction (front-to-back or back-to-front) and orientation (oblique or longitudinal) were the considered variables.

2.2.5. Abrasion/Polish

Only a single experiment was carried out since few polished surfaces had been observed up to the experimental design phase. Pumice rock in direct contact with the wood surface was used in this experiment (Table 1).

2.3. Archaeological wooden artifacts

Since 2022, several wooden objects manufactured by the aboriginal populations of the Canarian archipelago have been analyzed from a technological perspective. Tool marks documented on 22 Prehispanic artifacts (Table 2) are here compared to the experimental data obtained. The selection of objects was based on the presence of tool marks, their function, the provenance and the type of archaeological context -funerary or domestic- from which they were recovered. The selected objects come from Gran Canaria (n = 5), La Gomera (n = 5), La Palma (n = 5), El Hierro (n = 1) and Tenerife (n = 6). Most of the Prehispanic wooden objects do not come from archaeological excavations but were recovered during old expeditions, casual finds, or spoliations and were deposited in museums, losing their archaeological contextualization in many cases (Vidal-Matutano et al., 2021a). Even so, in some cases, the type of context (funerary/domestic) is known, despite having lost their archaeological contextualization (specific archaeological site). In this sense, the selected wooden artifacts come mostly from funerary contexts (funerary boards, wooden sticks, cist closures), due to the long trajectory of Canarian archaeology in the analysis of human remains from burial caves and other sepulchral structures (Table 2) (Alberto-Barroso et al., 2016; Arnay de la Rosa et al., 2017; Delgado-Darias et al., 2021). Two objects come from domestic contexts while for seven artifacts there is no available data on the archaeological site or the type of context (Table 2).

Table 2
Archaeological wooden artifacts considered in this work.

ID	Origin	Site or Area	Context	Type of artifact	Taxa
1614	Gran Canaria	Los Barros	Domestic	Structural element	*Pinus canariensis*
2704	Gran Canaria	Las Crucecitas	Funerary	Cist closure	*Pinus canariensis*
11,758	Gran Canaria	Las Crucecitas	Funerary	Cist closure fragment	*Pinus canariensis*
11,749	Gran Canaria	Unknown	Funerary	Funerary board	*Dracaena draco*
3271	Gran Canaria	Guayadeque	Domestic	Door	Lauraceae
ULL-621	La Gomera	Andén de la Carreta	Funerary	Funerary board	*Pinus canariensis*
TAG-083	La Gomera	Tejeleches	Funerary	Wooden stick fragment	*Salix canariensis*
IZQ-10	La Gomera	Los Polieros – Cave E	Funerary	Wooden stick fragment	*Salix canariensis*
IZQ-11	La Gomera	Los Polieros – Cave E	Funerary	Wooden stick fragment	Fabaceae
IZQ-14	La Gomera	Los Polieros – Cave E	Funerary	Wooden stick fragment	Lauraceae
169	La Palma	Unknown	Funerary	Possible grave goods	cf. *Salix canariensis*
170	La Palma	Unknown	Funerary	Possible grave goods	cf. *Morella faya*
250	La Palma	Unknown	Unknown	Wooden stick	Lauraceae
249	La Palma	Unknown	Unknown	Wooden stick	Lauraceae
NHM-1	La Palma	Huerto de Los Morales	Funerary	Funerary board fragment	*Pinus canariensis*
865–1	El Hierro	Guarazoca	Funerary	Funerary board	*Juniperus turbinata* ssp. *canariensis*
1198.1	Tenerife	El Portillo	Funerary	*añepa*	*Pinus canariensis*
1198.2	Tenerife	El Portillo	Funerary	*añepa*	*Pinus canariensis*
296	Tenerife	Taburco	Funerary	Funerary board	*Pinus canariensis*
784/5	Tenerife	Risco de los Guanches	No archaeological associated context	Wooden stick	*Morella faya*
318	Tenerife	Unknown	Unknown	Possible *añepa*	Lauraceae
307	Tenerife	Unknown	Unknown	*añepa*	Fabaceae

2.3.1. *Funerary boards*

Archaeological research regarding Prehispanic funerary contexts from the archipelago has yielded abundant evidence of desiccated wood remains directly associated with burials (Vidal-Matutano et al., 2021a). One of the most represented elements is the funerary boards (i.e., wooden boards for transporting and depositing bodies in funerary caves), which are present throughout the archipelago except in the two easternmost islands (Fuerteventura and Lanzarote). This work includes five funerary boards from five islands (ID 865–1, ID 296, ID 11749, ID ULL-621, and ID NHM-1), recovered at different times from unknown burial contexts (Table 2, Fig. 2).

2.3.2. *Wooden sticks and añepas*

Regarding funerary wooden sticks, their use as an element for transporting bodies or to provide consistency within the funerary bundle has been suggested (Del Arco, 1993; Vidal-Matutano et al., 2021a), although the interpretation as elements used during the life of the individuals (i.e., walking sticks) and deposited in the sepulchral contexts cannot be ruled out. Three wooden stick fragments (ID IZQ-10, ID IZQ-11, and ID IZQ-14, Table 2, Fig. 3b, c, d) come from the sepulchral site of Los Polieros – Cave E (La Gomera) dated between 383–535 cal. AD (Sánchez-Cañadillas et al., 2021). Another wooden stick fragment (ID TAG-083, Table 2, Fig. 3a) from the same island comes from Tejeleches, a burial site dated between 1045 – 1214 cal. AD (Sánchez-Cañadillas et al., 2021). Two complete wooden sticks come from La Palma (ID 249 and ID 250, Table 2, Fig. 3f-g), although from unknown archaeological contexts. Finally, one wooden stick (ID 784/5, Table 2, Fig. 3e) comes from Risco de los Guanches, Tenerife, and was recovered along with a wooden container and a few pottery vessels with no clear associated context (Diego Cuscoy, 1974).

The *añepas* (an Amazigh word) are distinctive wooden objects from Tenerife which, according to historical written sources, were batons evidencing the hierarchy of the Mencey or chief of each territorial demarcation of this island (Diego Cuscoy, 1968a, 1968b). Here, two *añepas* from El Portillo burial site (ID 1198.1 and ID 1198.2, Table 2, Fig. 3h-i) and two others with no archaeological contextualization (ID 318 and ID 307, Table 2, Fig. 3j-k) are included.

2.3.3. *Cist closures and structural elements*

Wooden cist closures (ID 2704 and ID 11758, Table 2, Fig. 4a-b) come from the necropolis of Las Crucecitas, Gran Canaria. Jiménez Sánchez (1946) describes them as wooden covers from a large cist containing the human remains of 14 individuals. A human bone from this necropolis was dated between 1184 – 1275 cal. AD (Santana-Cabrera et al., 2011-2012). Regarding structural elements, ID 1614 (Table 2, Fig. 4c) comes from Los Barros (Gran Canaria), and is part of the construction material used in the settlement. This archaeological context has been dated between 642 – 772 cal. AD (Navarro Mederos, 1990).

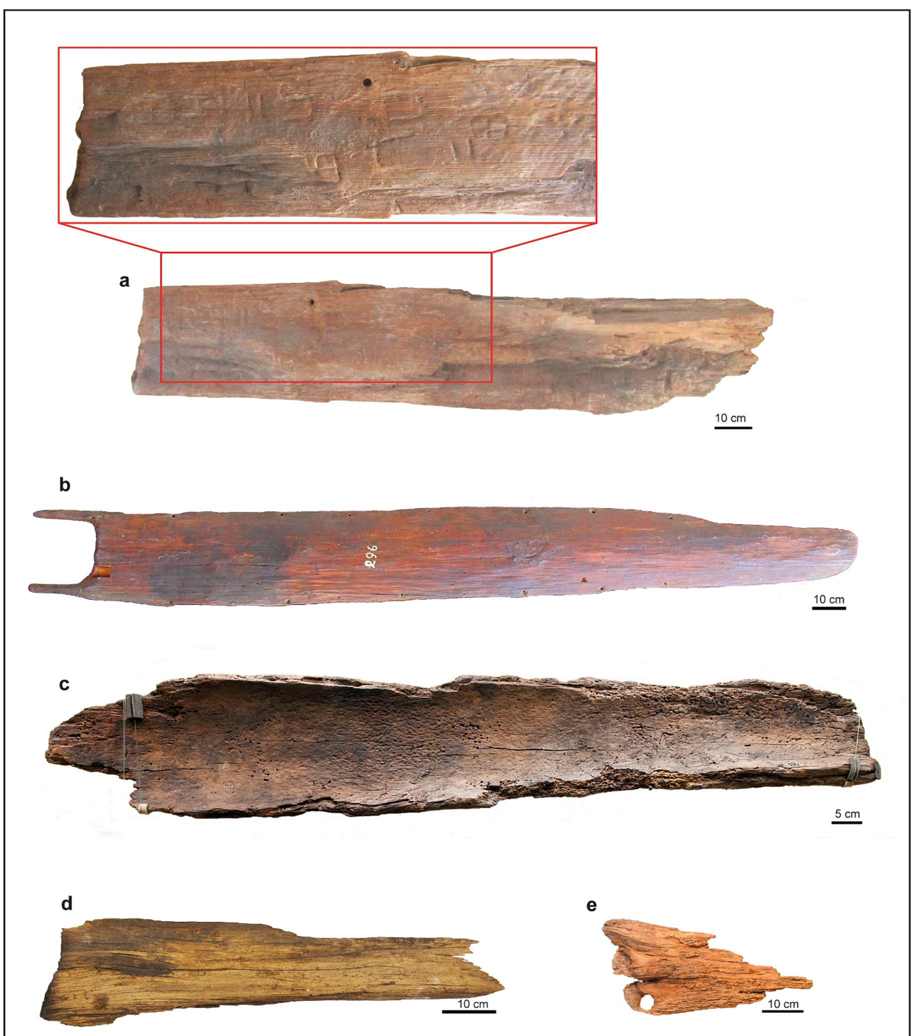

Fig. 2. Funerary boards considered in this work: a) ID 865-1, note the Lybico-Berber inscriptions on this funerary board, being the only Prehispanic wooden artifact showing these engravings; b) ID 296; c) ID 11749; d) ID ULL-621; e) ID NHM-1.

Fig. 3. Wooden sticks: a) ID TAG-083; b) ID IZQ-11; c) ID IZQ-14; d) ID IZQ-10; e) ID 784/5; f) ID 249; g) ID 250. *Añepas*: h) ID 1198.1; i) ID 1198.2; j) ID 307; k) ID 318 (a-c scale bar = 5 cm; d-k scale bar = 10 cm).

Finally, a wooden door (ID 3271, Table 2, Fig. 4d) comes from an unknown domestic context or a communal granary from the Guayadeque area (Gran Canaria).

2.3.4. Others

Two wooden artifacts from La Palma, which are unparalleled in other islands of the archipelago, have been included in this work (ID 168 and ID 170, Table 2, Fig. 4e-f). These artifacts come from an unknown funerary context and have been interpreted as boomerangs, weapons or, most likely, grave goods (Del Arco, 1993; Diego Cuscoy, 1968a).

2.4. Tool-mark and use-wear analysis

Archaeological wooden artifacts and experimental samples were analyzed with a Leica EZ4 W stereoscopic microscope with integrated camera (8-35x magnification) and treated with *Helicon Focus* software. Each trace or negative detected on the surface of wood was analyzed by recording its dimensions, depth, stop marks, orientation, distribution, concentration, section, etc. (see Pardo-Gordó and Vidal-Matutano, 2024) and documented with a 105 mm F2.8 macro lens. Surface modifications such as polished or abrasion areas, charring surfaces or fibre deformation were also recorded. Glossary and analytical terms used during the analysis of the archaeological and experimental material have followed the nomenclature used in Vidal Matutano et al., (2021b)

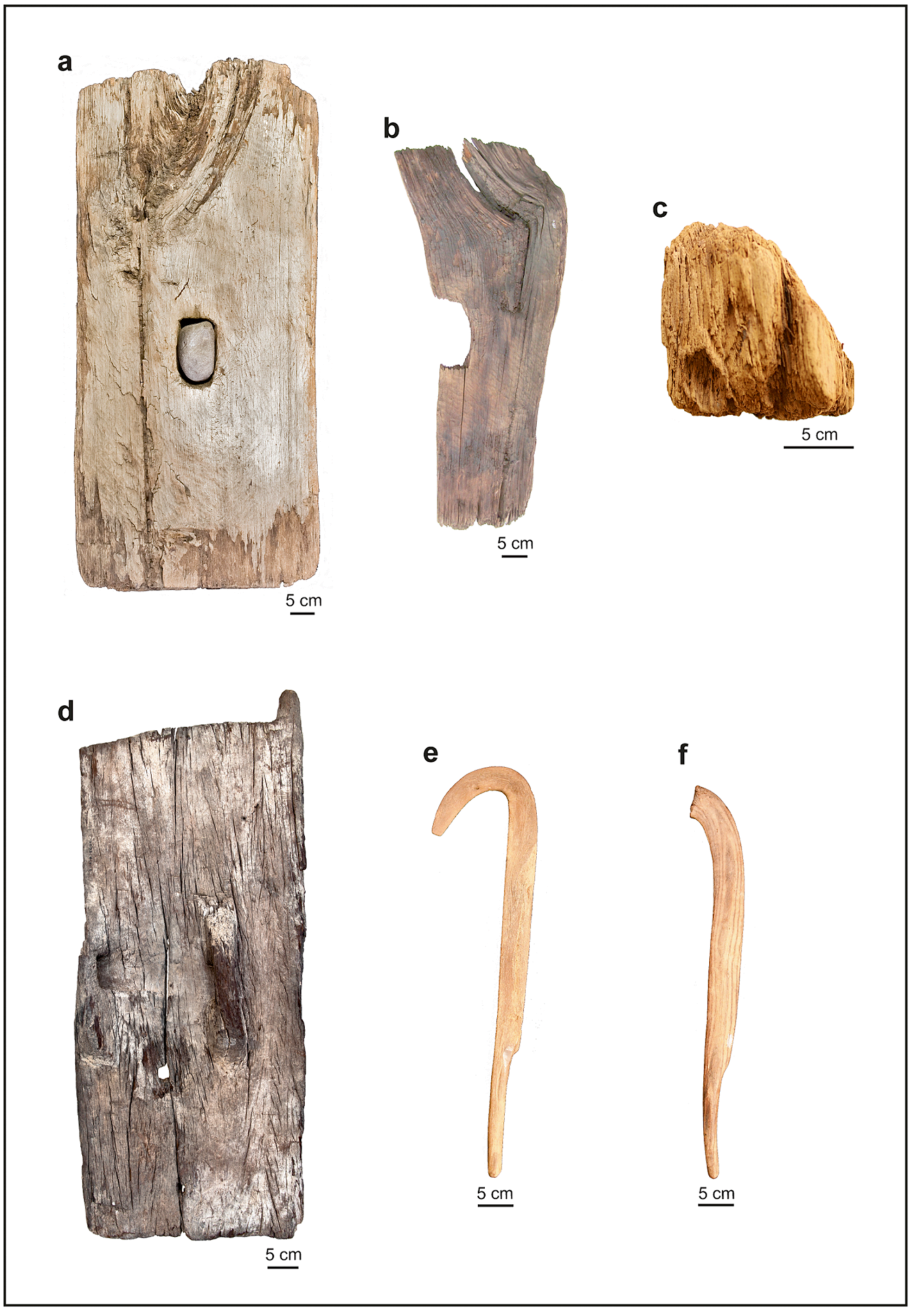

Fig. 4. Cist closures: a) ID 2704; b) ID 11758. Structural elements: c) ID 1614; d) ID 3271. Possible grave goods: e) ID 169; f) ID 170.

and Milks et al., (2021). Residue samples were taken from several archaeological wooden objects, which may provide information regarding the use or repair actions of the artifacts.

2.5. Statistical analyses

Classification methods were applied considering the mixt nature of our data (numerical and categorical variables). These variables were converted into a distance matrix for experimental-archaeological data comparison (see SM-1 and SM-2 for details). Absolute frequency data are generally measured using the Brainerd-Robinson coefficient (Robinson and Brainerd, 1952) whilst presence/absence values are usually calculated using the Hamming or Jaccard distance (Hamming, 1950; Jaccard, 1901). Here, Gower's coefficient (Gower, 1971) was applied to obtain the dissimilarity distance resulting in a number between 0 (identical observations) and 1 (maximum dissimilarity). *K-means* algorithm (Jin and Han, 2010) was performed to explore possible clusters of observations, a method widely used (Hodson, 1970; Aldenderfer, 1982; Simek, 1984; Vidal-Matutano, 2017). The establishment of the minimum number of clusters was achieved using the Elbow method (Schubert, 2023). *K-means* was recalculated by applying the Random Forest method which relies on machine learning to obtain a robust result from the generation and combination of data (Breiman, 2001). All statistical analyses and plots were performed with R software in its version 4.3.1 (Core Team, 2023) using several packages such as *cluster* (Maechler et al., 2022), *FactorMineR* (Lê et al., 2008), *factorextra* (Kassambara and Mundt, 2020), *cluster* (Maechler et al., 2022), *ggpubr* (Kassambara, 2023) and *randomForest* (Liaw and Wiener, 2002).

3. Results

3.1. Can we relate stop marks with specific woodworking actions and tools?

The following variables of the experimental dataset were considered to answer this question: action, tool, presence/absence of stop marks, front-type (step, hinge, or feather), width, depth, angle, orientation, and direction of the accident. The optimal number of clusters was established (Fig. 5a), developing the *K-means* approximation (Fig. 5c) and the Random Forest algorithm (Fig. 5d). Following previous observations, the best statistical results were obtained with the Random Forest approach (74.6 %) compared to *K-means* (66.2 %).

Of the 7 groups considered, only two of them presented acceptable similarity values (Fig. 5b):

- Group 3 (n = 12; Gower value of 0.24): step/feather/hinge terminations, straight/curved-front, longitudinal orientation, isolated marks, 45°-90° working angle, < 1 mm depth. All cases have been generated using flakes during debarking.
- Group 7 (n = 20; Gower value of 0.2): step terminations, straight-front, longitudinal orientation, isolated marks, 45°-90° working angle, mostly ≥ 10 mm depth. All cases have been generated using picks and flakes during debarking.

Regarding archaeological marks, 32 of 93 features present an acceptable degree of similarity with the experimental groups considered (SM-2, Question 3.1). Archaeological observations 163 and 165 are close to Group 3. Features no. 7, 18, 24, 32, 45, 50, 52, 54, 60, 61, 67, 120, 121, 131, 134, 135, 140, 142, 172, 175, 176, 180, 181 and 187 fit into Group 7. Finally, some archaeological observations (no. 21, 47, 51, 53, 127, 162, 164) present acceptable similarity values to both experimental groups but mainly to Group 7.

3.2. Can we establish a relationship between striations and specific woodworking actions and tools?

The following variables of the experimental dataset were considered to address this issue: action, tool, length, width, depth, orientation, angle, and section of the mark. After the establishment of the optimal number of clusters (Fig. 6a), the calculation of *K-means* (Fig. 6c), and the Random Forest algorithm (Fig. 6d), the results with a higher degree of explanation were obtained with *K-means* (65.9 %) compared to Random Forest (60.8 %).

Only 3 of the 7 groups considered have acceptable Gower values (Fig. 6b):

- Group 3 (n = 4; Gower value of 0.24): mostly transversal orientation, < 90° working angle, ≤ 20 mm length, ≤ 1 mm width, < 1 mm depth, generated from the regularization of the final surface using bone chisels.
- Group 4 (n = 7; Gower value of 0.30): oblique orientation, < 90° working angle, 10–15 mm maximum length, < 1 mm width, < 1 mm depth, V-shaped section, mostly associated to marks, generated from

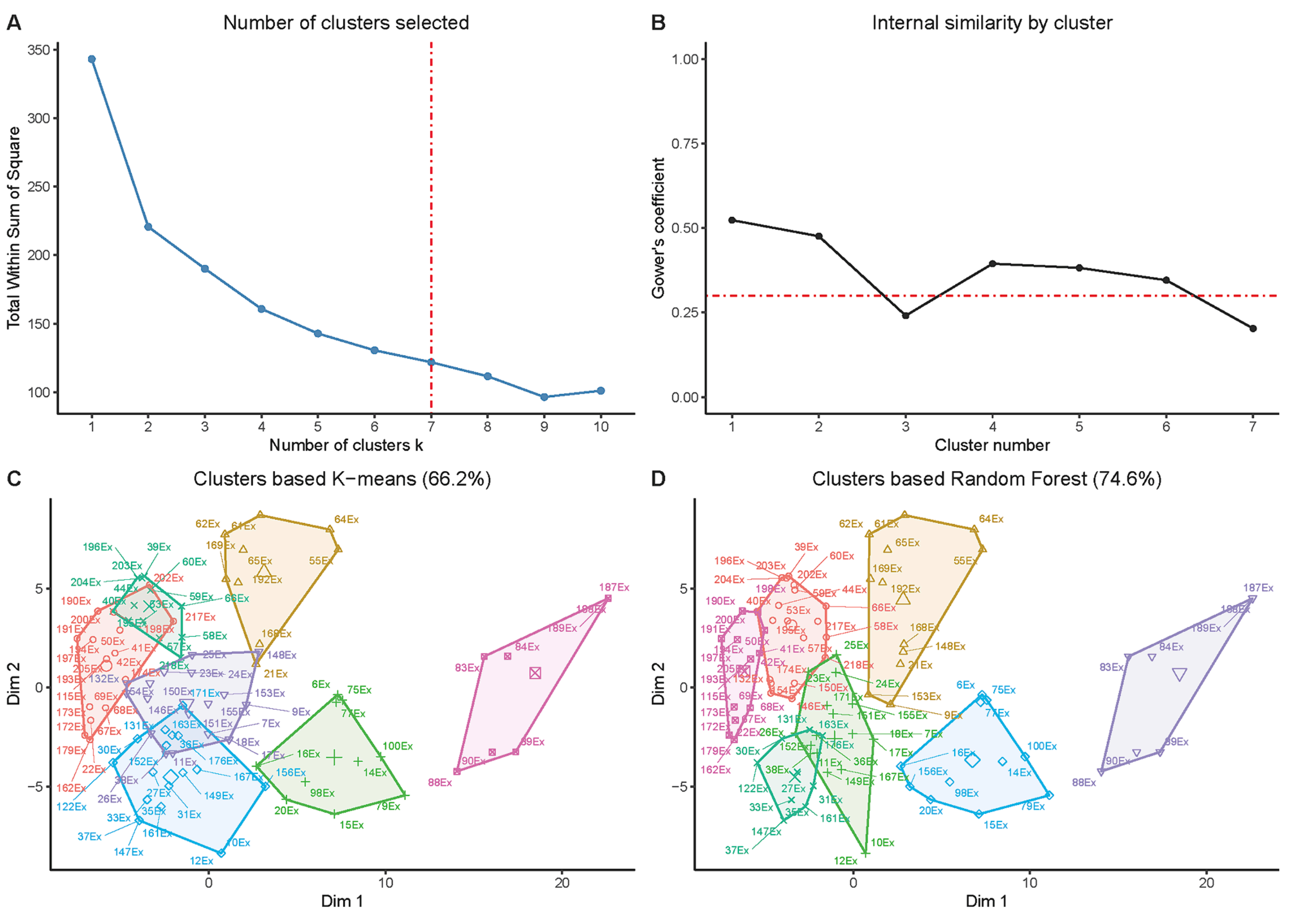

Fig. 5. Statistical results on experimental data related to stop marks, actions and tools. A) Exploration of the sum of squares from K-means. The vertical line indicates the number of groups considered. B) Gower coefficient indicating the internal similarity of the clusters defined in 3D: 1 (△), 2 (◇), 3 (X), 4 (+), 5 (▽), 6 (•) and 7 (⊠). The horizontal line refers to the maximum accepted similarity threshold (0.3, corresponding to 70 % similarity between observations within each cluster). C) Representation of K-means analysis. D) K-means recalculation using the Random Forest approach.

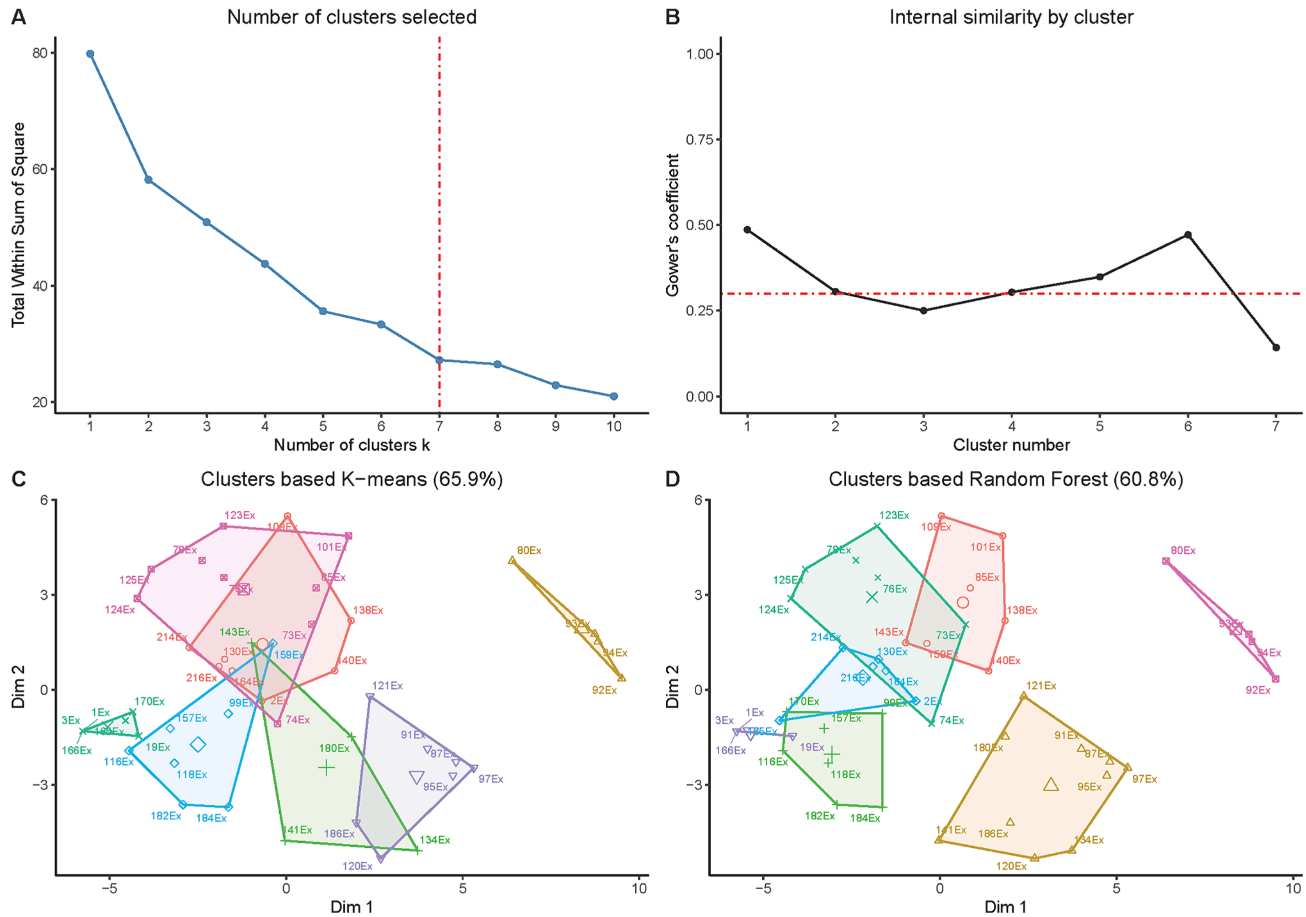

Fig. 6. Statistical results on experimental data related to striations, actions and tools. A) Exploration of the sum of squares from K-means. The vertical line indicates the number of groups considered. B) Gower coefficient indicating the internal similarity of the clusters defined in 4C: 1 (○), 2 (△), 3 (+), 4 (◇), 5 (⊠), 6 (▽) and 7 (X). The horizontal line indicates the maximum accepted similarity threshold (0.3, corresponding to 70 % similarity between observations within each cluster). C) Representation of K-means analysis. D) K-means recalculation using the Random Forest approach.

the regularization of the final surface using bone chisels and obsidian/coarse-grained volcanic rock flakes.

- Group 7 (n = 6; Gower value of 0.14): oblique orientation, parallel marks, < 90° working angle, 10–6 mm maximum length, < 1 mm width, < 1 mm depth, V-shaped section, mostly associated to marks. The observations in this group are associated to debarking using coarse-grained volcanic rock flakes.

Of the 72 archaeological features considered, 4 of them show an acceptable degree of similarity with the experimental groups (SM-2, Question 3.2). Accidents no. 66, 150, 161 and 197 are associated to Group 7.

3.3. *Can we relate facet marks to a specific type of tool (stone vs. bone)?*

The following variables of the experimental dataset related to this issue were considered: tool, presence/absence of stop marks, front-type (step, hinge or feather), maximum and minimum width, depth, and orientation of facet marks. Once the optimal number of clusters (Fig. 7a), the *K-means* (Fig. 7c), and the Random Forest algorithm (Fig. 7d) were obtained, the best aggrupation was observed through *K-means* (81.5 %) compared to the Random Forest approach (78 %).

All groups considered show an internal consistency according to Gower's coefficient (Fig. 7b):

- Group 1 (n = 2; Gower value of 0.14): hinge termination, curved-front, 5–8 mm maximum width, < 1 mm depth, longitudinal/oblique orientation, produced during regularization using bone chisels.
- Group 2 (n = 4; Gower value of 0.16): feather termination, curved-front, oblique orientation, 9–10 mm maximum width, 1–2 mm depth, generated from the regularization using bone chisels.
- Group 3 (n = 4; Gower value of 0.14): feather/hinge termination, curved-front, oblique orientation, 5–7 mm maximum width, 1 mm depth, produced during regularization using bone chisels.
- Group 4 (n = 2; Gower value of 0.07): step termination, curved/straight-front, longitudinal/oblique orientation, 6 mm minimum width, 3 mm depth, generated from the regularization using bone chisels.
- Group 5 (n = 2; Gower value of 0.14): step termination, straight-front, longitudinal orientation, 11–6 mm maximum width, 1–2 mm depth, produced during regularization using a bone chisel (observation no. 142) and an obsidian flake (no. 119).

Regarding the archaeological record, 4 accidents of a total of 13 were considered to show an acceptable degree of similarity with the experimental groups (SM-2, Question 3.3): accident no. 216 indicates similarity with Group 1; observations no. 11 and 167 are close to Group 3 and accident no. 16 is associated with Group 4.

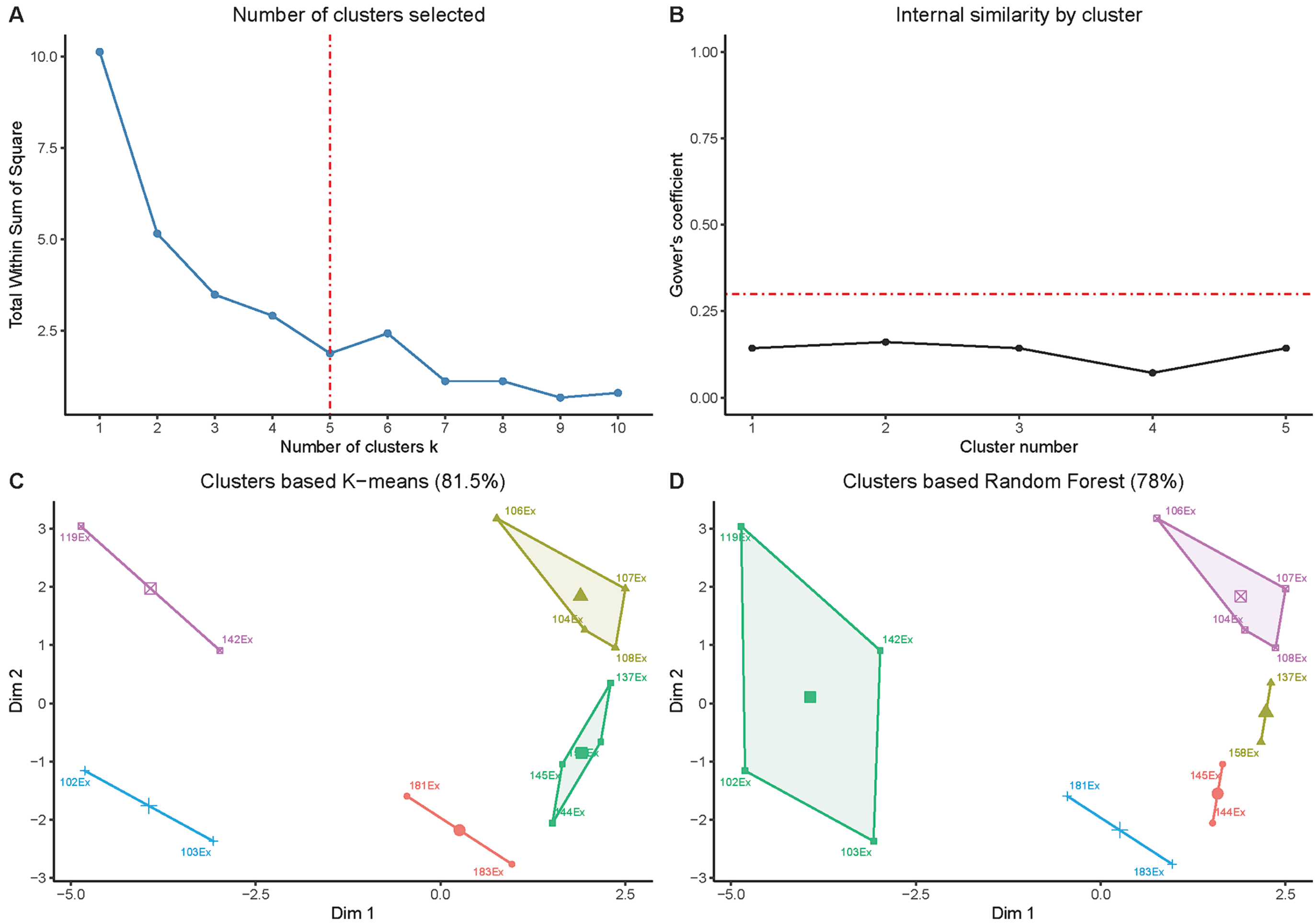

Fig. 7. Statistical results on experimental data related to facet marks and tools. A) Exploration of the sum of squares from K-means. The vertical line indicates the number of groups considered. B) Gower coefficient indicating the internal similarity of the clusters defined in 5C: 1 (●), 2 (△), 3 (■), 4 (+) and 5 (⊠). The horizontal line indicates the maximum accepted similarity threshold (0.3, corresponding to 70 % similarity between observations within each cluster). C) Representation of K-means analysis. D) K-means recalculation using the Random Forest approach.

3.4. *Can we identify the woodworking knapping technique (direct percussion / indirect percussion) through tool marks?*

The variables of the experimental dataset linked to this issue were considered (knapping technique, termination, front-type, orientation, work angle, and direction of the accident) and the optimal number of clusters was established (Fig. 8a). The running of the *K-means* approximation (Fig. 8c) and the Random Forest algorithm (Fig. 8d) identified the results with a higher degree of explanation with Random Forest (83.8 %) compared to *K-means* (73.7 %).

Of the 7 statistical groups obtained, 5 of them presented acceptable similarity values (Fig. 8b):

- Group 1 (n = 11; Gower value of 0.23): direct percussion, step termination, straight-front, 45°-90° working angle, longitudinal/oblique orientation, 2–10 mm maximum width, 10–20 mm depth, mostly generated from debarking using picks and coarse-grained volcanic rock flakes.
- Group 2 (n = 12; Gower value of 0.15): indirect percussion, hinge/step termination, straight/curved-front, 45°-90° working angle, longitudinal orientation, 7–12 mm maximum width, < 1 mm depth, produced during debarking using picks and coarse-grained volcanic rock flakes.
- Group 5 (n = 18; Gower value of 0): direct percussion, step termination, straight-front, 45°-90° working angle, longitudinal orientation, 2–12 mm maximum width, 10–30 mm depth, mostly generated from debarking using picks and coarse-grained volcanic rock flakes.
- Group 6 (n = 16; Gower value of 0.16): indirect percussion, step termination, straight-front, 45°-90° working angle, longitudinal orientation, 2–17 mm maximum width, 10–30 mm depth, frequently bidirectional work, produced during debarking and roughing using mostly picks and coarse-grained volcanic rock flakes, excluding observations no. 17 (bone chisel) and no. 21 (wooden wedge).
- Group 7 (n = 18; Gower value of 0.24): indirect percussion, step termination, straight-front, 45°-90° working angle, oblique orientation, 5–17 mm maximum width, ≥ 15 mm depth, parallel marks, generated from debarking and roughing using picks and coarse-grained volcanic rock flakes, excluding observation no.16 (bone chisel).

Of the 93 archaeological marks considered, 79 show an acceptable degree of similarity with the experimental groups (SM-2, Question 3.4). Among accidents that can be related to more than one group, the one with the highest similarity value has been selected. Archaeological marks no. 1, 132, 163, 165 and 166 are associated with Group 2. Most of the archaeological accidents considered for this issue (no. 2, 4, 7, 18, 20, 21, 24, 31, 32, 37, 45, 47, 50, 51, 52, 53, 54, 57, 58, 60, 61, 62, 67, 68, 71, 72, 73, 118, 120, 121, 127, 131, 133, 134, 135, 138, 140, 142, 144, 145, 151, 158, 162, 164, 168, 172, 174, 175, 176, 178, 179, 180, 181,

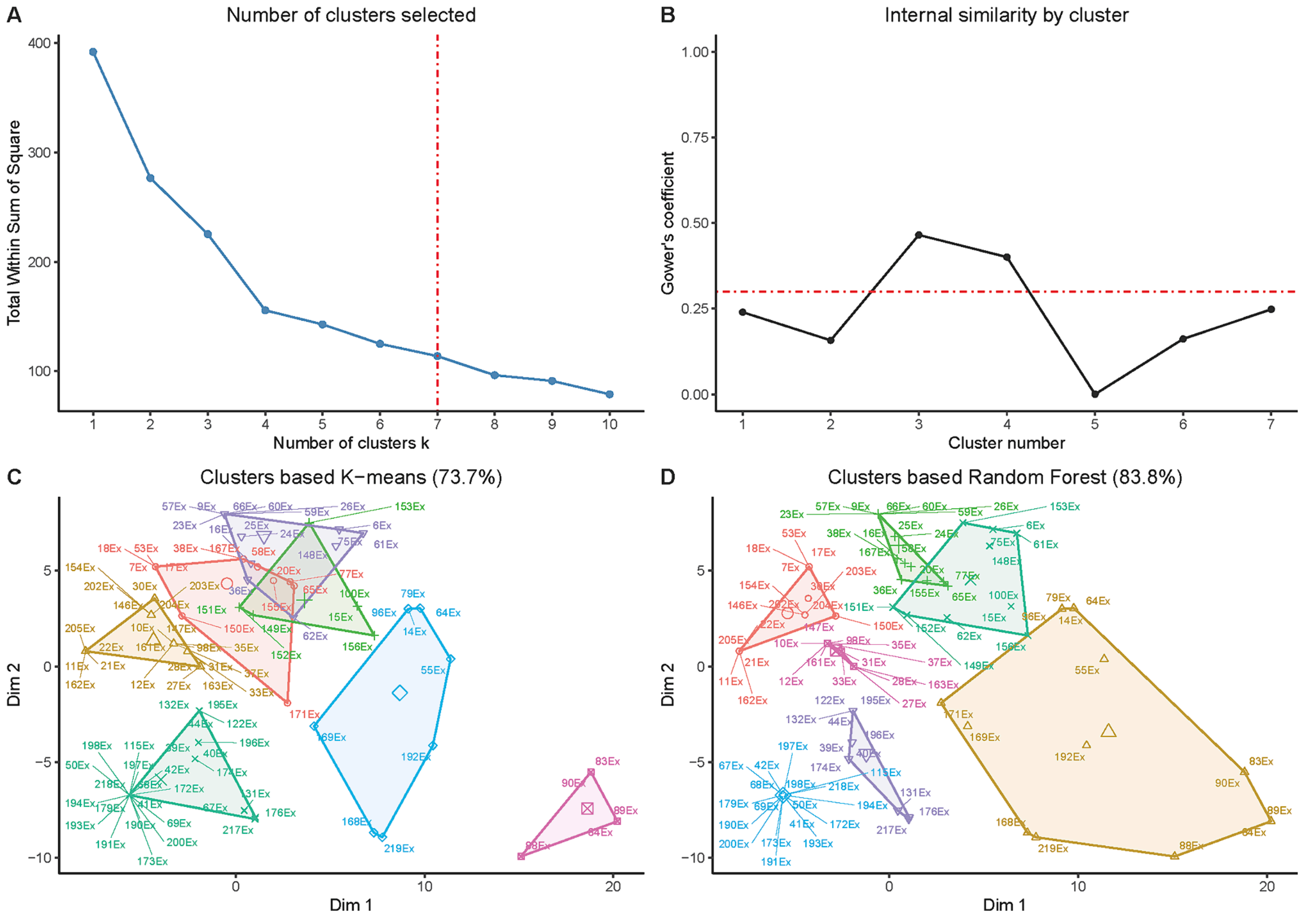

Fig. 8. Statistical results on experimental data related to knapping techniques and tool marks. A) Exploration of the sum of squares from K-means. The vertical line indicates the number of groups considered. B) Gower coefficient indicating the internal similarity of the clusters defined in 6D: 1 (▽), 2 (⊠), 3 (△), 4 (X), 5 (◇), 6 (●) and 7 (+). The horizontal line indicates the maximum accepted similarity threshold (0.3, corresponding to 70 % similarity between observations within each cluster). C) Representation of K-means analysis. D) K-means recalculation using the Random Forest approach.

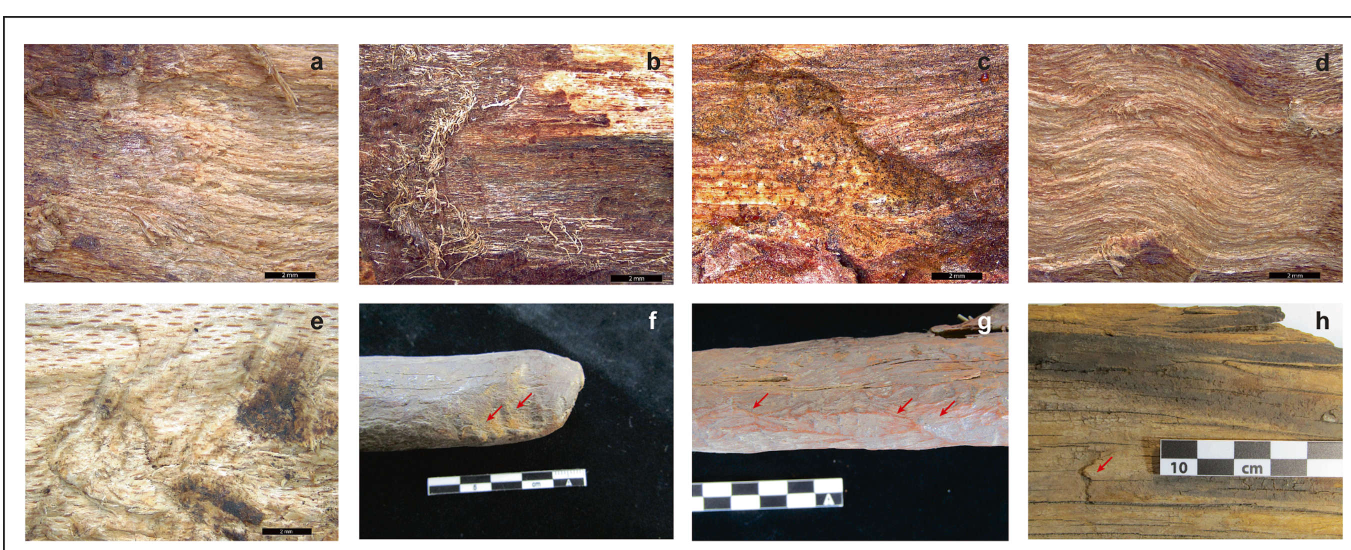

Fig. 9. Examples of tool marks included in statistical group 3 (section 3.1). Experimental marks: a) experiment no. 14; b) experiment no. 32; c) experiment no. 4; d) experiment no. 14; e) experiment no. 38. Archaeological marks: f-g) ID 296; h) ID ULL-621. Scale bar (a-e) = 2 mm.

187 and 217) are close to Group 5. Archaeological marks no. 22, 40, 44, 48, 119, 136, 137, 139 and 141 are associated with Group 7.

4. Discussion

Given the large volume of data recorded during the analysis of archaeological tool marks, a selection is compiled in this paper (see 2.3). However, this selection has been carried out considering the variability of objects (funerary boards, cist closure elements, doors, construction timber, wooden sticks, *añepas*) and their provenance, where all the islands with wooden artifacts preserved are represented. The comparison between experimental and archaeological traces, rather than answering conclusive questions about woodworking activities among Canarian aboriginal groups, allowed us to detect some previously undocumented observations, i.e. the suggestion of actions, type of tools or techniques in some cases.

The statistical results analyzed so far suggest a high presence of debarking tool marks (see 3.1, 3.2 and 3.4 for descriptions). Debarking using exclusively coarse-grained volcanic rock/obsidian flakes (Fig. 9 a-e) has been suggested in specific traces of funerary boards from Tenerife (ID 296, Fig. 9 f,g) and La Gomera (ID ULL-621, Fig. 9 h). Debarking using dihedral or trihedral bevelled tools and volcanic rock flakes (Fig. 10 a-d) is proposed in funerary boards from La Gomera (ID ULL-621, Fig. 10 e), Tenerife (ID 296, Fig. 10 f), El Hierro (ID 864-1, Fig. 10 g) and Gran Canaria (ID 11749); cist closure elements from Gran Canaria (ID 2704, ID 3749) and funerary wooden sticks from La Gomera (ID TAG-083, Fig. 10 h, and ID IZQ-10). These types of tool marks on finished objects could indicate the absence of intentionality to regularize the final surface of the artifacts, which is generally observed in aboriginal wooden objects of the archipelago except for some specific categories (i.e., wooden containers, specific *añepas*). This assessment is consistent with the functional use of the artifacts mentioned: structural elements or funerary objects (transport of the bodies to the burial caves or closing of burial cists) (Vidal-Matutano et al., 2021a). The statistical groups with which the archaeological marks present an acceptable degree of similarity (see 3.1) suggest the production of deeper marks using dihedral or trihedral bevelled tools than with the exclusive use of flakes. This observation could be related to the greater control in woodworking using picks.

Concerning linear features, very few striations are comparable with the experimental record (n = 4, see 3.2). Thus, the experimental program has not been able to reproduce most of the striations observed in the selected wooden objects. However, all the observed cases fall in the experimental group related to debarking using coarse-grained volcanic rock flakes (Fig. 11 a-e). It should be noted that the archaeological cases correspond to wooden sticks from Tenerife (*añepas* ID 1198.1, Fig. 11 f, ID 318, Fig. 11 g and ID 1198.2) and from La Gomera (funerary stick ID IZQ-10, Fig. 11 h). These artifacts were made on 3–4 cm diameter branches and, unlike other wooden sticks, they do not present a final polished/regularized surface. Thus, the striations observed could be associated with the debarking process whose marks were not eliminated. Despite being included in the same statistical group, the striae observed in the La Gomera object differ from those of Tenerife. This could respond to different functionalities (a funerary stick with a functional use vs. batons with a symbolic or hierarchical use) or different woodworking processes. In any case, further experimental research focused on the debarking and the final regularization of wooden sticks is necessary to obtain the greatest possible variability of linear accidents.

Facet marks produced during the experimentation generally were curved-front type when bone chisels were used, while the use of obsidian flakes is more related to straight-front facets. Nevertheless, both front types have been documented within the statistical groups using exclusively bone chisels (see 3.3, Fig. 12 a-d). Although few archaeological accidents have been statistically associated with the experimental facets, the final regularization of the objects is not a characteristic element in the manufacturing process of wooden artifacts by the aboriginal societies of the archipelago. In this sense, some objects show isolated facets or specific faceting areas but the complete faceting of the object has not been documented so far. Archaeological facet marks are related to different statistical groups, which suggests a wide variability in the way these marks were produced, at least, in Gran Canaria (ID 2704, Fig. 12 f and ID 11758, Fig. 12 h) and Tenerife (ID 296, Fig. 12 g and ID 307, Fig. 12 e). Most of the objects are structural elements except *añepa* ID 307, whose facet mark could respond to the removal of a branch knot. These results suggest discarding the use of obsidian flakes for faceting, as statistically acceptable results have been obtained when using bone chisels. Facet marks on ID 11758 exhibit striations inside the accidents that have not been observed during experiments involving bone chisels, suggesting the possibility of the use of other tools, such as coarse-grained volcanic rock flakes. Despite the similarity observed with the use of bone chisels, new experiments with greater diversification in the dimensions/configuration of these tools and the participation of other materials (shell tools, other types of bone tools, coarse-grained volcanic rock flakes, etc.) are necessary to increase the experimental sample.

Fig. 10. Examples of tool marks included in statistical group 7 (section 3.1). Experimental marks: a) experiment no. 38; b) experiment no. 4; c) experiment no. 14; d) experiment no. 14. Archaeological marks: e) ID ULL-621; f) ID 296; g) ID 864–1; h) TAG-083. Scale bar (a-d; h) = 2 mm.

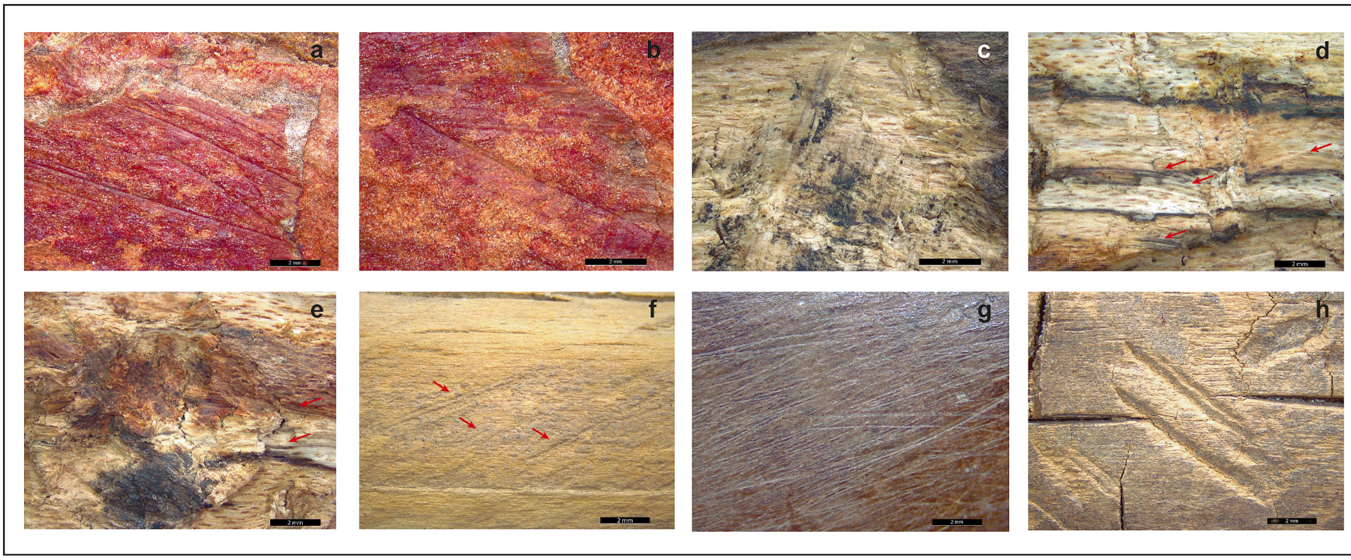

Fig. 11. Examples of tool marks included in statistical group 7 (section 3.2). Experimental marks: a-b) experiment no. 1; c-d) experiment no. 38; e) experiment no. 39. Archaeological marks: f) ID 1198.1; f) ID 296; g) 318; h) ID IZQ-10. Scale bar = 2 mm.

Fig. 12. Examples of tool marks included in statistical groups 1, 3 and 4 (section 3.3). Experimental marks: a) experiment no. 40; b) experiment no. 33; c) experiment no. 35; d) experiment no. 27. Archaeological marks: e) ID 307; f) ID 2704; g) ID 296; h) ID 11758. Scale bar (a-d) = 2 mm.

Some statistical calculations have focused on the technique (direct/indirect percussion) used during woodworking actions. The statistical groups close to archaeological accidents do not show appreciable differences in tool mark depths depending on whether direct or indirect percussion was used. Indirect percussion associated to debarking using picks and coarse-grained volcanic rock flakes (Fig. 13 a-f) is suggested for structural elements from Gran Canaria (ID 1614, Fig. 13 g) and funerary boards from El Hierro (ID 865-1, Fig. 13 h) and Tenerife (ID 296, Fig. 13 i). Other tool marks have been statistically grouped into indirect percussion associated with debarking and roughing using picks and coarse-grained volcanic rock flakes (Fig. 14 a-d). Some of these accidents show parallel marks of oblique orientation, also archaeologically identified, which may be the result of the tool dragging during indirect percussion. Tool marks included in this group have been observed in a wooden door from Gran Canaria (ID 3271, Fig. 14 e) and three funerary boards from Gran Canaria (ID 11749, Fig. 14 f), La Gomera (ID ULL-621, Fig. 14 g) and El Hierro (ID 865-1, Fig. 14 h). Direct percussion associated with debarking using picks and coarse-grained volcanic rocks (Fig. 15 a-e) is suggested for a higher variability of artifacts, including a door (ID 3271, Fig. 15 f) and a cist closure element from Gran Canaria (ID 3749), funerary boards from La Palma (ID NHM-1, Fig. 15 g), El Hierro (ID 865-1, Fig. 15 h), Tenerife (ID 296, Fig. 15 i), Gran Canaria (ID 11749) and La Gomera (ID ULL-621), wooden sticks from La Gomera (ID IZQ-10, Fig. 15 j and ID TAG-083, Fig. 15 k) and an *añepa* from Tenerife (ID 307, Fig. 15 l). These results point towards a widespread use in different islands of indirect percussion for roughing since this action requires controlled extractions during the configuration of the object. Technological marks observed on funerary sticks and *añepas* are exclusively included in the statistical group of debarking by direct percussion, which is consistent considering that these artifacts were configured on 3–4 cm diameter branches.

Ongoing research focused on the technological analysis of Prehispanic wooden objects from the Canary Islands is providing significant data on the processes of adaptation and innovation of aboriginal

Fig. 13. Examples of tool marks included in statistical group 2 (section 3.4). Experimental marks: a-c) experiment no. 14; d) experiment no. 26; e) experiment no. 36; f) experiment no. 38. Archaeological marks: g) ID 1614; h) ID 864-1; i) ID 296. Scale bar (a-f) = 2 mm.

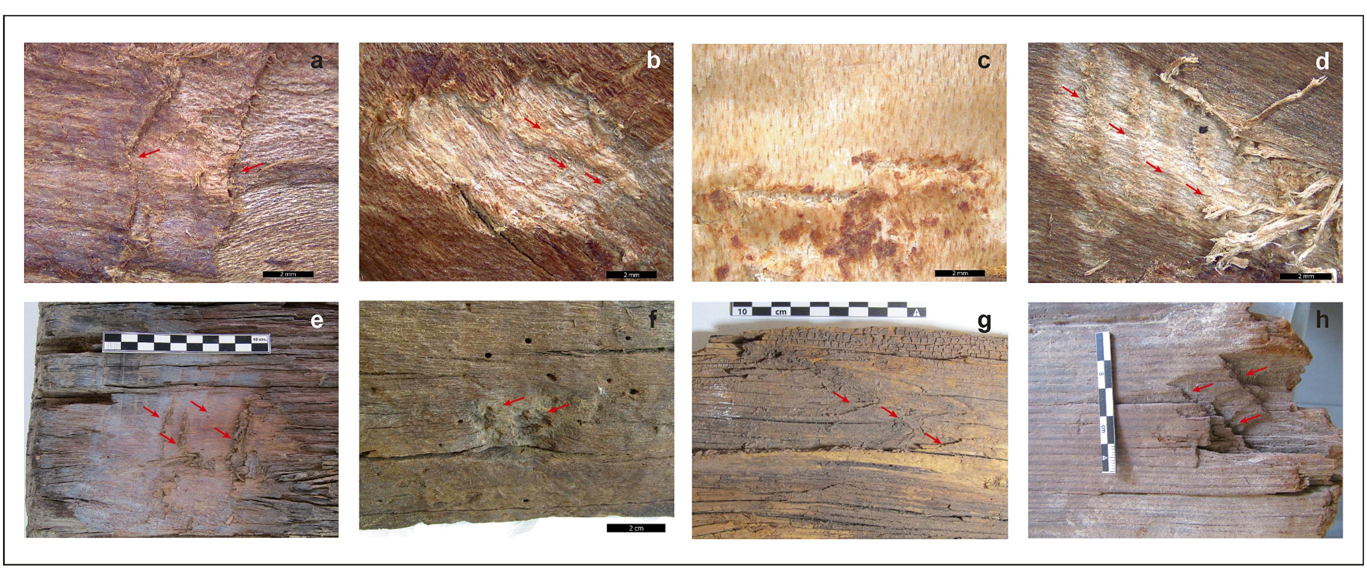

Fig. 14. Examples of tool marks included in statistical group 7 (section 3.4). Experimental marks: a) experiment no. 14; b) experiment no. 16; c) experiment no. 36; d) experiment no. 16. Archaeological marks: e) ID 3271; f) ID 11749; g) ID ULL-621; h) ID 864–1. Scale bar (a-d) = 2 mm.

Fig. 15. Examples of tool marks included in statistical group 5 (section 3.4). Experimental marks: a) experiment no. 3; b) experiment no. 4; c) experiment no. 5; d) experiment no. 15; e) experiment no. 5. Archaeological marks: f) ID 3271; g) ID 1NHM-1; h) ID 864–1; i) ID 296; j) ID IZQ-10; k) ID TAG-083; l) ID 307. Scale bar (a-e; j-l) = 2 mm.

societies for the successful development of woodworking activities in the context of absence of metal tools. In addition to the interpretations suggested from the statistical analysis of the tool marks on a selection of Prehispanic wooden objects, some other considerations can be mentioned. On the one hand, as indicated in previous studies (Vidal-Matutano et al., 2020, 2021a, 2021b) the identification of the raw material used by the indigenous groups of different islands is revealing the preferential use of the Canary Island pine. The selection of this taxon may respond to the greater extension of pine forests in the past landscape of the archipelago (González-Navarro, 2005) combined with cultural choices (i.e., traditional crafts over time focused on a taxon with similar physical properties to other known North African pine species). After pine, the supply of laurel forest and *fayal-brezal* wood (Lauraceae, *Morella faya*, *Salix canariensis*) also seems to be observed on different islands (Tenerife, Gran Canaria, La Gomera, La Palma). On the other hand, the selection of natural shapes was probably one of the criteria that would determine the manufacture of some artifacts, as this is a distinctive characteristic of non-metallurgic societies (Noël and Bocquet, 1987). As an example, the production of wooden sticks or the *añepas* would require the selection of straight young branches of 3–4 cm in diameter. In the Canarian laurel forest, it's common to observe the presence of young branches growing around a mature tree (Arozena-

Concepción et al., 2017) which would offer a desired shape for the manufacture of these objects. Similarly, some *añepas* were made from very straight young pine branches, so the selection criterion does not seem to be the taxon in these cases.

5. Conclusions

The experimental dataset presented in this work constitutes the first robust approach to the study of tool marks on Prehispanic wooden artifacts. This first experimental dataset focused on woodworking activities among the aboriginal groups of the Canary Islands allowed statistical comparisons with selected archaeological artifacts of different typologies and origins. The statistical approach applied has proved to be a valid method for avoiding subjectivities in the interpretation of the work marks (i.e., marks that are similar to the naked eye). In this sense, the experimental program revealed the complexity in its interpretation with similar marks produced using different tools or during different actions and, conversely, different marks generated with similar tools or during the reproduction of the same actions.

These first data constitute a starting point to better interpret the work marks on Prehispanic wooden objects and to obtain preliminary observations such as the predominance of debarking and roughing traces with respect to other less represented actions (planing, polish/abrasion), the probable use of bone chisels or similarly configured tools for planing or the preponderance of indirect percussion for roughing. Furthermore, statistical data suggest that the technical processes involved in wood crafts are not associated with specific categories of artifacts or specific islands. Thus, the technological adaptation of aboriginal societies to woodworking with non-metal tools produced similar results on different islands.

Further research with the development of experimental programs focused on specific actions (i.e., planing, polish) or categories of objects (i.e., containers, wooden sticks, *añepas*) will enrich the experimental tool marks dataset and, consequently, better define the technical processes involved. In addition, the future application of machine learning methods will allow the exploration of larger datasets and automatically detect patterns in tool marks produced within an island and across islands of the Canarian archipelago.

CRediT authorship contribution statement

Paloma Vidal-Matutano: Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Antoni Palomo:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Salvador Pardo-Gordó:** Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dorota Wojtczak:** Writing – review & editing, Visualization, Validation, Resources, Methodology, Investigation, Formal analysis, Conceptualization. **Amelia Rodríguez Rodríguez:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Jared Carballo Pérez:** Writing – review & editing, Visualization, Validation, Investigation, Formal analysis. **Idaira Brito-Abrante:** Writing – review & editing, Visualization, Validation, Investigation, Formal analysis. **Kiara Melián:** Writing – review & editing, Visualization, Validation, Investigation, Formal analysis.

Data availability

We have shared our data/code at https://doi.org/10.5281/zenodo.10511348.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2024.104661.

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