A research on the potential of a forgotten natural fiber in today’s world.
THE REVIVAL OF SPARTO

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1. Introduction

Spanish Broom (Spartium Junceum) or Sparto as it is widely known in Greece, is a plant that grows in most of the Mediterranean countries. This forgotten plant nowadays, used to be a valuable source for manufacturing every day objects such as shoes, ropes or baskets or worked as a substitute for common substances like coffee. People exploited almost every part of the plant; the stems, the leaves, the seeds in various ways and under multiple processes in order to take advantage of the broom’s properties and ease their everyday life. However the low efficiency of the traditional fibre extraction processes from its branches gradually led to the abandonment of the practices and of the broom itself.
1.1 Aim

The aim of this study is to explore the potentials of Spanish broom fibers in the modern world. Is it possible to compare them with today’s most famous fibres such as flax or hemp? Do they have what it takes to adequately stand next to the list with the best fibers in matters of strength and quality? Are the extraction processes competently cheap, fast and with no unbeatable obstacles to be talking about a sufficient production? These and more questions are attempted to be answered in depth.

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1.3 Περίληψη

Το Σπάρτο είναι ένα φυτό που αναπτύσσεται στην Ελλάδα και σε άλλες Μεσογειακές χώρες. Υπάρχουν πολλές αναφορές από την αρχαιότητα μέχρι και λίγες δεκαετίες πριν, ότι από το φυτό αυτό γνώταν εξαγωγή πολύ ποιοτικών ινών. Σύμφωνα με τις αναφορές, οι άνθησης χρησιμοποιούσαν όλα τα μέρη του φυτού για διαφορετικούς σκοπούς. Εκμεταλλεύονταν δηλαδή τις ωφέλιμες ιδιότητες του για τις καθημερινές τους ανάγκες. Ωστόσο η εκμετάλλευση αυτού του φυτού σταμάτησε πριν πολλά χρόνια και το φυτό, συνεπώς και οι ίνες του ξεχάστηκαν.

Σκοπός αυτής της αρχαιότητας είναι η ανάλυση των προσποικικών των ινών του Σπάρτου στη σύγχρονη εποχή. Είναι εφικτή η σύγχρονη του με πιο διαδεδομένες ίνες όπως το λινάρι ή η κάνναβη; Μπορούν να ανταγωνιστούν αυτές τις ίνες σε θέματα δύναμης και ανιχνεύσης; Είναι η εξαγωγή τους αρκετά εύκολη, χρήσιμη και οικονομική, ώστε να μπορούν για εκατονταετικό μήνας παραγωγής; Επιχειρείται στη συνέχεια μελέτη να απαντηθούν αυτά τα ερωτήματα σε βάθος.

Οι ίνες μπορούν να οριστούν ως λεπτές κλώστες από φυσικά ή τεχνητά υλικά που μπορούν να χρησιμοποιηθούν για να κατασκευαστεί ύφασμα χρησίμενο, όπως [9]. Οι ίνες μπορούν να είναι είτε φυσικές, παραγόμενες από τα ζώα, τα υδάτινα ή τα ορυκτά, όπως το μέταξτο,το βαμβάκι και το ύφασμα, ή συνθετικές όπως το ύφασμα και ο πολυεστέρας.

Παρόλο που οι συνδετικές ίνες είναι αλεξιγμόνες από τον άνθρωπο και, συνεπώς, είναι πολύ πιο εύκολες και προσαρμόσιμες όσον αφορά για παράδειγμα την ορισμική μήκους ή μεταβολές στη δομή των ινών, οι φυσικές ίνες παρέχουν πολλά πλεονεκτήματα όπως για παράδειγμα η χαμηλή πυκνότητα.

Οι φυσικές ίνες είναι ακριβώς αυτό που υποδηλώνει το όνομα τους. Φυσικές. Οπότε οι ίνες είναι σχετικά με τη χρήση παρουσιάζονται διαφορές και ανιχνεύσεις. Δεν έχουμε όλες τις ινές τα ίδια ανατομικά χαρακτηριστικά. Η επιλογή της κατάλληλης μεθόδου εξαγωγής, εξασφαλίζει σε μεγάλο βαθμό από το είδος του φυτού, καθώς και την απαιτούμενη απόδοση των ινών. Είναι επίσης σημαντικό με το μέρος του φυτού που χρησιμοποιείται (φύλλοι, φύλλα, ξύλο κλπ) [11]. Πολλά πείραμα είναι διαχειρίσιμα και πολλές θεωρίες έχουν διατυπωθεί αναφορικά με αυτό. Η βασική διάκριση μεταξύ των μεθόδων εξαγωγής είναι το κατά πόσον περιλαμβάνουν η όχι τη χρήση χημικών ουσιών.

Το Σπάρτο αποτελεί από κάθε σκοπό άλλη με υψηλές ίνες, κατάλληλες για την κατασκευή υφασμάτων. Ωστόσο, είναι κατάλληλος για πολλές ιδιότητες του φυτού. Ο όμηρος αναφέρεται στην Παλαιά την κατασκευή υφασμάτων για τα πλόια από Σπάρτο και αυτό ήταν μόνο η αρχή.

Το Σπάρτο είναι ένας θάμνος που κυμαίνεται στα 1 με 2 μέτρα και εμφανίζει διάσταση μικρά κίτρινα άνθη, εμφανίζοντας μήνυμα Μάτι και Ισολό. Το χρωμάτιση μπορεί να φυτεύεται και σε αφρόδειες ακτινοβολές. Από το μπορεί να χρησιμοποιηθεί χάρη στο αυτό το χαρακτηριστικό, ως ενίσχυση σε σαθρά εδάφη. Λειτουργεί με τον μηχανισμό της σιμβολικής. Δεσμεύεται ότι και το
διοικειται στις ρίζες, εμπλουτίζοντας παράλληλα το έδαφος. Χάρη σε αυτό μπορεί να αναπτυχθεί σε πολύ χαρακτηριστικό και αναπτύσσεται σε τρόπο πολύ εύκολο. Οι σπόροι μπορεί να μείνουν βιώσιμοι στο έδαφος μέχρι και 20 χρόνια. Τέλος, φθινοπωρίζεται από τις ρίζες του κάτι που αποτελεί έξοχο μηχανισμό για έξοχα γλυκά. Αυτός είναι ένας από τους λόγους που το Σπάρτο συναντάται πολύ σχεδόν στις αθηναϊκές οδούς.

Είναι όμως η ίνα του Σπάρτου αρχατά ποιοτική για να συζητήσουμε για την αναβίωσή της; Η σύγχρονη της με το λινάρι μας δείχνει ακριβώς αυτό. Το Σπάρτο εμφανίζει μεγαλύτερη επιμήκυνση ως τη θραύση υποδηλώνοντας ότι υφάσματα από το σπαρτό θα είναι πιο ευέλικτα και μαλακά. Η πιγνότητα είναι μικρότερη η ίδια με το λινάρι. Γεγονός που το καθιστά κατάλληλο για τη χρήση του στην αυτοκινητοβιομηχανία με τη μορφή σύνθετου. Παρουσιάζει χαμηλότερη ανάκτηση υγρασίας και καλύτερη δυναμική σταθερότητα, χαρακτηριστικά που μπορεί να επηρεαστούν την άνεση του ρομπότου. Επίσης έχει υψηλότερη χρυσιτικότητα που σημαίνει ότι οι ίνες του θα έχουν καλύτερη υφή ενώ παράλληλα εμφανίζονται πιο λείες από τις ίνες του λιναριού.

Το Σπάρτο έχει εγκαταλειφθεί για πολύ μεγάλο διάστημα. Είναι προφανές από τις πληροφορίες που παρουσιάζονται σε αυτή τη μελέτη ότι είναι ιδιαίτερα ουσιαστική η επιστροφή στην εκμετάλλευση αυτών των ινών. Για το λόγο αυτό, κρίθηκε απαραίτητη η διεξαγωγή πειράματος. Ετσι, επιτυγχάνεται η καλύτερη γνώση του φυτού, των διαδικασιών εξαγωγής και της δυναμικής τους καθώς και μελετώνται σε μεγαλύτερο βάθος οι ιδιότητες του φυτού.
2. Natural Fibres

Fibres can be defined as thin threads of natural or artificial materials that can be used to make cloth, paper, etc. Fibers can be either natural, produced by animals, plants or mines such as silk cotton and flax, or synthetic like nylon and polyester.

![Figure 2.1 Raw Fibres](image)

2.1 Why Natural Fibres?

Whereas synthetic fibres are man-controlled and therefore are much more versatile and adaptable referring for example to length regulation or alterations to fiber structure, natural fibres provide a multitude of advantages.

- They are quickly and easily grown [3].
- Natural fibres help to reduce weight, as their density is comparably low [2]. (1.15 – 1.50 g/cm³ versus 2.4 g/cm³ for e-glass) [3].
- Given their low density, plant fibers can be compared to glass fibers in matters of specific properties, strength and stiffness. [5]
- They have good thermal and acoustic properties and therefore are suitable for automotive industries [2].
They are environmentally friendly as the composites made with natural fibres are biodegradable and have a very low energy input form the gathering of the raw material to the final product making $\[4\],[5]$. Also in case of fire, toxic gases are significantly reduced.

- Lower eco-toxicity appears also due to minimum to no demand for pesticides,[5]
- Therefore, the consumption of diesel during farming remains at very low levels and so are the CO\textsubscript{2} emissions. [5]
- They are cost saving compared to glass and carbon fibres.
- They produce greater abrasion resistance to mixing and molding equipment assisting to further cost reductions [5].

However natural limitations exist. Compared to glass fibers, natural fibers appear to have low tensile strength. Also the percentage of moisture absorption is relatively high inducing a series of deficiencies. The surface deforms causing swelling and vacuums, which result in lower strength and an increase in mass [4]. Practices such as applying the most appropriate extraction process or sealing the final product can work as real solutions to the above problems.

2.2 Source of Natural Fibres

Natural fibres can be categorized according to their origin. Silk, hair and wool are typical examples of fibres deriving from animals whereas cotton, flax, bamboo or banana fibres all come from vegetables. Below there is a synoptic scheme presenting some of the most used fibres classified in relation to their origin.
2.3 Anatomy of Natural Fibres

2.3.1 Chemistry of Plant Fibres

Cellulose is a linear polymer that consists of glucose units. Basically cellulose can stack to form hydrogen bonds. This results in a hydrophilic polymer with high tensile strength [12]. Cellulose can be considered as the main structural component that provides strength, stiffness and structural stability to the fibres. Fibre characteristics and whether or not a fibre is suitable for an application, all greatly depend on the amount of cellulose the fibre carries.

Hemicelluloses, which are branched polymers (not linear), are associated with pectin, cellulose and aromatic constituents within plant cell walls [fig.2.3.1]. Hemicelluloses can be defined as a group of non-cellulosic polysaccharides that differ in both composition and structure, depending on their origins. They are highly hydrophilic and easily hydrolyzed in acid [13].
These polymers have undergone continuous research since they are considered responsible for many functional characteristics. They are also of great importance as they cause alterations to the processed fibres. An example can be seen in flax fibres. During the retting of the flax, the cellulosic fibres are separated from the non-fibre components. However, non-cellulosic carbohydrates and other materials might remain on the surface of the fibre, causing unwanted results such as non-uniform dying [12].

![Figure 2.3.1 Scheme of the cell wall of an onion. Cellulose and hemicellulose are arranged into layers in a matrix of pectin polymers [12]](image)

**Lignin** is a hydrophobic polymer and is not hydrolyzed by acids [13]. It is also considered responsible for strength, rigidity and protection against microbial pathogens of cell walls [12]. Lignin’s chemical structure changes, depending on its source. It also acts as an adhesive between the fibres and it provides them with stiffness [11]. The amount of lignin content affects the structure, the properties, the fibre characteristics and the hydrolysis’ speed. Fibres with smaller amount of cellulose have higher lignin content. In addition lignin amount and location differ in every plant, affecting the retting methods and their efficiency as well as the effectiveness of the final fibre [12].

**Pectins** are called matrix polysaccharides. Together with hemicelluloses act as adhesives helping to hold together tissues, including fibres. They affect resistance, water absorption and flexibility of the fibres. Although the content of pectins in fibres are very low, they greatly affect the extraction process of the fibre. For example in order to extract cotton fibres, a method using NaOH is applied. During this method the fibres are inserted in a NaOH solution, causing pectin degradation, which results in easy separation of the fibres [12].
Below you can see the percentages of the chemical components for some of the most utilized natural fibres.

<table>
<thead>
<tr>
<th>Fiber</th>
<th>Cellulose (wt%)</th>
<th>Hemicelluloses (wt%)</th>
<th>Lignin (wt%)</th>
<th>Pectin (wt%)</th>
<th>Moisture Content (wt%)</th>
<th>Waxes (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flax</td>
<td>71</td>
<td>18.6-20.6</td>
<td>2.2</td>
<td>2.3</td>
<td>8-12</td>
<td>1.7</td>
</tr>
<tr>
<td>Hemp</td>
<td>70-74</td>
<td>17.9-22.4</td>
<td>3.7-5.7</td>
<td>0.9</td>
<td>6.2-12</td>
<td>0.8</td>
</tr>
<tr>
<td>Jute</td>
<td>61-71.5</td>
<td>13.6-20.4</td>
<td>12-13</td>
<td>0.2</td>
<td>12.5-13.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Kenaf</td>
<td>45-57</td>
<td>21.5</td>
<td>8-13</td>
<td>3-5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramie</td>
<td>68.6-76.2</td>
<td>13.1-16.7</td>
<td>0.6-0.7</td>
<td>1.9</td>
<td>7.5-17</td>
<td>0.3</td>
</tr>
<tr>
<td>Nettle</td>
<td>86</td>
<td></td>
<td></td>
<td></td>
<td>11-17</td>
<td></td>
</tr>
<tr>
<td>Sisal</td>
<td>66-78</td>
<td>10-14</td>
<td>10-14</td>
<td>10</td>
<td>10-22</td>
<td>2</td>
</tr>
<tr>
<td>Henequen</td>
<td>77.6</td>
<td>4-8</td>
<td>13.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PALF</td>
<td>70-82</td>
<td></td>
<td>5-12.7</td>
<td></td>
<td>11.8</td>
<td></td>
</tr>
<tr>
<td>Banana</td>
<td>63-64</td>
<td>10</td>
<td>5</td>
<td></td>
<td>10-12</td>
<td></td>
</tr>
<tr>
<td>Abaca</td>
<td>56-63</td>
<td>12-13</td>
<td>1</td>
<td></td>
<td>5-10</td>
<td></td>
</tr>
<tr>
<td>Oil palm EFB</td>
<td>65</td>
<td></td>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil palm mesocarp</td>
<td>60</td>
<td></td>
<td>5.7</td>
<td>0-1</td>
<td>7.85-8.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Cotton</td>
<td>85-90</td>
<td>0.15-0.25</td>
<td>40-45</td>
<td>3-4</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Coir</td>
<td>32-43</td>
<td>15-31</td>
<td>12-20</td>
<td>8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 2.3.2 Chemical compositions (%) of selected natural fibres.

2.3.2 Morphology of Plant Fibres

The chemical structure of a plant fiber is what makes it suitable or not for further use. However this is not the only important factor. Shape and size of the fibres also play a significant role to the functionality of the fibre.

Depending on the fibre, shape and size vary greatly. We observe big differences among the fibers in matters of length and diameter but also within each fiber. We also observe differences to the geometry of the fibres. For instance, soft wood fibers present small variations in relation to length, but they have big alterations in their cross-section dimensions across a growth ring. The differences are even greater when we are observing bast fibers, if we compare for instance ramie fibers that have a length up to 550 mm with jute fibers with a length of 2-3 mm.
A reason why this happens could be that we use both primary and secondary bast fibers. An obvious example is that of hemp fibers. Primary hemp fibers reach lengths up to 25 mm whereas secondary hemp fibers have a length of 2-3 mm. Another reason would be the different environmental conditions. Alterations in temperature, soil conditions, wind etc. can have a great impact on the fibers. [12]

![Figure 2.3.3 Fibre Diameter and Length](image)

2.4 Processing

Natural fibres are exactly what their name suggests. Natural. That said, it comes without saying that anything related to nature presents differences and abnormalities when compared to one of its kind. Not all fibres carry the same anatomical features. The selection of the most suitable extraction method greatly depends on the type of the plant as well as the required performance of the extracted fibres. Is it also relevant to the part of the plant that is being used (bast, leaves, wood etc.) [11]. Numerous experiments have been made and many theories have been built based on scientific arguments. The basic distinction between the extraction methods is whether or not they include usage of chemical substances.
2.4.1 Natural Process

Harvesting

The first step is harvesting the plant. Depending on the plant the branches are cut during a specific period considered best for fibre quality. In case the plant has hard parts, they are being separated to keep the soft pliable branches. Finally the branches are tied in bundles and left to dry under the sun, usually in the shape of nest (photo from video). The duration of drying again varies depending on the plant, the moisture and the temperature conditions.

![Flax Drying](image)

Figure 2.4.1.1 Flax Drying

Retting

After drying different retting procedures had been applied. Retting can be described as the microbial process during which the chemical bonds that hold the stem together break and then it is easier to separate the fibres from the woody part [10].

In Greece, they used to boil the bundles for about half an hour and then soak the bundle for 10 days in a stream of running water [9]. An article from the Textile Research Journal [8] suggested that the bundles were first heated in a water tank at the temperature of 30.6-33 degrees Celsius and then the retting lasted for 20 days.
Figure 2.4.1.2 Jute Retting in India

Furthermore, an article from the University of Zagreb suggested that the soaking took place in seawater for 21 days at an average of 22 degrees Celsius. Another article from the US Department of Agriculture suggests that one of the most traditional methods is the field (or dew) retting during which the stems are cut and left in the field to rot. Although this method is inexpensive and does not include water usage, it needs moisture conditions to break the chemical bonds and requires constant supervising to make sure that fibre quality is preserved [10].

Figure 2.4.1.3 Dew retting of hemp in the Netherlands
Last but not least a documentary on a flax processing factory during the 40’s [w1] shows that big quantities of flax were placed in big tanks that were injected with both hot air and water until the water reached the temperature of 32 degrees Celsius and left in these conditions for 70 hours. After the retting process, the bundles were left to dry in the sun or in a tank with hot steam infusion. Generally, retting methods with water insertion produce fibers with higher quality and uniformity but require a large amount of labor to be produced as well as capitals.

Figure 2.4.1.4 Stacking flax in a tank for retting (1940-1949).
Breaking

When the fibres are dried after the retting process, they pass through the stage of breaking. Breaking shutters the hard inner core of the plant, making it easier to release the outer fibers. This can be accomplished for small quantities with a wooden hand tool (fig. 2.4.1.6) or a handmade machine with an attached wooden arm that makes a vertical up-and-down movement (fig. 2.4.1.7, fig. 2.4.1.8) [w3] [w2]. For greater amounts of fibres, a more complicated machine had been manufactured. This machine uses cogwheels, through which the stems pass and break. (fig. 2.4.1.9) For the seawater [7] method the fibers were being rubbed against stone plates and then rinsed with seawater to be separated from the wooden part.
Figure 2.4.1.6 Breaking Flax with hand tool

Figure 2.4.1.7 Breaking Flax with wooden machine
Figure 2.4.1.8 Breaking Flax with wooden machine

Figure 2.4.1.9 Breaking Flax Machine
Next is the step of scutching or beating. Most of the beating tools were handmade. In general, any kind of wooden paddle could serve the purpose. In most cases a wooden tool, sculpted in the shape of a sword, was used to beat the fibres (fig. 2.4.1.11). The ‘sword’ hit the fibres against a wooden surface. The bundles were being beaten \[9\] with the paddle until the remains from the breaking step were removed. Of course for bigger masses of fibre production many variations of scutching machines have been created.
Figure 2.4.1.12 Scutching flax

Figure 2.4.1.13 Scutching machine
Figure 2.4.1.14 Scutching machine in action

Figure 2.4.1.15 Scutching mechanism in flax processing factory (1940-1949)
Combing

The fibers obtained from beating are full with chuffs and knots. Thus, what follows is combing or hackling the fibers. For this purpose multiple combs (mainly for flax processing) have been manufactured throughout the years and named according to their area of origin. Basically a comb is a heavy board with nails or spikes inserted through it in rows, sparse or dense for finer results. The whole bundle of fibers is pulled through the spikes so that any knots or chuffs are left behind, revealing each time finer fibres [w2] [w4] [w5].

Figure 2.4.1.16 Hackling. Belfast, Ireland (1905)
Figure 2.4.1.17 Comb 230 years old

Figure 2.4.1.18 Different types of combs
2.4.2 Alkali Process

Freshly picked samples are tied in bundles of 100 gr and inserted in a tank with a 15% sodium hydroxide solution at a temperature of 120 degrees Celsius for 3 hours. After the processing, the wooden part of the fibers is removed easily [7].

2.4.3 Physico Chemical Process [DiCoDe procedure]

During the physico-chemical process, bundles of 100 gr are inserted in a tank with a 15% sodium hydroxide solution at a temperature of 100 degrees Celsius for 15 minutes. The fibers extracted are rinsed with distilled water until they are neutral and then they are placed in a stainless steel autoclave at 120 degrees Celsius and pressurized at 10 atmospheres for 3 hours. A quick decompression follows and the fibers are dried for 24 hours at 105 ±5 degrees Celsius and finally brushed [6] [7].
2.4.4 Microwave Procedure

A new method from the University of Zagreb suggests inserting 50g of the broom with 300ml of 15% NaOH in a Teflon reactor and then in the microwaves to 900W for 10 minutes. After this period the broom is rinsed with hot and then cold distilled water. The fibres are then easily separated from the wooden part [7].
3. Spartium Junceum (Sparto)

3.1 Introduction

Modern lists with plants whose fibers are used for textile manufacturing, usually include plants such as cotton for its lightweight fibers, hemp for its fibers’ durability, jute for its strength, flax, ramie and many more. What you almost never see included in these lists is the Spanish Broom. Oddly enough, this valuable plant rarely appears on recent lists, researches or papers analyzing the various ways of natural fibers usage, as if its is of no value. In addition to the inadequate reports, most of modern texts that are discussing the Spanish broom, are dealing, on full-length analysis, with different ways to control its growth or even to completely eradicate it.

However, written and verbal testimonials suggest otherwise. Starting from the Greek ancient times, Homer mentions in his Iliad ropes made from Sparto. More specifically Homer mentions that the ships were sewn together with Sparto ξενοφραφάς δόμος δοράς, η ναυς, παρόσον τρυπάντες τας ναυς σπάρτος αυτάς συνέρραπτον) 16. Varro speaks of Sparto as if it was used to sew together ships’ timbers. Pliny in his books of Natural History analyzes the use of Sparto for manufacturing ship’s ropes, bedding, shepherd’s clothes and footwear 9 15. Finally the Roman agronomist Columella reports that Sparto’s cultivation was wide and that it was sown in ploughed up furrows 7.
More recent papers mention the usage of Sparto by the Greeks, the Romans and the Carthagians for the manufacture of nets, ropes, bags, sails, clothing and for covering roofs. In France, where the broom is called Genêt d’Espagne, the fibre industry was connected to Sparto. There is proof that in Montpelier a Sparto industry was present making coarse cloth ‘of fine texture and beautifully bleached’, mattress coverings and sheeting. However by the end of the 19th century the industry was already dying out. Samples of this era’s industry can be found at Kew’s Botanical Gardens Museum in Great Britain.

Last but not least, in an attempt to crosslink the documented reports with real testimonies, interviews were taken in Greece. It appears from these interviews that Sparto was very well known among Greek people. Reports were made, pointing that in Western provincial areas in Greece the usage of Sparto was wide, especially for making brooms, baskets and ropes. There have been also testimonies discussing the benefiting from the plant during the war periods, when they handcrafted shoe soles from the broom’s fibers.

3.2 Description

Figure 3.1.2 Sparto in Halkidiki, Greece
Spartium Junceum or Spanish broom as it commonly known, is a perennial broom that can be found in areas around the Mediterranean Sea, in sunny areas of the northwest Africa and southwest Asia. Furthermore it can be found in the United States, since it was introduced there in the 1850’s as an ornamental plant but also for erosion control. In California, the broom was seeded in 1900 along the highways after fire incidents [17][w6][i5].

Sparto belongs to the family of legumes (Fabaceae) and it is the only species of the genus Spartium [7] but its is compared very often with similar looking brooms such as the genera Cytisus and Genista.

Sparto is a shrub that grows 1-2 meters tall with older examples showing cases of 4-5 meters tall. The main stems are usually 5 – 10 centimeters thick. They are finely ribbed and they are round in cross section, which is a quick and easy way to distinguish it from the similar Scotch broom whose stems are 5 angled and star-shaped in cross section.

Figure 3.2.1 Comparison of the star shaped in cross section stem of Scotch broom(A) and of the round shaped in cross section of Spanish broom(B). The stem of the Spanish broom is so finely ribbed, you can barely see it.
The long deeply green stems have very sparse deciduous leaves 1-3 cm long and 2-3 mm broad. The leaves are very simple, the grow one by one and they make it possible to immediately tell a Spanish broom form either Scotch, French or Portuguese broom. All the three other species grow leaves that are compound, divided into 3 leaflets.

Figure 3.2.2 Comparison of the scotch broom’s leaves which are consisted of 3 leaflets (A) and the Spanish broom’s simple leaves (B)
Table 3.2.3 Brooms’ characteristics for easy identification [26]

<table>
<thead>
<tr>
<th></th>
<th>Scotch broom</th>
<th>French broom</th>
<th>Spanish broom</th>
<th>Portuguese broom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>stems</strong></td>
<td>usually 5-angled; star-shaped in cross-section</td>
<td>8- to 10-ridged; round in cross-section</td>
<td>finely ribbed; round in cross-section</td>
<td>8- to 10-ridged; round in cross-section</td>
</tr>
<tr>
<td><strong>leaves</strong></td>
<td>compound, 3 leaflets, sometimes single on new twigs; deciduous</td>
<td>compound, 3 leaflets, usually dense; evergreen</td>
<td>simple, sparse; deciduous</td>
<td>compound, 3 leaflets, sometimes single on new twigs; deciduous</td>
</tr>
<tr>
<td><strong>flowers</strong></td>
<td>single or paired in leaf axils; slight to no fragrance</td>
<td>4 to 10 in headlike clusters at ends of short axillary branchlets; slight fragrance</td>
<td>several in open racemes at stem tips; strong fragrance</td>
<td>single or paired in leaf axils</td>
</tr>
<tr>
<td><strong>petals</strong></td>
<td>yellow or partially to entirely dark red</td>
<td>yellow</td>
<td>yellow</td>
<td>yellow</td>
</tr>
<tr>
<td><strong>calyx</strong></td>
<td>2-lipped; top lip minutely toothed; smooth (glabrous)</td>
<td>2-lipped, top lip 2-lobed to near middle; lower lip shallow, 1 to 3-lobed; covered with short hairs (pubescent)</td>
<td>1-lipped, parted to base on top, rarely 2-lipped and 5-lobed; smooth (glabrous)</td>
<td>2-lipped, top lip minutely toothed; covered with short hairs (pubescent)</td>
</tr>
<tr>
<td><strong>seed pods</strong></td>
<td>flattened; glabrous with margins densely lined with long hairs; about 1/4-2&quot; (0-5 cm) long, ½&quot; (1.3 cm) wide</td>
<td>slightly flattened; densely covered with long hairs; about ½-1½&quot; (1.3-3.8 cm) long, ¼&quot; (0.6 cm) wide</td>
<td>slightly flattened; densely covered with long hairs; about 1½-4½&quot; (3.8-11 cm) long, ¼&quot; (0.6 cm) wide</td>
<td>slightly inflated; densely covered with long hairs; about ½-2&quot; (1.3-5 cm) long, ½&quot; (1.3 cm) wide</td>
</tr>
</tbody>
</table>

However the leaves fall away very early and then the plant is covered with intensively yellow flowers, 1-2 cm across, with a distinct sweet scent. The flowers can be seen between May and July and after that they fall off to give their way to the legumes (seed pods) that grow up to 10 cm long.
When the seedpods are mature they turn dark brown and they are covered with long, soft almost white hair. Each seedpod contains 10-18 seeds. The seeds play a very important role for the plant. When they are mature enough, during August and September, the pods burst open and the seeds are ejected several feet from the plant. One plant can produce between 7,000 to 10,000 seeds in just one growing season. Seeds can remain viable in the soil for up to 30 years. This way seeds are gathered in the soil making it feasible for the broom to keep reproducing on its own for years.
The most important prerequisite for the growth of the broom is the presence of sun. It often grows in soils with enough moisture. However it is perfectly capable of growing very poor soils, dry and rocky. This explains why it is frequently found on the sides of highways where they are all day exposed to sun. A main reason why this happens is because of its feature of xerophile plants, meaning it can tolerate very long periods of drought. A second reason why the broom can grow in very poor soils is because of its unique surviving mechanism, called symbiosis. Spanish broom has the ability to fix nitrogen from the atmosphere and bind it in the roots lumps. This procedure not only allows it to grow in low quality soils but also provides it with the benefit of enriching the soil and making it thicker. Furthermore its roots are very deep and as a result it bind the soil very strongly.

3.3 Uses of Spanish broom

As we covered previously there are various testimonies referring to the multiple used of Spanish broom. The oldest references focus on the use of the broom’s fibers for making ropes for boats, footwear, mattress coverings, nets and sails or for covering roofs. But this is not all.

Spanish broom, or weaver’s broom as it is also known as, is also used for the manufacturing of baskets, canvas, mats, coarse cloth or for stuffing pillows. The broom’s fibres are superior to those of flex, hemp or cotton because of its ability to tolerate humidity. It does not rot or loses its strength.

Figure 3.3.1 Cloth made from Spanish Broom
Source- Museum Victoria
But not only the final fine fibers are useful. As with flax processing, during the stage of hackling, the fibers are pulled through the nails. This way the rough, full of knots and wood remains fibers, are being combed to produce fine pieces of thread. What is left behind, in the hackles, is the so-called tow, the shorter pieces of the fibers. This may seem useless at first, full of chaffs and boons from the stages of hackling and scutching but with a more persistent processing it can be spinned as well into a thicker thread for bags, wash cloth or rope baskets \[w12\]. Tow may be discarded as a waste for fire starting purposes or it can be used for crafting paper.
Besides the fiber, other parts of the plant have been proved to be useful and valuable as well. The stems of the plant can be rubberized and used for conveyer belts [21]. Furthermore the woody part can be used for its cellulose for the manufacturing of very strong paper [w11][15].

The small, yellow flowers of the plant, temporary but with an intense colour and odor are useful as well. They produce honey and thus they are attracted to bees. Because of their beautiful colour the plant is used also for ornamental reasons. The broom’s flowers can be distilled to produce essential oil, used for fragrances or cosmetics or for flavoring in food and beverages. They also produce a very intense dye [20][w8][w9][w10][21].

Figure 3.3.4 Distilling Spanish broom’s flowers

Spanish broom was also used for medicinal purposes as well. Its properties are similar to those of the common broom but it is five to six times more active [20]. It has been proved effective for stimulating bowel movement and increasing urine output. Broom tops were made into a juice, which was used as a diuretic and laxative [20][w9][18].

However large doses can cause vomiting and purging with renal irritation and low blood pressure and it can speed up the heartbeat. In extreme cases it can cause even fatal poisoning [18][20].
Last but not least there is another very interesting way the broom is being used. Its roots are long and strong, going very deeply into the ground and this proves to be very helpful for unstable grounds as it binds the soil very well. Also because of its symbiotic mechanism that is covered above, it has the ability to enrich low quality soils.

3.2 Abandonment of Spanish broom

Although there are so many reports about past uses of Spanish broom, nowadays very few people have the knowledge of it and even fewer researchers have analyzed its potential. The abandonment of this plant was gradual and there were multiple reasons that contributed to that.

The first problems that were encountered had to do with the difficulty of extracting the fibers from the stems. The low efficiency and the low production caused by the conventional maceration process automatically limited the possibilities of the broom and made it too challenging to be applied on larger scale in textile industry. This happens due to the high degree of attachment that the fibers have on the branches but also because it is difficult to detach the fibers from the internal ligneous and pectin substances. Furthermore at the time the broom was abandoned it had to compete with the more abundant and cheaper materials such as cotton and hemp \(^\text{[22][15][24]}\) whose processing required less effort.

More recently there have been many reports and references about the Spanish broom but not with a positive accent. Spanish broom grows very quickly and its growth is really difficult to detain due to its reproducing mechanism. The seedpods eject the seeds several feet from the parent plant and they stay viable for 20 years or more. Also one plant can produce between 7000 to 10000 seeds in just one growing season \(^\text{[w13]}\).

All of the above may seem beneficial for such a valuable plant but this is not the case everywhere. Spanish broom was introduced in San Francisco in 1848 as an ornamental plant. By 1930’s it was planned along many highways of southern California. However almost 20 years later the broom had expanded further the initial cultivation and can be now found in many more places \(^\text{[w14]}\). In California, Spanish broom is considered to be “troublesome, aggressive, intrusive, detrimental or destructive to agriculture or to important native species and difficult to control or eradicate”. This comes from the California State Department of food and agriculture, which has listed Spanish broom as a class C pest species. At the same time the California Exotic Pest Plant Council has Spanish broom in their list of the most invasive wild and pest plant, aggressive invader that displace native and disrupt natural habitats.
The reason why Spanish broom is considered a noxious weed is because it can out-compete native plants. Its dense stems are said to be unpalatable and impenetrable for wildlife and make regeneration of other plants difficult. They can also create a fire hazard because of the old inner stems that provide a highly flammable fuel. Finally because of its admirable mechanism of fixing nitrogen and enriching poor quality soils, it makes it easy and possible for other non-native weed to grow as well [15][25][26].

3.3 Sparto: an economic opportunity

The bad associations about the Spanish broom are numerous. However most of them deal with the difficulty of eradicating it as it is against its expanding nature. Also most of the reasons that led to these complications arise from its good qualities. But what if we change the scope on this? What if the goal is to grow and exploit the potentials of this amazing plant?

The economic prospects of Sparto are exceptionally many. First of all there is a significantly big amount of products that derive from that plant. Whether we are aiming at its strong fibers for manufacturing products like clothes, rugs, furniture etc. or at its flowers for dye, honey or fragrance, we have a great result. The financial outcome of Sparto’s cultivation is really promising.

Furthermore even when we look at it from an agricultural aspect, Sparto provides an opportunity. The qualities of this plant are numerous. It can grow in the poorest soil. It has the ability to grow in dry, sandy, low quality soil while at the same time enriching it by providing it with the nitrogen that it lacks [26][7][18][7]. This constitutes a great advantage over flax or hemp, as the last two require high quality soil each year [7]. As far as the harvesting is concerned, it doesn’t take any effort or resources as it reproduces on its own. The seed pods eject thousands of long lived seed each year, meaning that the agricultural processes that are part of other plants cultivation, are in this case
unnecessary. In addition to the long-lived seeds, each parent plant is also valuable for a period of almost 20 years. Finally, its cultivation retains a low environmental impact [27].

Spanish broom has diverse biological properties. Besides the ones mentioned before, it is essential to mention the flexibility of the plant and its ability to tolerate humidity [21][15][16][27].

On the other hand, there is not always the need or the resources to begin an extensive cultivation of a specific plant. In this case Spanish broom consists an opportunity as well. With its major presence all over Greece, Italy or Spain it is waiting to be exploited. The fact that it grows in coastal areas with rocky soil and clean air, not exposed at all to pesticides in contrast to cotton for example, is an additional advantage [22][6].

Moreover, in California it is considered a pest, an obnoxious weed with the urgent need to get rid of it. This might be the biggest opportunity of all. Starting to create something out of a raw material that is regarded as useless and hazardous and not only proving its undoubtful values but also making it profitable.

3.4 Comparison of Spanish broom and flax

3.4.1 Introduction

It is undeniable that the cultivation of Spanish broom and the use of its parts for multiple purposes consist a great opportunity. The real question deals with the specific characteristics of Sparto’s fibers. There has been an increase of demand for cellulosic fibers such as flax, hemp, ramie, sisal or jute mainly because of the global market pursuing more “eco” and recyclable products. Also, because natural fibers provide a multitude of advantages in comparison to synthetic fibers such as the biodegradability, the low density the appropriate stiffness or the high disposability. The above fibers are nowadays widely used for applications in the textile industry or for manufacturing composite materials. However, Sparto’s fibers have been completely abandoned primarily because of the low efficiency of the traditional extraction processes.

Therefore, the question is if it is possible to extract the fibers in a more efficient way, producing fibers with better characteristics than those obtained by the maceration process. Additionally, whether or not these fibers are comparable to the commonly used ones.

3.4.2 The experiment

Two scientific publications, one from the Textile Research Journal (A) [8] and one from the Institute of Biopolymers and Chemical Fibers (B) [24] in Poland have attempted to find the answer. Both studies are trying to describe the chemical composition, morphology and tensile properties of the Spanish broom fibers in comparison with flax.
The A study uses for the experiment flax collected from Poland and Spanish broom form Croatia whereas the other study uses broom and flax collected from Italy. In spite of the different origins of the plants the results are very similar.

In the A study the fibers are extracted with 2 different processes. At first the traditional maceration process is applied. More specifically the samples are retted in heated water at 30.6-33 °C, the Spanish broom for 20 days and the flax for 3 days. The increased retting period for the Spanish broom is caused by its tougher stem. After that follows the mechanical processing, the breaking and scutching. In the second process called osmotic degumming, the samples are placed in a 200ml glass gauge filled with warm water and then placed in a tank full of water at 30 °C. One end of the rubber hose was immersed in the glass gauge and the second in a plastic container. This process works with physical laws such as water diffusion and osmotic pressure. The process had duration of 28 days for the broom and 3 days from the flax. Then the mechanical process followed (breaking, scutching).

The B study uses a process known as DiCoDe or physical chemical process, which has been more recently applied and it is expected in general to be faster, more convenient and give better results in fibre yield. During this process the samples are immersed in 15% sodium hydroxide solution at 100 °C for 15 min. Then the hot sprigs are washed to obtain a level of neutrality and they are introduced in an autoclave at 120 °C and 1Mpa pressure for 3 hours. Finally the fibers are washed again and dried.

3.4.3 The results

First of all, the chemical composition of the fibers is analyzed. The cellulose content of Spanish broom is higher that the flax, lignin is similar and pentosans and pectins are lower in Spanish broom. However these amounts depend highly on the details of the extraction processes. That means that small alterations for example in the amount of NaOH usage may produce better results and remove further hemicelluloses and lignin from fibers.

<table>
<thead>
<tr>
<th></th>
<th>Spanish Broom fibres</th>
<th>Flax fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulose, %</td>
<td>91.7 ± 0.1</td>
<td>75.3 ± 0.3</td>
</tr>
<tr>
<td>Lignin, %</td>
<td>3.2 ± 0.4</td>
<td>4.2 ± 0.1</td>
</tr>
<tr>
<td>Pentosans, %</td>
<td>4.1 ± 0.3</td>
<td>16.3 ± 0.2</td>
</tr>
<tr>
<td>Pectins, %</td>
<td>0.0 ± 0.0</td>
<td>3.2 ± 0.3</td>
</tr>
<tr>
<td>Ash, %</td>
<td>1.0 ± 0.2</td>
<td>1.0 ± 0.1</td>
</tr>
</tbody>
</table>

Figure 3.4.3.1 Comparison of chemical composition of Spanish broom and flax fibers [24]
Spanish broom fibers have a smaller diameter with a variation of 7-10 µm whereas flax fibres have a variation of 17-24 µm. These numbers affect fiber properties such as water absorption.

The colour of spanish broom was yellower and less bright than flax. However this could be a result of the storage conditions and/or the selected extraction process.

Both studies draw a lot of attention to the tensile properties of the fibers. Spanish broom fibers have shown higher tenacity and strain at break, implying the decreased rigidity. Elongation is a very important factor for manufacturing purposes. Higher elongations means that the material can withstand bending and shaping without breaking. This means that the fibers are more flexible and softer. Also both of the fibres have low density which makes them suitable for the automotive industry.

Figure 3.4.3.2 Stress-strain test (a) for Spanish broom fibers and (b) for flax Fibers both obtained by osmotic degumming [8]

Figure 3.4.3.3 Stress-strain test (a) for Spanish broom fibers and (b) for flax Fibers both obtained by water retting [8]
Figure 3.4.3.3 Tensile properties of Spanish Broom compared with flax fibres [24]

It should be noted here that the broom fibers extracted by osmotic degumming showed decreased toughness. Furthermore, the broom fibers showed a higher coefficient of variation, meaning that flax fibers exhibited better uniformity of breaking elongation. One reason that could be responsible for that could be the implementation of the traditional maceration process. In general, the breaking tenacity depends highly on the maceration process.

Next, the moisture regain is analyzed. The samples were tested at different contents of relative humidity. The water, in the form of vapor or liquid, penetrates into the fibre and is absorbed by hydrogen bonds, which cause swelling of the fibers. The swelling consequently can influence the rate of heat transfer or moisture-vapor transfer through the textile made from the fibers. This may affect the comfort or the dimensional stability of the fabric [29]. The results prove that Spanish broom fibers show low moisture regain which makes them appropriate for the manufacturing of comfortable clothing.

Figure 3.4.3.4 Moisture regain of Spanish broom and flax fibers [24]

Furthermore, Spanish broom fibers show as good or even better thermal stability compared to flax fibers, depending on the extraction process. This proves the suitability of Spanish broom for reinforcement in composite materials.

The index of crystallinity is also calculated. The analysis of crystallinity has a great significance. The orientation of the cellulose crystals determines the texture of the fibers and its properties. If the crystallographic orientation has a big amount of orientation then the sample will have a strong texture [w15]. In our case, the cellulose crystals are better oriented in Spanish broom fibers.
The fineness of the fibers is also determined, again showing that the Spanish broom fibers are finer than those of the flax, especially the ones extracted by osmotic degumming.

3.4.4 Conclusion

All of the above confirm the high qualities of the Spanish broom fibers. Most of the morphological characteristics of Spanish broom fibers are very similar to those of flax and their properties are comparable. Moreover, the tensile properties and thermal stability of Spanish broom fibers are as good or even better than flax fibers. Overall, the conclusion is that Spanish broom fibers can successfully replace flax fibers in the textile industry or in the production of composite materials.
4. Experiments

4.1 Introduction

Spanish broom fibers have been forgotten for a long time. It is clear from the information presented above that it is more than meaningful to return to the utilization of Spanish broom fibers. Thus, it was deemed necessary to conduct a series of experiments in order to get more acquainted with the plant, the extraction processes and the possibilities but also to investigate its properties in more detail.

4.2 Materials

Spanish broom shrubs (Spartium Junceum) were grown spontaneously in Dionysos, Athens (Greece). The area was exposed to sunlight and the plant was grown on the roadside as expected.

Figure 4.2.1 Spanish broom in Dionysus, Athens (Greece).

The hill was full of randomly placed shrubs in full growth, proving its reproducing mechanism. Old and younger plants were present, something you could tell with a quick view from the brown colour of the old stems.

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1 All of the experiments were conducted in Studio Tjeerd Veenhoven, Groningen, Netherlands.
The experiments took place in early August. By that time the stems have lost all of their yellow flowers. However they had still plenty of mature seedpods almost ready to burst open.
The branches were cut with scissors near the core of the main tree, where the wooden thick part was seen.

Spanish broom is a shrub easily confused with similar plants such as Scotch, French or Portuguese broom. In order to confirm its identity, certain tests were conducted in an effort to cross check the information of the prior research.
The seedpod samples were 5-10 cm long and each one contained 10-17 seeds.

![Figure 4.2.6 Spanish broom seeds](image1.jpg)

A couple of remaining flowers were 1-2 cm long and dark yellow.

![Figure 4.2.7 Spanish broom flowers](image2.jpg)
A few sparse leaves were also present. They had a dark brown colour and their length was ranging between 2-2.5 cm. The most important fact however, was that they were simple in contrast to the other brooms that have leaves with 3 leaflets.

Figure 4.2.8 Spanish broom leaves

Next, the stem was observed. It was finely ribbed and round at cross section. At this point it was certain that the stems from the right plant were obtained.

Figure 4.2.9 Spanish broom stem
4.3 Extraction methods

4.3.1 Preparation

After the harvesting, the next step is to clean the branches from any dirt they might have on the surface.

![Figure 4.3.1.1 Harvested Spanish broom](image)

Besides the dust, the seedpods or any remaining leaves were moved as well.

![Figure 4.3.1.2 Cleaning of the stems](image)
After the cleaning, it was important to make a brief separation of the useful stems from the old brownish stems.

Next the fibrous pliable parts of the branches were separated from the woody part.
The pliable branches were tied into bundles of approximately 100 gr.

Finally, the bundles are let to dry under the sun.
4.3.2 Natural Process

Spanish broom bundles, weighting 100gr, were placed in a tank full of boiling water for a duration of half an hour. After the boiling, the bundles were left in the tank for the retting phase. The water was replaced every day with cold water.

Figure 4.3.2.1 Boiling Spanish broom

Figure 4.3.2.2 The bundle after boiling for half an hour
The retting lasted 10 days. The bundles were removed and left to dry under the sun. Then the stems were processed as previous papers have suggested.

The stems were beaten and hackled. However the results were not successful. The beating smashed the fibrous and the wooden part of the stems and made it impossible to separate the one from the other whereas the hackling did not provide anything more to the result.

Figure 4.3.2.3 Beating Spanish broom stems

Figure 4.3.2.4 Hackling Spanish broom stems
For the second experiment the bundles were boiled for half an hour but let to ret in running water, more specifically in a canal for 20 days. The picture below shows the retted broom covered in a mash used for the purposes of the retting.

![Figure 4.3.2.5 Spanish broom retted in running water](image)

After the period of 20 days, the bundle was removed from the canal. It was washed with plenty of cold water to remove all of the micro-organisms from the surface of the stems.

![Figure 4.3.2.6 Spanish broom retted in running water](image)
The retting serves the purpose of easing the separating of the cellulose fibers from the wooden core of the stem by loosening the bonds that hold everything together. However in the case of this experiment, the retting period was too big resulting in the fibers completely dissolving.

Nevertheless, this experiment was still beneficial, because it became clear that the stems were full of fibers. When the stems were washed, the water was full of hair-like substances, indicating the possibilities of the process.
In a final attempt to obtain the fibers, the parts obtained from the previous step, were placed in a solution of NaOH at a temperature of 100 °C. The solution was used to solubilize the hemicelluloses and remove most of the lignin so that the fibers can be detached. Unfortunately the fibers could not be untangled from the mixture.

Figure 4.3.2.8 Fibers in the NaOH solution

The next experiment was conducted with more precision. Only the youngest of the stems were selected for the process. Any wooden parts were removed as well as any old stems with brown colour. Also, stems with very small length, which are expected to produce very small, short fibers, were removed from the sample.

Figure 4.3.2.9 Sample selection
When the right stems were selected, they were tied in bundles weighting 100 gr.

Figure 4.3.2.10 Weighting the bundles

Then, the bundles were boiled, this time for 1 hour.

Figure 4.3.2.11 Boiling Spanish broom
Exactly after the boiling, a fiber was pulled out of the water to be tested. The boiling duration of 1 hour was more appropriate, as this time the outer fibrous shell was easily pulled off the stem.

Figure 4.3.2.12 Peeling off the fibrous shell

The bonds that held together the fibrous shell with the inner wooden core were now extremely loose. The wooden core was now completely detached.

Figure 4.3.2.13 Detached wooden core.
In a very short amount of time, the exterior fibers of the whole bundle were detached from the stem and were now ready for processing.

Figure 4.3.2.14 Fibrous outer shell separated

The fibers were combed to separate them and remove the unwanted substances

Figure 4.3.2.15 Combing Spanish broom
The fibers had finally a hair-like appearance. However the surface of the fibers was not yet free from lignin and pectin, which work as an adhesive between the fibers. This was very obvious as the colour of the fibers was green and there were thick layers of the substances.

Figure 4.3.2.16 Fiber full of lignin and pectin

Once again, it was decided to proceed with a different experiment. This time after boiling and retting, the stems went through the stage of breaking. Before braking the stems were left to dry.

Figure 4.3.2.17 Breaking Spanish broom
The stems were broken with a piece of wood in the same manner that the flax was being broken. After breaking the fibers were combed. This time the fibers obtained were even more rough than in the previous experiment. This may have been a result of processing the stems while completely dry.

Figure 4.3.2.18 Comparison of fibers obtained from experimenting with extraction processes

For the next experiment the stems were boiled, retted and processed while they were still damp. In an attempt to improve the step of breaking, a construction was made, suitable for processing a bigger amount of stems.

Figure 4.3.2.19 Breaking machine
The breaking process really assisted in loosening the bonds and now the fibrous shell was very soft.

Figure 4.3.2.20 Stem after breaking

The separation of the fibres from the inner core was achieved very effortlessly.

Figure 4.3.2.21 Stem after breaking
The fibers obtained were full of chaffs and knots. In order to remove them the fibers went through the stage of scutching.

Figure 4.3.2.22 Fibers obtained from breaking

The fibers were placed on a vertical board and then beaten repeatedly with a wooden paddle.

Figure 4.3.2.23 Scutching
For the purpose of the next step, a quick construction with wood and nails was made to serve as a comb. A couple of fibers were passed through the nails to separate them and clean them from unwanted substances.

![Figure 4.3.2.24 Nail fiber comb](image)

The resulted fibers were better than all of the previous experiments. The fibers had now a yellow colour and the surface was completely free from knots and chuffs. However the texture was still pretty rough which makes them unsuitable for weaving wearable apparel.

![Figure 4.3.2.25 Spanish broom fibers](image)
A final attempt was made to extract better quality fibers with a natural process. The bundles were boiled for an hour and left to ret for 10 days. After this period the fibrous shell of the fibres was peeled off. This time the shells were placed on a wooden board and beaten with a wooden hammer, following an old Greek recipe. When the old Greeks treated Sparto, left to ret in the rivers, they peeled off the outer fibers and beat them against stone plates. This way the substances were pushed away, leaving behind very clean fibers.

Figure 4.3.2.26 Beating fibers

Figure 4.3.2.27 Substances pushed away
Then, the fibers were scutched, further removing the pectin and lignin substances. This time the scutching was done with a metal knife, achieving more precision. The fibers revealed after this step were more clean and bright than any of the previous experiments.

Finally the fibers were combed to remove any knots.

Figure 4.3.2.28 Scutching with metal knife

Figure 4.3.2.29 Combing fibers
The fibers obtained were very bright, soft and had a sufficient length to make them suitable for not only for composites but also for weaving.

![Combing fibers](image)

**Figure 4.3.2.29 Combing fibers**

However, not only the obtained fibers are useful. The tow, the remained fibers from the stage of hackling, is useful too. It can be used for stuffing pillows and mattresses as it is or it can be spinned into cordage. Its value depends on how clean it is in the end of the extraction process. In our case, the tow produced from the last process was adequately clean and could be used very easily.

![Spanish broom Tow](image)

**Figure 4.3.2.29 Spanish broom Tow**
4.3.3 Physical-chemical process

Once again, the longer stems and younger stems were selected for this process. They were tied in bundles of 100 gr.

Figure 4.3.3.1 Spanish broom bundle

Next, a 15% NaOH solution was made and was heated at a 100°C.

Figure 4.3.3.2 NaOH solution
The bundle was immersed in the boiling solution for 15 min.

Exactly after the hot springs were removed from the solution, they were washed with plenty of cold water in order to achieve a level of neutrality.
The outer fibrous shell was easily peeled off the solid, ligneous part while the stems were still wet.

Figure 4.3.3.5 Peeled off fibers

The humid fibers were inserted in a pressure cylinder and then pressurized at room temperature with air (10 atm).

Figure 4.3.3.6 Inserting fibers in pressure cylinder
The vessel was heated at 120°C for 3 hours.

Figure 4.3.3.7 Heating the pressurized fibers

Immediately after this period, the cylinder was degassed very rapidly.

Figure 4.3.3.8 Degassing
The obtained fibers were washed again with plenty of cold water.

Figure 4.3.3.9 Washing

They were then squeezed to remove excess moisture.

Figure 4.3.3.10 Squeezing wet fibers
Finally the fibers were dried.

The resulted sample was very dry and fragile. The fibers were very weak and the colour was very dark, indicating possible complications such as elongated treatment or high temperatures. Inappropriate equipment and the lack of precision that this entails may have also been the causes for the insufficient results.
4.4 Conclusion

Overall, the experiments were successful. The results were judged according to their appearance, texture, colour and strength. Some of the resulted fibers have a sufficient quality to be used for example for ropes, especially the ones that are more roughly textured. Others however are very fine, bright colored, soft and long and therefore are perfect for weaving and composite making purposes.

Figure 4.4.1 Results
The resulted tows were also very interesting. Some of them were not very clean resulting in a very rough texture and some were bright and soft. Depending on the quality, the tow can be used for stuffing mattresses, as reinforcement in composites or it can be spun and made into a woven.

Figure 4.4.2 Tow with different qualities
5. Future potential

5.1 Introduction
Spanish broom fibers have a very high quality. Their strength and texture makes them suitable for various applications. In this section, it is attempted to investigate the possibilities of applying this excellent material in well known fields, such as composite manufacturing or textile weaving. Furthermore, less known for natural fibers applications are explored, such as utilization for building construction.

5.2 Composites
In an effort to examine the efficiency and adequacy of Spanish broom for well known applications, a couple of experiments have been conducted. The facilities for these experiments were not always the most appropriate and, thus the results may present deficiencies. However, they were sufficient to draw conclusions on the functionality of a future application.

5.2.1 Experiment
For this experiment, the Spanish broom tow was used for reinforcement. Bio based epoxy resin was used as a matrix. The tow was placed carefully around the walls of a plastic cup. The main focus was to keep it uniform with a certain width.

Figure 5.2.1.1 Materials
Epoxy resin, suitable for production of composite structures by wet lay-up methods, was used for the experiment. It is also appropriate for vacuum bagging. The resin was applied with a brush. The amount of resin to be applied was determined by the absorption of the fibers. The application ended when the thick layer of fibers was completely wet.
For the purposes of the experiment, a concrete mix was poured into a smaller-diameter cup, and this was placed inside the first cup to form a mold. This was necessary for the stage of vacuuming, as the air that is sucked out of the bag would ruin the shape of the composite.

![Mold](image1)

**Figure 5.2.1.4 Mold**

The vacuum system used, consists of a vacuum pump to drain the air from the bag, a trap structure to collect any excess resin that may leak during the procedure, a gauge to measure atmospheric compression, two valves to control the pump and the trap a hose to connect the system with the bag and sealing rings to secure the bag from any air leakage.

![Vacuum system](image2)

**Figure 5.2.1.5 Vacuum system**
Each mold was placed in a plastic bag and then all of them were placed in a thicker plastic bag, one that is able to withstand the amount of atmospheric pressure that will be applied. The pump was turned on and the air was drained from the plastic bag. As a result, the composites were allowed to cure in uniform pressure.

Figure 5.2.1.6 Vacuum system in action

The objects were left to cure overnight. It is apparent from the photo that the plastic bag around the mold became extremely tight.

Figure 5.2.1.6 Objects exactly after vacuuming
Overall, the composites were successful. The deformations were minimum and the bonds that hold the fibers together were very strong. Further tests are recommended, to ensure the composites’ strength and quality and to prevent possible complications such as delamination.

Figure 5.2.1.7 Sparto-resin composite next to Sparto tow

Figure 5.2.1.8 Sparto-resin composites
5.2.2 Potential

The possible applications for these composites are various. A first example could be the automotive industry. Even since the 1980’s, interiors for door panels were manufactured using natural fibers. Mainly focusing on the natural fibers’ low density but also because of their low cost, nowadays more and more well-known car manufacturers are investing in incorporating natural fibers in their productions.

Figure 5.2.2.1 Composite parts for motorcycles

Figure 5.2.2.2 Composite parts for cars
However, not only the automotive industry is taking advantage of the natural fiber composites. More and more industries and smaller companies are designing products that are enhanced by the good qualities of the natural fibers composites.

Figure 5.2.2.3
Composite case

Figure 5.2.2.4
Flax speaker

Figure 5.2.2.5
Flax chair

Figure 5.2.2.6
Hemp sunglasses
5.3 Woven

5.2.2 Introduction

Besides working as reinforcement for composites, Sparto could also be used in the traditional way that natural fibers are used. Weaving. Good insulation, no toxicity and biodegradability are just some of the reasons why Sparto would be attractive for the textile industry.

5.2.3 Experiment

The long, clear and soft Sparto fibers would produce with the proper processing a high quality textile, suitable for wearable clothing. However, in this experiment it is attempted to produce a woven from the rough Tow, the fibers that remain in the comb after the stage of hackling.

Fist step, the spinning. A small string of fibers is pulled from the tangled Tow and spinned by hand. The process is repeated for a long period until the whole bunch is transformed into a uniform thread.

Figure 5.2.3.1 Spinning Sparto
At first the thread looks rough and with thickness variation. A second or third repetition of the process helps to maintain uniformity. Also, keeping the fibers moisturized helps them to stay together after spinning and eases the act.

Figure 5.2.3.2 Sparto thread after first spinning

Figure 5.2.3.3 Sparto thread
After that the stage of weaving follows. For the purpose of this experiment a basic construction to ease the process was manufactured.

Figure 5.2.3.4 Sparto woven

Figure 5.2.3.5 Sparto woven detail
The result is promising, indicating that with proper equipment and better processing, the quality of the woven will be very high. Below two examples of Sparto textiles are presented.

Figure 5.2.3.6 Sparto textiles
a) after mechanical extraction
b) after the physical chemical extraction

5.2.4 Potential

The possibilities of applying the woven Sparto in everyday life are limitless. First of all, it can be applied in the textile industry. More and more companies are turning towards a more ecofriendly direction for their products. Clothing, bags, home accessories like carpets and many more.

Figure 5.2.4.1 Flax textiles
Figure 5.2.4.2 Flax clothes

Figure 5.2.4.3 Flax backpack

Figure 5.2.4.4 Jute rug

Figure 5.2.4.4 Natural fibres rugs
The woven fibres however, are not only useful as a textile but also for the production of composites. Woven mats are used as reinforcement in resin matrixes.

![Thermoformable flax composite](image)

**Figure 5.2.4.4 Thermoformable flax composite**

5.3 Other uses

5.3.1 Introduction

Besides being spun into a woven or used as reinforcement for composites, Sparto can be processed in many more ways. Given the fact that Sparto’s properties are similar to flax it is certain that the processes currently used by industries dealing with natural fibers, can be applied to Sparto as well.

Sparto can be spinned but it can also undergo the process of needling, molding or rubberizing.

5.3.2 Needling

In this process the tangled fibers are bonded together with a special technique. Thousands of spiked needles are repeatedly passing in an out the fiber web. In order to enhance the binding, a thin layer of latex may be used underneath the web. Finally needled fibers are produced in rolls and sheets. The needled products may be used as a filament for mattresses, upholstery or as a thermal insulator.
5.3.3 Rubberizing

During this process, natural fibers are spun into a fleece and then sprayed with latex. The latex helps the curled fibres to bond. Next, they are pressed and treated with the addition of a curative at high temperature into sheets. The resulted products have great acoustic and thermal insulation ability.
This process has the advantage of being customized. The rubberized material can be molded in any shape. After the fibers are spun and sprayed with latex, they are pressed into a mold and treated. This way rubberized fibers can be adjusted for any purpose and have a variety of applications such as seat cushions, car seats or packaging production.
Figure 5.3.3.3 Packaging with rubberized coir

Figure 5.3.3.4 Packaging with rubberized coir
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