



Variations in the morphological characteristics of *Stipa tenacissima* fiber: The case of Tunisia

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ABSTRACT

Esparto fibers are cellulose-based fibers extracted from esparto (*Stipa tenacissima*) leaves. Morphological characteristics (length, width, and coarseness) of esparto fibers are analyzed in relation to growing conditions and plant biology. Seven localized sites in Kasserine in central western Tunisia are examined. The analysis of variance showed that all investigated characteristics vary significantly with site, season, and leaf level. Leaves reach minimum level in winter and maximum level in fall. Fiber differentiation is closely related to the vegetative cycle. Fibers are short and wide at the leaf base (basal level) and grow longer and thinner above the leaf. Results on the raw material (esparto leaves) were confirmed by results on esparto pulp.

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1. Introduction

Stipa tenacissima, or esparto grass (Alfa), is a fast-growing perennial plant that thrives in dry areas of North Africa and southeast Spain (Cerde, 1997). It belongs to the poaceae family. Its fiber-rich leaves can reach 1 m in length. The tufts of *S. tenacissima* are circular and homogeneous when young but become empty at the center as they age and begin to die. The leaves are thin, ribbon-like, smooth, shining, solid, and covered at the base with a hairy sheath. Esparto leaves mature in the fourth to eleventh month after budding, depending on location and climatic conditions (Ghrab, 1981). For example, in Tunisia, the leaves of *S. tenacissima* take from four to six months to mature in the Thelepte region, which belongs to the arid superior bioclimatic stage. On the other hand, they take from eight to eleven months in the Nadhour region, which belongs to the arid lower climatic stage (Ghrab, 1981).

According to Harche (1978), the biological cycle of *S. tenacissima* comprises two growing seasons (fall and spring) and two latent seasons (winter and summer). In fall the esparto tufts are in full vegetative phase. Thus, most leaves are mature, and the younger

ones start to develop and lengthen. However, in winter most leaves are young and the growth halts due to the cold weather. In spring, the season of inflorescence, flowering generally begins in May and finishes at the end of June (Mehdadi et al., 2006). Early flowering may be observed in April if the previous autumn rains were sufficient and the winter was warm. Thus, flowering varies according to the location and the variability of climatic conditions over the years (Ghrab, 1981).

In an ecological study, it was shown that esparto grass grows in almost all the geomorphological units, regardless of land topography. It even clings to rocky hillsides. However, the most dense and spatially extended populations are found in low-lying areas and on permeable glaciis (Ghrab, 1981). Besides, in edaphic terms, esparto grass grows in shallow, permeable, calcareous soil with a very sandy texture and less well in clayey, salty soil. According to Pouget (1980), esparto prefers a stony soil with high calcareous content (30–40%) and low gypsum content (~2%), and does not adapt well to soils with clay and loam content ranging from 12 to 20% (Ghrab, 1981). Moreover, Esparto grass thrives in a wide range of bioclimates and is resistant to large variations in temperature. Nonetheless, it achieves optimum growth in arid superior and semi-arid lower bioclimatic stages (Ghrab, 1981; Nabli, 1989).

The uses of this plant are very diverse. Indeed, it is used to make handcrafted espadrilles and baskets (Akchiche and Messaoud Bouregghda, 2007), as alternative livestock feed during periods of forage scarcity (Genin et al., 2007), and to manufacture rope and mats. Furthermore, this plant serves as an invaluable natural barrier

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Table 1

Location and environmental characteristics of the study sites.

Site location	Density (tufts/ha)	Land topography	Geographic coordinates	Altitude (m)	Bioclimatic stage	Chalky (%)	Clay (%)	Loam (%)	Sand (%)	Texture of soil
Jelma	5000	Plain	L:35°32'98" l:9°41'17"	421	Arid superior P: 206.03 mm T: 27.72 °C	24	8	19	73	Sandy loam
Guira	9125	Plain	L:35°02' l:8°56'20"	681	Arid superior P: 223 mm T: 24.94 °C	33.66	12.66	31	56.44	Sandy loam
Salloum Nord	9375	Slope	L:35°8'13" l:8°59'	745	Semi-arid lower P: 295.47 mm T: 24.94 °C	35.66	14.33	24	61.67	Sandy loam
Salloum	9650	Mountain	L:35°05' l:8°54'	1193	Semi-arid superior P: 467.5 mm T: 17.5 °C	64	15.33	32	52.67	Loam
Zelfane	8900	Plain	L:35°23'25" l:8°47'5"	1000	Semi-arid superior P: 454.2 mm T: 15.8 °C	5	21	3	76	Sandy clay loam
Kshime el kalbe	9750	Glacis	L:35°6'15" l:8°40'30"	843	Semi-arid lower P: 265 mm T: 16.35 °C	51.33	10	28.66	61.33	Sandy loam
Fekka	9250	Plain	L:35°47'35" l:8°22'	737	Arid lower P: 232 mm T: 17.41 °C	38	7.66	11	81.34	Loamy sand

that limits the desert's expansion, thanks to its well-developed root system that retains and protects the ground (Mehdadi et al., 2005). Moreover; it is also used as a main source of fiber for papermaking (Akchiche and Messaoud Bouregghda, 2007). Bouiri and Amrani (2010) showed that Alfa presents morphological and technological characteristics suitable for the production of bleached kraft pulp, making this species an excellent raw material source for the pulp and paper industry. Indeed, Alfa fibers form excellent sheets with good bulk (Bouiri and Amrani, 2010), while Alfa paper pulp produces a well-filled, dense paper with excellent inking capacity and very good folding properties. It is used to manufacture blotting paper, cigarette tubes, cigarette filter tip paper, lightweight papers, and good-quality printing and writing paper (Hurter and Eng, 2001).

In Tunisia and Algeria, Alfa is considered one of the most interesting non-wood plants for the production of fibers for papermaking (Anon, 1974; Nadji et al., 2006). In Tunisia the entire esparto supply is appropriated by the National Company of Cellulose and Esparto Paper (SNCPA Kasserine, Tunisia), where the fibers are extracted for use in cellulose pulp and paper manufacturing. Therefore, the esparto leaves used for papermaking are harvested annually from the entire esparto population during a specific six-month period set by the Ministry of Agriculture (from September to February). This irrational exploitation may account for the progressive regression of the surface area of the esparto (Ghrab, 1981), and could be explained by poor knowledge of the biology of this plant.

Extensive research has been conducted on the fiber and pulp characteristics of Alfa, including pulp properties, chemical composition, and cell wall architecture (Harche and Catesson, 1985; Nadji et al., 2006; Akchiche and Messaoud Bouregghda, 2007; Bouiri and Amrani, 2010). These studies provide valuable information about the general morphological structure of Alfa fiber as a raw material in papermaking. In particular, morphological properties play important roles in strength development of paper properties (Seth, 1990a,b). Indeed, higher fiber length is associated with higher paper properties mainly tensile strength and tearing resistance (Seth, 1990a). Fiber coarseness is strongly related to tearing resistance (Seth, 1990b). In opposition to coarse fibers, fine fibers collapse easily during paper pressing and thus, promote fiber

bonding which determine to large extent paper strength (Seth, 1990b). Similarly, larger fibers result in higher bonded area between fibers and thus better bonding strength. Marrakchi et al. (2011) evaluated the impact of refining on the morphology of the Alfa fibers and their suitability thereafter on the pulp properties. However, and to the best of our knowledge, up to now there was no report about the variation in morphological characteristics of Alfa fibers in relation to growing conditions. Thus, this study focuses on the variability of morphological characteristics of Alfa fibers (length, width, and coarseness) with growing season, site, and leaf level. Ultimately, it aims to improve the quality of paper by identifying the optimal period and site for the harvesting of this plant.

2. Materials and methods

2.1. Sampling

Leaves of the tussock grass *S. tenacissima* (esparto) were analyzed. Samples were taken across the biological cycle in 2006 (winter: mid-January, spring: mid-April, summer: mid-July, and fall: mid-October) from seven localized sites (Table 1) in central western Tunisia, particularly the Kasserine Region (Fig. 1). Leaves were sampled from several tufts harvested from each site. They were then dried in a steam room at 60 °C for 72 h and mixed to enable random sampling, each sample containing five leaves. Samples were then divided into five levels (see Fig. 2) according to leaf length (basal, apical, and three median levels). The basal level of the leaves from two sites (Fekka and Salloum) was further divided into five sublevels. The median part was examined for coarseness. For comparative purposes, the morphological characteristics of esparto pulp fibers harvested in three different seasons (summer, fall, and winter) were evaluated.

2.2. Sample preparation

For the morphological analysis, the leaves of *S. tenacissima* were macerated using Franklin (1945) method. Two grams (g) of Alfa fibers were introduced into a 30 ml bottle containing 20 ml of a solution in equal parts of glacial acetic acid and hydrogen peroxide, then

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