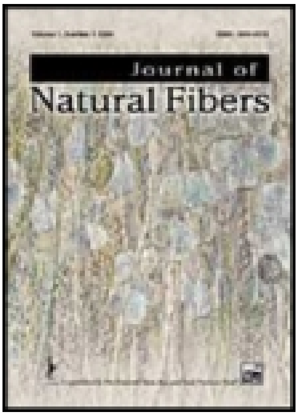

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Eighty Years of Studies on Industrial Hemp in the Po Valley (1930–2010)

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The Department of Agroenvironmental Science and Technology (DiSTA), University of Bologna, has been studying industrial hemp since 1930s. In the pioneering studies we mostly addressed agronomic issues while most recently, fiber quality and characteristics, along with innovative fiber processes, have been mostly investigated. In general, even though significant progresses have been achieved and innovative production strategies proposed, significant bottlenecks still remain unsolved, especially for the textile uses. Most likely, the production of bio-polymers and non-textile compounds can be economically self-sustaining in a short term, while fiber processing for textile uses still needs significant improvements.

KEYWORDS *hemp, stem production, fibre quality, fibre processing, harvest time*

INTRODUCTION

Industrial hemp (*Cannabis sativa* L.) is a C_3 annual crop native to Asia, imported to Europe (Eastern England) in the 16th century. Alike flax, hemp is renowned for the quality of stem fibers, particularly the bast fibers located in the outer part of the stem. The inner part of the stem, namely woody core, is much richer in lignin and thus less noble than the surrounding stem part. Nevertheless, it could be profitably commercialized for several non-textile applications (e.g., horse bedding).

The interest in industrial hemp as source of natural fibers is not new. Definitely, hemp has been one of the globally most important crops for

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mankind up until last century, occupying up to 820,000 ha in central Russia, mainly in Ukraine. It was probably the earliest plant grown for textile purposes, and probably the oldest example of human industry. There is trace of hemp cloth in ancient Mesopotamia, which dates back to 8,000 BC. Hemp was likely the largest cash crop until the 20th century, and in the United States you could be jailed for refusing to grow hemp in the mid-1700s. About 80% of all textiles, clothes, bed linen, fabrics, sails, etc. were made from hemp until the early 1800s, while it is surprising to see that people barely recognize it today.

Italy reached significant hemp cultivation area as well, with up to 135,000 ha grown in the North of the Peninsula in the mid-1900s (Venturi and Amaducci 1999). The commercial interest in hemp evaporated rapidly with the advent of more economic feedstocks like raw cotton and synthetic fibers, and also because of narcotic issues and the increase of labor cost. Less than 9,000 ha were cultivated in EU-27 in 2010 (Eurostat). Nonetheless, the research continued to maintain keen interest on industrial hemp as testified by large projects at national and international levels such as Hemp for Europe, Harmonia, and Hemp-Sys. Moreover, unlike cotton, cultivation of which is restricted to the sub-tropical areas and needs massive use of agricultural inputs, hemp is a broadly adapted and low-impact crop requiring low fertilization rates, and no herbicides and irrigation. When incorporated into conventional crop rotations, hemp generally provided significant benefits for the succeeding crop (Ranalli and Venturi 2004; Stickland 1995; van der Werf 2004). These studies contributed to triggering a renewed interest in hemp by revealing outstanding potential for traditional and innovative applications for such bio-polymers in the automotive (Karus and Vogt 2004) or aeronautic industries, insulating board for bio-building (Karus and Vogt 2004), or to reinforce cement (Sedan et al. 2007).

The relationships between agricultural practices and fiber fineness, chemical composition, strength, and breaking tenancy were also matter of deep investigations during the aforementioned projects (Amaducci 2003; Amaducci and Venturi 1998). Although interesting new insights have been achieved over the years, the uneconomic fiber processing still remains the main bottleneck for the hemp-based textile market. Textile apart, the following applications were identified as the most promising: (i) straw and hurds for the car industry (Bledzki et al. 2006; Karus and Vogt 2004;), (ii) bio-building compounds (Kymäläinen and Sjöberg 2006); (iii) seed oils for the food industry (Kriese et al. 2004); and (iv) essential oils and secondary metabolites from inflorescences for cosmetics, antimicrobials, and pharmaceutical applications (Karus and Vogt 2004; Nissen et al. 2010). Other potential uses of hemp are in the phytoremediation of polluted soils (Linger et al. 2004) and for thermo-chemical (Venturi and Venturi 2003) and second-generation bio-ethanol production through cellulose hydrolysis and sugar fermentation (Zatta and Venturi 2009a; Zatta et al. 2011). Finally, the lignin-rich core, which comprises 70%–80% of the stalk, could be profitably separated through a scutching process and then used for non-textile applications such as animal bedding, fiber board and other bio-building materials, filler for blending with thermoplastics and plastic hemp, or is finally burned to obtain energy (Mankowski and Kolodziej 2008; Zatta et al. 2010).

Since the 1930s, the Department of Agroenvironmental Science and Technology (DiSTA), University of Bologna, has been directly or indirectly involved in countless initiatives on industrial hemp, contributing significant insights on this crop, mostly in agronomy and crop physiology and, to a lesser extent, in fiber processing. The majority of Italian studies on industrial hemp come from the research group of Bologna University. Over 70 papers and book chapters, four PhD and several degree theses, covering different disciplines from genotype selection to fiber processing, were written on hemp. Moreover, enormous information has been collected by farmers and stakeholders that significantly contributed to increasing our know-how on hemp. The present paper attempts to review our almost 80-year experiences on industrial hemp in the perspective of a renewed and competitive hemp marketplace. At the same time, we analyze some possible shortcuts to overcome the barriers that limit the hemp potentialities under the emerging green economy market.

THE EVOLUTION OF HEMP STUDIES IN NORTH ITALY

Our earliest studies on hemp, dating back to the 1930s, addressed the effect of the day length on crop development (Crescini 1930a, 1930b). These studies confirmed the short-day nature of the hemp and the influence of day length on sex expression. It was demonstrated that flowering occurs after the summer solstice, and that male flowering is earlier than female one, namely proterandry. The researches then focused mainly on agricultural practices, selection of new genotypes, and development of new prototypes to provide affordable feedstocks to the enterprises. It was also evidenced that the new high-yielding genotypes such as Fibranova, C.S., and Eletta Campana had lower fiber quality than traditional genotypes, mainly Carmagnola. New agronomic practices, mobile scutching machine, and green scutching were designed and developed (Ferri and Venturi 1967; Mancini and Barbieri 1964; Venturi 1968, 1970a, 1970c), and innovative retting processes including microbial flora were the objects of some pioneering studies by Sacchetti (1962). Nonetheless, even though these studies significantly contributed to increasing knowledge on hemp, fiber processing for textile industry still remained greatly uneconomic. About 1,200 h/ha were needed for delivering fibers to the textile industry, which made hemp a poorly competitive crop after the advent of cotton, flax, and synthetic fibers

FIGURE 1 Traditional harvesting and handling systems of industrial hemp. From left to right: hemp stems grouped in bundles; bundles bound and then air dried in the field; bundles immerged in ponds for 7–10 days for water retting. About 1,200 h/ha were needed for delivering feedstocks to the textile industry (color figure available online).

in the textile marketplace (Figure 1). Along with restrictions and prohibitions as a drug crop, the uneconomic fiber processing was likely the main reason of the rapid commercial decline of hemp to almost disappearance nowadays (Table 1).

The studies on hemp resumed strongly in the 1980s with the selection of low-THC genotypes (Rivoira et al. 1984) and, above all, with three large projects funded by the European Union aimed at bringing hemp back to fashion, while creating awareness of its potentialities for challenging textile and non-textile markets (Amaducci 2003; Amaducci and Venturi 1998; Karus and Vogt 2004; Struik et al. 2000; Toonen et al. 2004). The optimal plant density and fertilization doses were tailored for the newly developed low-THC genotypes, as well as innovative and economic processes were designed and tested (Amaducci 2003; Amaducci, Műssig, et al. 2008; Figure 2).

Nevertheless, since the entrepreneurs still were skeptical whether to invest in hemp, researches were not industry-driven, generally proceeding in a piecemeal while pursuing contingent objectives. Small partnerships were formed only for textile (Hemp-sys project), papermaking (Italian Paper and Pulp Organisation), bio-building compounds, and plywood (Interregional No Food project) uses. Nonetheless, despite a weak liaison with the industry, some pioneering and important studies on agronomy (e.g., plant density, nitrogen fertilization, and harvest time) and fiber quality provided interesting clues, e.g., on bottom-up fiber quality variation along stem profile (Amaducci et al. 2005, Amaducci, Zatta, Pelatti, et al. 2008), that paved the way for successive industry-targeted studies. For example, new genotypes were selected, especially for textile uses (Di Candilo et al. 2002; Toonen et al. 2004), and the agricultural practices optimized, accordingly (Amaducci, Zatta, Pelatti, et al. 2008). In that context, a new harvester prototype for non-textile uses of hemp was developed (Zatta and Venturi 2009b) and innovative semi-industrial textile processes were designed in collaboration with the Canapificio Linificio Italia (Amaducci, Műssig, et al. 2008).

TABLE 1 Chronological list of hemp studies and main outcomes by the University of Bologna since 1930

Period	Main industrial use	Main research topics	Main findings	Significant events	Funding bodies
1930–50	Textile	Retting, agronomy, and seed production	Selection of monoecious varieties	Advent of economic raw cotton and synthetic fibres	Government
1960–70	Textile and papermaking	Testing new genotypes; optimization of harvesting	Set up of innovative agricultural practices and machineries	Single convention of narcotic drugs (1961): the first international treaty to prohibit hemp	CNPC (National Consortium of hemp producers)
1970–80	Papermaking	Agronomy and physiology	Selection of low-THC genotypes	EU Regulation 1308 for hemp and flax markets (1970); Prohibition of *C. sativa* and *C. indica* (Nat. Act. 30-9/90, Art. 26 of 1975)	ENCC (National corporation of cellulose and paper)
1980–90	–	–	–	–	–
1990–00	Textile and papermaking	Physiology and genotype allocation in EU	Environmental benefits evidenced	National Act 02/12/97 Prot. 1°0734 –Possibility to cultivate up to 1,000 ha of hemp in Italy.	EU (Hemp for Europe project)
2000–06	Textile and alternative industrial uses	Phenology, harvesting, and fibre processing	A new textile system designed and tested at pilot-scale	–	EU (Harmonia and Hemp-Sys project)
2006–09	Bio-building, polymers (non-textile uses)	Harvesting and industrial process	New prototypes for stem cut; several links with enterprises	International Year of Natural Fibres by FAO (2009)	Italian interregional project (No Food)

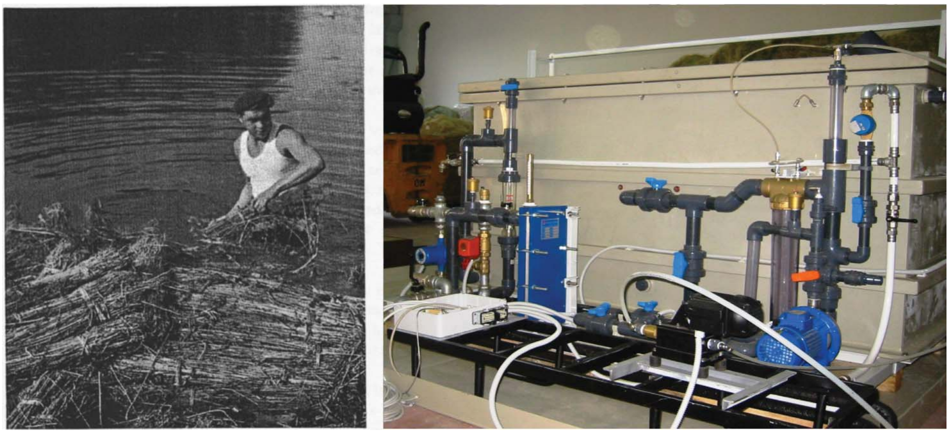

FIGURE 2 From a traditional water retting to the innovative bio-degumming system (color figure available online).

STUDIES ON THE RELATIONSHIPS BETWEEN FLOWERING AND YIELD

Hemp is a proterandrous (males bloom earlier than females; Crescini 1930b) and obligate photoperiodic plant absolutely requiring short days for flowering. There is a great difference among hemp genotypes in flowering time, which is broadly known to play a very crucial role in stem yield and fiber quality (Amaducci et al. 2005; Mediavilla et al. 2001; Venturi 1969; Venturi and Amaducci 1999). We observed, for example, from 4 to almost 100 flowering days in Felina and Fibranova, respectively. Based on flowering time, we indicate three main groups of genotypes (Amaducci, Colauzzi, Bellocchi, et al. 2008; Zatta et al. 2008): early, intermediate, and late (Table 2). Early and intermediate genotypes were selected under northern latitudes; therefore, if grown under southern climatic conditions they start flowering earlier with a consequent much lower biomass yield than potential capacity.

Compared to dioecious genotypes, that have male and female flowers on the same plant, the monoecious types have generally shorter flowering periods and higher canopy uniformity. Nonetheless, it should be recognized that longer flowering periods are generally associated to higher yields. A mathematical description of the growing cycle aimed at predicting the flowering occurrence in monoecious and dioecious hemp genotypes was a matter of a recent study by DiSTA (Amaducci, Colauzzi, Bellocchi, et al. 2008; Amaducci, Colauzzi, Zatta, et al. 2008). The main objective was to elaborate and validate a phenology model under a range of temperature and day length regimes. The authors recorded three distinct growth and reproductive phases: juvenile, photosensitive, and flowering, and estimated the different sensitivity to photoperiod of several monoecious and dioecious

TABLE 2 Stem yield (d.w.), stem pure fibre content (% dw.), fibre fineness, and seed availability of the industrial hemp genotypes tested in Bologna

Genotype	Sexuality	Cycle length[1]	Stem yield[2] (Mg/ha)	Fiber (%)	Fineness (μm)	Commercial interest
Chamaleon	Monoecious	I	5.6–9.9	20.4–21.2	–	Yes
C.S.	Dioecious	L	11.9–17.8	16.5–17.2	–	Yes
Carmagnola	Dioecious	L	15.1–16.6	15.4–15.6	23.8–25.1	Yes
Dioica88	Dioecious	L	13.3–16.7	19.7–20.4	–	Yes
Eletta Campana	Dioecious	L	12.6–15.1	19	–	No
Epsylon68	Monoecious	I	6.3–12.3	18.9–19.2	24.4.2–28.6	Yes
Fedora17	Monoecious	E	3.7–7.7	17.8–18.9	–	Yes
Fedrina74	Monoecious	E	6.1–6.4	–	–	No
Felina34	Monoecious	E	4.2–6.3	18.5–20.4	26.3–26.9	Yes
Ferimon	Monoecious	E	3.3–5.6	17.7–20.7	23.8–25.7	Yes
Fibranova	Dioecious	L	12.9–16.5	20.2–20.6	25.7–29.2	Yes
Fibrimon 56	Monoecious	E	6.5–6.8	–	–	No
Futura75	monoecious	I	7.5–12.5	18.5–19.4	25.4–27.1	Yes
Futura77	Monoecious	I	11.5–18.7	–	–	No
Kompolti H-TC	Dioecious	I	11.5–18.4	–	–	No
Lovrin	Dioecious	I	8.8–13.5	16.7–16.9	–	No
Superfibra	Dioecious	L	9.8–10.5	19	–	No
Tiborszallasi	Dioecious	I	6.2–12.2	14.3–15.1	21.3–23.0	Yes

[1]E = early (40–60 days); I = intermediate (60–90 days); L = late (90–120 days).
[2]Variation between early and late harvesting.

genotypes. Different genotypes were mainly characterized for the sensitivity to photoperiod: Felina 34 and Futura were regarded as low sensitive cultivars, whereas Tiborszallasi the highest sensitive one. Carmagnola and Fibranova showed an intermediate sensitivity. Under optimal climate conditions, Felina 34 differentiated for its relatively short juvenile phase, only 13 days compared to about 20 days estimated for the other cultivars. The calibration and comparison against independent data revealed that this model was successfully used in decision support for predicting hemp flowering and production under a variety of latitudes (Amaducci et al. 2012). Moreover, the strong influence of climate conditions, especially air temperature (Amaducci, Colauzzi, Bellocchi, et al. 2008) and rainfall, on flowering time (Venturi 1967; Venturi and Amaducci 1996) may significantly bias the model forecast.

ENVIRONMENTAL BENEFITS

The early sowing period, resistance to biotic stresses, and the high radiation-use efficiency (Struik et al. 2000; van der Werf et al. 1996) make hemp a very competitive crop against weeds (de Meijer and van der Werf 1994; Ranalli and Venturi 2004), thus allowing to avoid herbicides and pesticides. Moreover, the ability of rooting deeply makes hemp a low nitrogen- and irrigation-demanding crop, leading to significant environmental benefits compared to other competing arable crops, such as cotton. To our knowledge there are few studies on the environmental impacts of hemp, and only two on the cradle-to-farm gate impact assessment (van der Werf 2004; van der Werf and Turunen 2008). In extreme synthesis, the authors compared hemp to conventional arable crops like wheat, sugar beet, and potato, showing that energy consumption for growing hemp was considerably lower (only 11.4 GJ/ha) than the energy required for the aforementioned crops; moreover, the environmental impacts of hemp in terms of eutrophication, climate change, acidification, and terrestrial ecotoxicity were clearly the lowest (van der Werf 2004).

A significant number of studies attributed the low water and fertilization requirements of hemp and the improvements of soil structure to a singular ability of hemp to develop roots to depth (Amaducci et al. 2000; Du Bois 1982; van der Werf 2004; Venturi and Amaducci 1999). However, it was surprising to find no study addressed to quantifying hemp rooting along a representative soil profile. A recent experiment by our group was therefore finalized to understand the pathway of hemp rooting in a soil profile of 2 m (Amaducci, Zatta, Raffanini, et al. 2008). Briefly, we found that a significant amount of root biomass can be up to 2 m depth, although 50% of roots are in the upper 20 cm of soil. The total root biomass, ranging from 2.5 to 3.5 Mg/ha in function of soil characteristics, was significantly higher than other annual crops like maize, sugar beet, and winter wheat, and was not affected by plant density. In conclusion, not only does hemp address many environmental concerns by reducing the agricultural inputs requirement, but it also evidences a considerable ability of rooting to depth thus offering viable opportunities to sequestering stable carbon amounts in the soil.

CROP MANAGEMENT, PRODUCTIVITY, AND FIBER QUALITY

In the period 1930–2010, a total of 18 genotypes, equally divided between monoecious and dioecious genotypes, were tested in Bologna (Table 2). The effects of N-fertilization (100–200 kg/ha), plant density (30–360 plants/m^2), and harvest time (early to late flowering stage) were major objectives of our studies. In general, stem dry biomass was significantly higher in the Italian dioecious genotypes than French monoecious ones (Table 2). However, stem yield alone is not sufficient for the evaluation of a genotype, but stem fiber content and quality are essential factors as well. The latter traits are generally intrinsic; nonetheless they can significantly change with climate, which, in turn, influences the flowering time and period (Amaducci, Colauzzi, Bellocchi, et al. 2008; Amaducci, Zatta, Pelatti, et al. 2008; Mediavilla et al. 2001; Venturi and Amaducci 1996). In general, cellulose yield averaged 7–10 Mg/ha with insignificant differences in fiber content among genotypes (Zatta and Venturi 2009a). In contrast, fiber quality changed with time: cellulose increased up to 56%–65% until late flowering. At the same stage, hemicellulose averaged 14% (up to 17%), whereas lignin accounted for about 10% (Amaducci et al. 2000; Zatta and Venturi 2009a). After scutching, no significant differences were found in chemical composition between short and long fibers. Cellulose, hemicellulose, and lignin contents averaged 70%, 10%, and 2%, respectively. In contrast, they accounted for 51%, 21%, and 10% in the woody core, in that order (Zatta et al. 2010).

Most of our efforts over the last 10 years have been focused on fiber determination and characterization. Briefly, hemp stems showed primary and secondary extraxylary fibers (Figure 3; Amaducci et al. 2005); the first develop from the apical meristem and then gather bundles. Fibers stretch during internode elongation, then cambium produces secondary fibers (phloem and xylem), namely secondary growth (Amaducci and Gusovius 2010). Primary and secondary fibers, therefore, differ in the cell length, cell wall thickness, strength, and stage of lignification (Amaducci, Zatta, Pelatti, et al. 2008; Hoffmann 1957). The primary fiber maturity, calculated by the difference between fiber wall thickness and lumen weight, and fineness decreased from bottom to up (Amaducci, Zatta, Pelatti, et al. 2008; Mediavilla et al. 2001), at a faster rate in the longer internodes (Amaducci et al. 2005), whereas the secondary fibers were shorter (2 mm), more lignified, and grouped in layers (Figure 3). According to the authors, fiber formation seemed mostly influenced by harvest time, density, and genotype, in that order (Amaducci et al. 2005; Amaducci, Zatta, Pelatti, et al. 2008). Usually, the number of layers and fiber thickness decreased upwards and with higher plant densities (Amaducci, Zatta, Pelatti, et al. 2008). In term of fiber fineness, the three best genotypes were Tiborsazallasi, Carmagnola, and Ferimon, whereas Felina, Epsylon 68, and Futura 75 were the worst ones. In general, with the exception of Ferimon, the dioecious genotypes showed a better fiber quality than monoecious types (Zatta et al. 2008; Table 2).

According to the literature, plant density, nitrogen fertilization, and harvesting time are generally the most important factors for stem yield and fiber quality. Therefore, the majority of our agronomic studies were oriented towards optimizing these factors. Our first experiments on the effects of plant density on hemp stem yield date back to 1960 (Amaducci 1969; Venturi 1970b); countless experiments have been carried out to establish the optimal plant density for different end-uses thereafter. Based on multi-year studies, we can conclude that 30–75 plants/m^2 are optimal for seed production (Venturi 1965; Vogl et al. 2004), whereas 90–100 plant/m^2 is the target for textile end-use (Amaducci, Műssig, et al. 2008; Venturi 1967; Westerhuis et al. 2009). Some studies report that plant density is positively related with fiber content (Cromack 1998; van der Werf et al. 1995); however, even exploring a significant range of plant density (45 to 360 plants/m^2), we were unable to state a clear relationship between plant density and stem yield, neither we found a clear effect of plant density on fiber content (Amaducci 1969; Amaducci, Zatta, Pelatti, et al. 2008; Venturi and Amaducci 1997), with the exception of the finer primary fibers and less secondary fibers content that were positively related with plant density (Amaducci, Zatta, Pelatti, et al. 2008; Figure 3). Significant effects of plant density were on stem height (positive) and stem diameter (negative) that anyway mutually offset, thus resulting in unchanged stem yields. In general, plant densities exceeding 200 plant/m^2 showed irregular canopies and smaller plants (Amaducci et al. 2002a; Venturi and Amaducci 1997), the fibers were finer, and the secondary growth reduced if compared to the optimal plant density (Amaducci et al. 2005; Amaducci, Zatta, Pelatti, et al. 2008). Therefore, it can be concluded that 100–150 plants/m^2 are optimal for maximizing fiber quality and stem yield, at the same time, whereas 70–100 plant/m^2 are optimal for non-textile applications, because fiber fineness is a secondary parameter for this purpose.

In general, hemp showed limited response to N-fertilization between 60 kg N/ha and 240 kg N/ha (Amaducci et al. 2002b; Struik et al. 2000; Venturi and Amaducci 1997). The optimal dose resulted in 60–80 kg N/ha, which can be considered a low rate if compared to most arable crops. Nitrogen doses lower than optimal caused shorter internodes and reduced the biomass yield (Struik et al. 2000); on the other hand, exceeding 60–80 kg

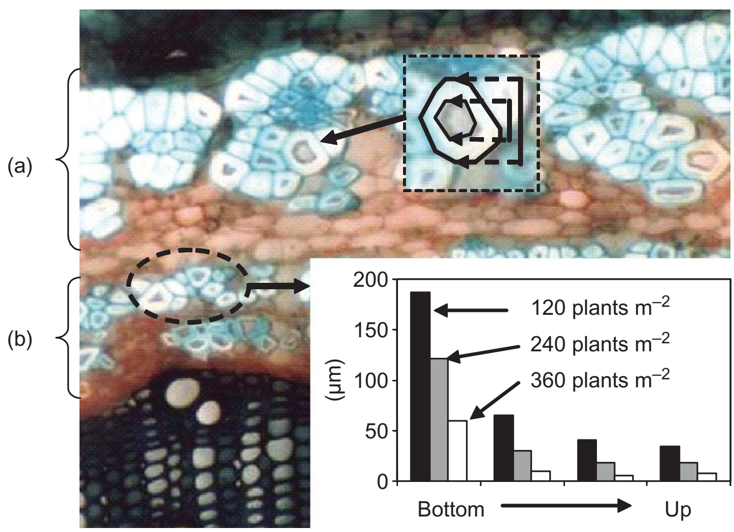

FIGURE 3 Stem cross-section of hemp with primary (a) and secondary (b) extraxylary fibres. Zoomed figure at top shows the methodology for determining the maturity index, i.e., by subtracting the inner lumen diameter to the outer diameter. The histograms represent the thickness of the secondary fibres (μm) measured at three plant from bottom to up along plant profile (color figure available online).

N/ha led to an excessive leaf vigor, more frequent pathologies, and a more irregular canopy development (Amaducci et al. 2002b; Venturi and Amaducci 1997).

The full female flowering stage resulted in the optimal harvest time for textile use. Fiber softness, color, and brightness reached the highest scores at this stage (Venturi 1970b); moreover, the primary fibers showed the highest degree of maturity, while the shorter and lignin-rich secondary fibers were generally minimized (Amaducci et al. 2005; Amaducci, Zatta, Pelatti, et al. 2008). In the case of non-textile use (e.g., compressed panels, energy, bio-polymers, etc.), fiber quality is much less important while biomass yield is prioritizing (Zatta and Venturi 2009a). Harvesting can be, therefore, postponed to the end of growing season in order to reach the highest biomass yield. Only in the case of 2nd generation bio-ethanol, the late harvest could lead to negative effects because of the lignin increase during senescence (Sun and Cheng 2002).

FIBER PROCESSING

Hemp stems for textile uses were traditionally grouped in air dried bundles in the field. After drying, bundles were immerged in ponds for water retting for 7–10 days, and then scutched to extract fibers for yarn production. All these processes are extremely time consuming (over 1,200 h/ha, Figure 1), causing health concern, and economically not feasible. Therefore, to provide innovative and economically field-to-yarn production systems was a major objective of our studies in the framework of the European "Hemp-sys" project (Figure 4). During this project, an innovative system based on existing flax machines was designed and tested at pilot scale level (Amaducci 2003; Amaducci, Műssig, et al. 2008). Briefly, 1 m long stems are cut and kept parallel in the field and then picked up by flax baler machine. Scutching is done before retting, namely green scutching, by a conventional flax machine. In our experiments, only long fibers were retted, namely bio-degumming process, under controlled microbiological conditions (temperature and pH). In general, highly homogeneous fibers were produced through the bio-degumming process that generally offset the higher costs of hemp processing compared to those of the flax chain. Nonetheless, the higher energy requirement of the bio-retting process caused higher environmental impacts compared to flax (van der Werf and Turunen 2008). Basically, the two major barriers of the new hemp processing system are the difficulties in maintaining stems parallel in the field, and the cementing effects by pectins that prevent bark and core separation, in turn hampering the green scutching process (Amaducci, Műssig, et al. 2008).

Alternative industrial applications other than textile are in papermaking, in making panels for bio-building, in bedding, and in furniture and

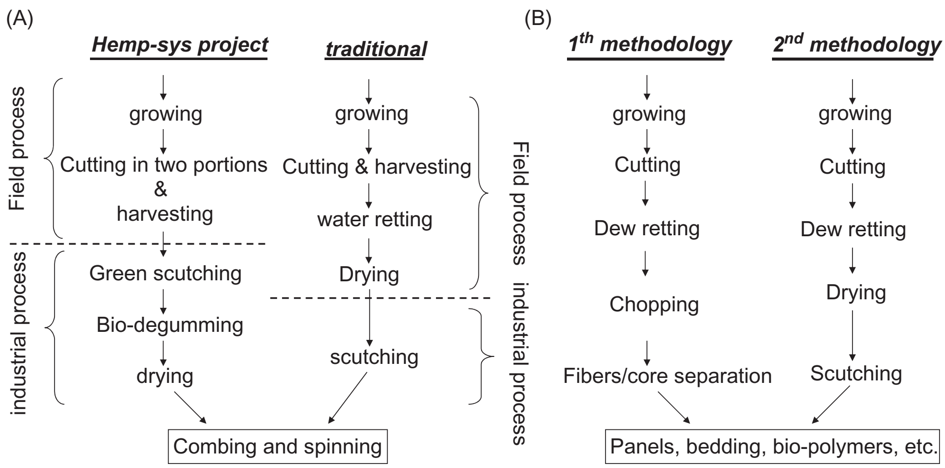

FIGURE 4 Alternative hemp processing schemes for textile (A) and non-textile end-uses (B).

automotive industries. The woody core could be also used in horse and rabbit beddings, or for pelletizing for domestic production of energy. For that purpose, hemp is cut and left in the field for two to four weeks for the dew-retting. Two harvesting and handling options were proposed and tested for non-textile uses (Figure 4). Basically, they differ in the way of stocking feedstocks, and for the bark/core separation method. In the first option, the stems are chopped, stored, and then the fiber and core separated through a multilayer shakers systems. A limit of this system is the low bulk density of feedstock as biomass is not pressed. In the second option, hemp is cut by a multilayer double-bladed mower, then baled by a conventional baler machine, and finally separated into the two main components, core and bark (Venturi et al. 2007; Zatta and Venturi 2009b). Several machines with differently stacked and staggered cut bars to obtain 0.5–1.2 m stem portions were developed and tested in Germany, Czech Republic, Poland, and Italy.

CONCLUSION

For almost 80 years, the DiSTA, former Institute of Agronomy, of the University of Bologna, has been struggling with agronomic issues and the issue of hemp production costs for textile and non-textile applications. Bridging such long-term and interdisciplinary studies, covering different research topics, might sound too generic or ambitious for a short review. Nonetheless, though we had intermittent funding for hemp studies, researches were fairly consistent; mostly oriented to agronomy concerns and new genotypes in the early studies, and on fiber quality, characteristics, and processing, thereafter.

Researches on agronomy, phenology, and physiology led to the following general considerations. From seed to harvest, hemp may gain the access to Aladdin's cave, showing broad adaptability to different climates and farm machines, low nitrogen and herbicide requirements, high drought tolerance, and positive rotational effects. Definitely, the re-introduction of hemp into the conventional cropping systems does not appear challenging or problematic.

Nonetheless, because of labor-intensive and uneconomic fiber processes, hemp still remains unfeasible for today's farming system, unless innovative and economic processes or production schemes will be designed and validated. In collaboration with other partners, we recently designed an innovative and promising approach for fiber processing that hopefully may contribute to improving hemp competitiveness. However, some significant bottlenecks have been evidenced in the process line that suggests caution and the need of further studies before it scales up to a commercial level.

Fiber quality is of secondary importance for non-textile applications; thus, commercializing hemp for uses other than textile can be a more realistic challenge in a short term. Some examples of promising non-textile products that can be obtained by hemp are wood-filled and glass-reinforced composites, especially in the car industry, hemp hurds for paper, or alternative plastic compounds. Last but not least, hemp grain is a source of high-quality food oil containing gamma linolenic acid (GLA) along with a unique mixture of omega 6 and 3 fatty acids. At present, the main drawbacks are the low seed yield and stability of the oil.

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