Renaissance of Industrial Hemp: A Miracle Crop for a Multitude of Products

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The US, which historically has been a major producer of hemp, has recently reintroduced industrial hemp production. The idea is to provide agriculture and farming communities with new economic opportunities (2018 Farm Bill) to replace lost income from formerly more profitable cash crops such as tobacco. Industrial hemp is a scalable crop that could provide significant economic and environmental benefits; however, the true valorization of industrial hemp will hinge on significant innovation and the development of high-value applications. Utilization of the whole hemp plant may be the key to attaining economic, environmental, and social sustainability. Further, strong community outreach and education is required to overcome the stigma attached with industrial hemp due to its morphological and genetic similarities to its psychoactive-rich (> 0.3% tetrahydrocannabinols (THC)) analogue. This editorial identifies critical research, educational, and community outreach platforms to develop a robust US industrial hemp program, with a goal to enable the renaissance of this miracle crop. Collaboration of the forest sector, universities, and industries is urged for the establishment of a center or consortium that fosters the future advances amongst more productive hemp cultivars, local farming practices, and bioproducts development for economic outlets for this miracle crop.

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Introduction

Hemp has been described as the most heralded and traded commodity in the world until the 1830s, and such a favorable past reputation has been attributed to the diversity and importance of its byproducts (Conard 1994; Bowyer 2001; Barnard 2015). There are approximately 30 countries that currently permit farmers to grow industrial hemp, while it was only recently that the United States reintroduced its production through the 2018 Farm Bill. Industrial hemp, which has the Latin name *Cannabis sativa* L., is defined as containing less than 0.3% content of delta-9 tetrahydrocannabinols (psychoactive substances) (Agricultural Improvement Act of 2018). This makes it unsuitable as a narcotic, but very useful for a myriad of other applications (Edyta *et al.* 2015). It is one of the oldest cultivated crops and once held an esteemed status in the US as legal tender (money) and as a major source of oilseed and fibers (Herer 1992). Industrial hemp can be harvested for more productive seed (de-hulled, viable whole (feminized and non-feminized), and non-viable whole), fiber (bast and hurd), or extract (Full-spectrum oil (FSO), Isolates (Cannabidiol (CBD) and Other Cannabinol (CBN), Cannabigerol (CBG), Cannabichromene (CBC), *etc*.; and Terpenes) cultivars, or hybrid (seed, fibers and extracts). In the last several years, extract and seed production dominated the market due to stronger demand for uses in many industries including pharmaceuticals, food, beverages, cosmetics, paint, bioplastics, biodiesel, *etc.* On the other hand, demand for hemp fibers has decreased due to difficulties in processing and availability of a number of natural and synthetic fiber alternatives. Thus, novel processing techniques with the focus on social, economic, and environmental sustainability is required to enhance the hemp value chain.

Hemp can be reharvested after just four months of cultivation to give a fiber that consists of an outer ring of more valuable long phloem fibers ("bast") and an inner core of less valuable short xylem ("hurd") fibers (Small *et al*. 2003; Cherney and Small 2016). The separation of hurds from fibers can be accomplished either by using a traditional process commonly known as "retting" (related to "rotting") through several methods for selectively removing binding substances (such as pectin) or using a modern decortication process resulting in nearly 3 tons of bast fibers and 7 tons of hurds per hectare. Bast fibers are the long fibers favored for composites, textiles, and specialty papers. Hurd fibers, on the other hand, are widely regarded as a low-value byproduct primarily used for animal bedding and hemp–lime construction applications.

Any efforts to commercialize industrial hemp most likely will require the coordination and integration of high value product streams such as essential oils in tandem with, for example, one or more of the following: molded parts and packaging products, tissue and hygiene products, nonwoven and textile materials, cellulosic plastic composites, and building materials such as fiberboard. Such a product portfolio will ultimately create greater economic opportunities for many rural southern communities that currently face economic hardship due to the dwindling of tobacco and related legacy cash crops.

Production of Biochemicals: Essential Oil Extraction

Essential oils, which are present in industrial hemp, represent a key opportunity. Cannabidiols (CBDs), for example, are emerging as a superior class of bio-based chemicals with the potential to replace many existing pharmaceuticals in addressing numerous human ailments including seizures. CBDs find themselves as one class among the numerous cannabinoids in hemp only recently becoming more and more amenable to human health applications from both legal and social perspectives. There are several alternative extraction methods, such as ethanol extraction, hydrocarbon (e.g., tetrafluoroethane) extraction, and supercritical carbon dioxide extraction for isolation of essential oils. Without question, the purity can be expected to depend on extraction protocol; indeed, the safest and the highest yields without compromising the final product qualities of the oil is supercritical fluid extraction (SFE). It is the process of separating the extractant (CBD) from the flowers and leaves using supercritical fluids that can be used on a large scale to either strip a material from a product (*e.g.*, decaffeination) or collect a desired product (*e.g.*, essential oils) such as limonene. Carbon dioxide is made at supercritical extraction conditions > 31 °C and 74 bar of pressure (June-Wells 2018a,b; June-Wells and Lindback 2018). However, a shortcoming of SFE is that waxes and fatty acids are also soluble and need to be separated during refinement before usage.

Sustainable Fiber Production and Bioproducts

Industrial hemp has some favorable features as a pulp resource. The core fibers of hemp hurds allow facile pulping liquor penetration due to their thinness. Sodium carbonate, the alkalinity of which is too weak to be effective for most wood resources, can be used for its pulping and fibrillation. Autohydrolysis, in conjunction with enzymes, is another approach that has proven efficient for the defibration of fibers from hemp (Barta *et al.* 2010; Gandolfi *et al*. 2013) without harsh chemicals associated with pulping (*e.g.*, the kraft process). Autohydrolysis employs water at a high temperature and pressure to cleave acetyl groups in hemicellulose that bind lignin to cellulose. During this reaction, acetic acid is generally liberated to catalyze the reaction and liberate cellulose (Barta *et al*. 2010). Hemp paper can be bleached easily with oxygen delignification due to its chemical composition and morphology (Danielewicz and Surma-ślusarska 2011). In general, it requires lower levels of harsh chemicals for processing. A new approach to sustainable processing of industrial hemp has been developed in the Authors' labs (Naithani *et al.* 2018) that may be described as low intensity, safe, environmentally compatible, and low chemical usage. Whole hemp is processed with hot water under pressure to facilitate defibration. The produced fibers can be used in place of wood fibers in existing hygiene and packaging products with improved sustainability, economics, and robust quality. Though the hemp hurd fibers cannot be expected to provide the levels of strength associated with typical wood-pulp fibers, they may be suitable as part of fiber blends in products where such attributes as absorbency and smoothness are needed. The longer bast fibers of industrial hemp can be considered, along with softwood fibers, for reinforcement of tissue and associated products. Packaging and heat-molded products can also be considered.

Ligno-Nanocellulose Production

The rational manufacture of nanocellulosic materials may impact many commercial markets including coatings, composites, packaging, foams, construction, electronics, automotive, cosmetics, and medicine. Attractive properties include biodegradability, renewability, high crystallinity, high mechanical strength, stiffness at low density, transparency, thermal expansion, solvent resistance, high surface area, and tunable chemistry. High costs from existing feedstocks and production strategies currently pose a significant barrier to commercialization originating from time restraints, low throughput and solids content, and undesirable alteration of the morphology of the nanomaterials. However, research breakthroughs have been achieved in the Authors' laboratory in the production of cellulose nanofibrils from high pressure/temperature water treatment of hemp fibers using a high-speed grinding process. This approach enables very efficient application of high shear and friction, thus defibrillating hemp fibers into nanoscale fibers containing both cellulose and lignin within much less time than conventional methods. The results of the oscillatory milling process have been found to depend on the levels and quality of lignin in the hemp. However, the ability of hemp to respond to this mechanical energy for nanofibrillation appears to be unique.

Educational and Outreach

The work done in industrial hemp not only has fundamental and applied ramifications, but it is also translatable to education and outreach. As alluded to earlier, the stigma associated with this crop can be erased, but only by careful and persistent education. Such work is very valuable to ensure that societal acceptance, favorable policy and regulations, and overall industrial R&D work continue uninterrupted and with incentives to foster successful penetration into US markets.

Summary

Current efforts at the Department of Forest Biomaterials at North Carolina State University, in addition to past research and development efforts, have provided promising data supporting the valorization of industrial hemp. It has been found that industrial hemp can be regarded as a cash crop whose time has come. The high inherent value of this lignocellulosic material seems sufficient to assure a positive reputation in the coming years. However, wide societal acceptance will require a concerted effort amongst researchers, government, and industry to highlight its substantial benefits. Continued work in this arena can be expected to reveal further unique properties and byproducts and therefore provide evidence of the utility of industrial hemp in many markets.

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