

DERLEME MAKALE (Review Article)

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Evaluation of the Fiber of the Naturally Distributed *Typha* Species in Turkey in terms of Textile Industry

Türkiye’de Doğal Olarak Yayılış Gösteren *Typha* Türlerinin Elyaf Özelliklerinin Tekstil Endüstrisi Açısından Değerlendirilmesi

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ÖZ

Günümüzde doğal kaynakların hızla tükenmesi, aşırı tüketim ve sera gazı salınımının neden olduğu küresel ısınma, sürdürülebilir üretim anlayışını kaçınılmaz hale getirmiştir. Tekstil sektörü, üretim ve tüketim süreçlerinde yüksek çevresel etkiye sahip olması nedeniyle sürdürülebilir malzeme arayışına yönelmiştir. Bu bağlamda, biyobozunur özellikleriyle çevre dostu nitelikler taşıyan doğal liflerin önemi giderek artmaktadır. Bu çalışma, günümüz yaşam biçimlerinin ve tüketim alışkanlıklarının yol açtığı çevresel sorunlara çözüm getirebilecek sürdürülebilir hammadde ve tasarım yaklaşımları kapsamında *Typha* liflerini ele almaktadır. Özellikle biyomateryal temelli yenilikçi üretim modellerinin, mevcut tekstil sektörüne nasıl entegre edilebileceği değerlendirilmektedir. Araştırma kapsamında, sucul ekosistemlerde doğal olarak yetişen *Typha* cinsine ait bitkilerden lif üretimi ve bu liflerin potansiyel kullanım alanları incelenmiştir. *Typha* türleri yetiştiricilik müdahalesine gerek duymadan doğal koşullarda gelişmekte olup, Türkiye’de altı türle temsil edilmektedir; bunlardan en yaygın *T. latifolia* L.’dir. Yapılan çalışmalar, *Typha* liflerinin pamuk lifleriyle benzer fiziksel özellikler taşıdığını ve tekstil dahil çeşitli alanlarda değerlendirilebileceğini göstermektedir. Bu makale, *Typha* liflerinin sürdürülebilir tekstil üretiminde alternatif bir doğal hammadde olarak önemini vurgulamakta ve gelecekteki çalışmalara yönelik bilimsel farkındalık yaratmayı amaçlamaktadır.

ABSTRACT

The rapid depletion of natural resources, environmental problems caused by overconsumption, and global warming resulting from greenhouse gas emissions have made the transition to sustainable production inevitable. The textile industry, having significant environmental impacts throughout its production and consumption stages, has increasingly turned toward the use of sustainable materials. In this context, natural fibers with biodegradable properties have gained importance as eco-friendly alternatives. This study addresses *Typha* fibers within the scope of sustainable material and design approaches that can provide solutions to environmental problems caused by contemporary lifestyles and consumption habits. It particularly evaluates the potential integration of innovative bio-based material approaches into existing textile production systems. Within this framework, the research focuses on fiber production from aquatic plants of the *Typha* genus and investigates their potential areas of application. *Typha* species grow naturally in aquatic ecosystems without the need for agricultural intervention and are represented by six species in Turkey, the most common being *T. latifolia* L. Previous studies have shown that *Typha* fibers possess physical properties similar to cotton and can be utilized in various industrial fields, including textiles. This article highlights the significance of *Typha* fibers as an alternative natural raw material for sustainable textile production and aims to promote scientific awareness for future research in this field.

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Giriş

In recent years, rapid population growth, and changes in living standards and fashion have also brought about changes in textile consumption habits. The limited nature of natural resources and the rapid consumption pose a major risk to humanity. These developments affect the textile sector in every way. The structural stability of the fibers combined with low cost, high demand and a wide range of applications has led to a major expansion in the production and consumption of synthetic fibers today. Most synthetic fibers are both expensive and not easily biodegradable, causing environmental pollution. The production of polyester (polyethylene terephthalate or PET) and other synthetic polymer fibers (acrylic, polyamide and polypropylene) depends on petrochemical materials that create persistent pollution for the environment. During the production of PETs, which contain toxic polycyclic aromatic hydrocarbons (PAHs), these chemicals are released into the air and cause environmental pollution. In this respect, it creates great concern in terms of human security (Chakma, 2018). Today, the textile industry includes a cycle that includes intensive applications in terms of natural resources, energy, chemicals, emissions and waste (Jaamaa and Kaipia, 2022; Kiran and Salihođlu, 2023; Saha et al., 2024). The textile sector consumes approximately 100 million tons of non-renewable resources worldwide every year and causes approximately 100 billion m³ of water and more than one billion tons of carbon dioxide emissions (Ellen MacArthur Foundation, 2017).

Accounting for around 2% of total global greenhouse gas emissions, the textile industry remains a significant emitter, even when excluding emissions associated with transport, washing, and product use (Sadowski et al., 2021). In addition, the increase in fast fashion in recent years has approximately doubled ready-made clothing production and shortened the lifespan of fabrics (Ellen MacArthur Foundation, 2017). The resulting change, development and waste from production have reached a level that cannot be ignored in environmental terms. For these reasons, more sustainability and more durable and sustainable products that will meet basic human needs in the textile industry have revealed the need to develop both ecological integrity and social equality. At the latest point, research has shown that instead of synthetic fibers, synthetic fibers with changeable dynamic properties and dating back to B.C. It focuses on natural fibers that have been used for different purposes such as fabric, yarn, and clothing since 7000 BC (Chakma, 2018).

Naturally grown fibers can be obtained without any agricultural intervention. However, today, many countries in the world use thousands of acres of agricultural land for cotton cultivation and plant fiber production and also undertake the economic cost of cultivation. At the same time, while the pesticides and fertilizers used during cultivation harm the environment, the amount of water consumed is also significant. In contrast, fibers obtained from naturally grown plants will both reduce costs and will not cause

environmental pollution during the agricultural production process. Studies have long indicated that plant fibers occupy an important place in global textile production. In 2003, the worldwide distribution of textile fibers showed that synthetic fibers were the most widely used material, followed by cotton, and together these two fiber groups accounted for 86.32% of total textile production (Lawrence, 2003). At that time, cellulosic fibers represented approximately 4% of total fiber use, a proportion significantly higher than that of silk, which accounted for only 0.14%. Linen was also used at very low levels, and silk was identified as the least utilized fiber in textile production. The combined share of linen, jute, and ramie was 7.24%, with jute being the most commonly used among these fibers and ramie the least. Animal fibers constituted a relatively small proportion of total production, with wool accounting for about 2.3%, a figure considerably lower than that of plant-based fibers. The percentage distribution of fibers used in textiles in 2003 worldwide is shown in Figure 1.

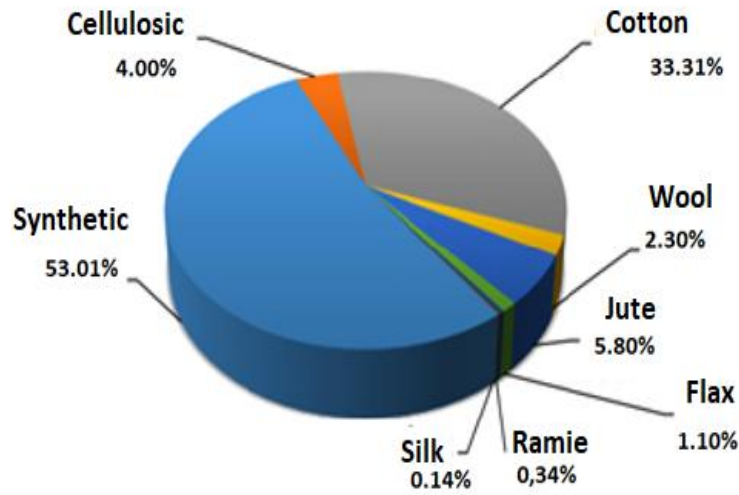


Figure 1. Percentage distribution of fiber use in world textile production in 2003 (Lawrence, 2003)

Şekil 1. 2003 yılında Dünya tekstil üretiminde elyaf kullanımının yüzdesel dağılımı (Lawrence, 2003)

Recent global textile fiber data from 2023–2024 reveal both continuity and notable shifts in these patterns. Synthetic fibers have further strengthened their dominance, now accounting for approximately 69% of total global fiber production, largely driven by the expansion of polyester. Cotton remains the most widely used natural fiber and continues to rank second overall; however, its share has declined to around 19%. Together, synthetic fibers and cotton now constitute nearly 88% of total global textile fiber use, indicating an increased concentration in these two fiber categories compared to 2003. Man-made cellulosic fibers, including viscose and lyocell, have slightly increased their share to approximately 6%, reflecting growing interest in regenerated fiber alternatives. In contrast, other plant-based fibers such as jute, linen, and hemp collectively account for about 5% of total production, representing a relative decline compared to their combined share in 2003. Animal fibers have become even more

marginal, with their total share decreasing to around 1%; wool remains the dominant animal fiber, while silk continues to be the least used fiber overall, with a share of approximately 0.1%. The percentage distribution of fibers used in textiles in 2024 worldwide is shown in Table 1.

Table 1. Estimated Global Textile Fiber Distribution by Fiber Type in 2024. (https://texchangeworld.com/global-fibre-output-grows/?utm_source=chatgpt.com)

Tablo 1. Lif Türüne Göre Tahmini Küresel Tekstil Elyaf Dağılımı 2024. (https://texchangeworld.com/global-fibre-output-grows/?utm_source=chatgpt.com)

Fiber Type	Estimated Share (%) – 2024
Synthetic Fibers	~69% (Polyester is Dominant; Majority of Total Fiber Production)
Plant Fibers (Total)	~24 %
Cotton	~19 %
Other Plant Fibers (Jute, Flax, Hemp, Etc.)	~5 %
Chemical / Semi-Synthetic Fibers (Mmcf)	~6% (Viscose, Lyocell, Etc.)
Animal Fibers (Total)	~1% (Mostly Wool; Silk Much Lower)
Wool	~0.9 %
Other Animal Fibers (Silk, Etc.)	~0.1 %

Overall, a comparison between 2003 and 2024 demonstrates a clear intensification of synthetic fiber dominance in global textile production. While cotton has maintained its position as the leading natural fiber, the proportional use of other plant-based and animal fibers has remained low or declined over time, reinforcing the central role of synthetic materials in contemporary textile manufacturing.

However, plant fiber sources are still being investigated and various plants are being evaluated for this purpose (Mortazavi and Moghadam, 2009). The fact that the plant grows in sufficient quantities without being cultivated and that it renews itself in a short time further increases this attractiveness. *Typha* species, one of these fiber sources, are of great importance in terms of their distribution in wetlands in Turkey (DSİ, 2009).

This literature study, together with examples from around the world, aims to shed light on the production and use of fiber from *Typha* species, and future studies to be conducted in Turkey. Since *Typha* is a natural plant fiber, research-oriented studies are needed for the use of the plant in the production of fiber-based products. *Typha* fibre's chemical composition, physico-chemical analysis, fiber quality and suitability for use in textiles should be explained. Within the scope of the study, *Typha* species, physical and chemical characteristics of the plant, extraction method and properties for final use in textiles are conveyed.

Distribution and Some Characteristics of *Typha* Species

Typha is distributed in tropical and temperate regions of the world (Londonkar et al., 2013) except Central and Southern Africa, South Asia, Australia and Polynesia (Altınayar, 1988). In Turkey, it has been detected in Thrace, Northwestern and Central Anatolia (Altınayar, 1988). In the regions where it is distributed in the world, 12 species are known to spread in marshes and wetlands of various depths. These plant species, which are commonly found in wetlands, are used as a source of food and medicine (Londonkar et al., 2013). In addition, *Typha* species is found densely in irrigation canals and high groundwater areas worldwide and in Turkey. The *Typha* genus causes major problems in irrigation systems in Turkey together with other aquatic plants. The most important of these problems are blockage in channels and decrease in flow rate (Altınayar, 1988; Seyithanoğlu, 2008; Karahasan and Bayrak Özbucak, 2015). It is stated that six species of the *Typha* genus are distributed in Turkey. These taxa are given in Figure 2 (Altınayar, 1988).

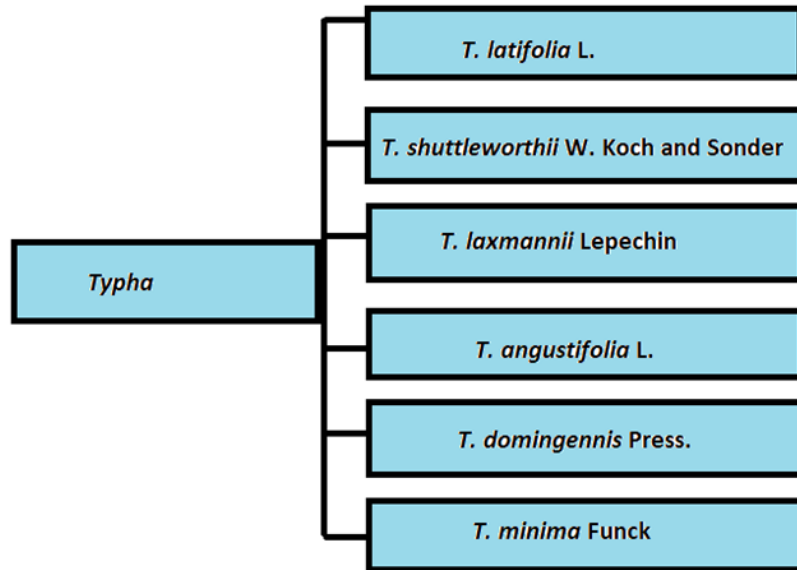


Figure 2. *Typha* species are distributed in Turkey (Altınayar, 1988)
Şekil 2. Türkiye'de yayılan *Typha* türleri (Altınayar, 1988)

T. Shuttleworthii and *T. minima* species distributed in Turkey are under strict protection according to the Bern Convention. Among these species, *T. latifolia*, which is widespread in Turkey, is distributed in nutrient-rich, low-current riverbanks, marshes, lakes, coastal areas of aquatic systems and water channels (Altınayar, 1988). *T. latifolia* grows in a wide variety of wetland habitats. The communities occupied by *T. latifolia* vary from early succession stages to late stages (Setyawati et al., 2015: 392). In *Typha* species, both sexual and asexual reproduction is observed (Galatowitsch et al. 1999; Larkin et al., 2012; Geddes et al. 2021), while it is stated that they reproduce asexually

from the nodes of creeping stems and underground stems (Altınyar, 1988; Seyithanoğlu, 2007).

Despite the ecological and economic importance of aquatic vegetation, research on many plant species thriving in aquatic environments remains limited. Several native wetland species, including *T. latifolia*, *Salix petiolaris*, *T. angustifolia*, *Phragmites australis*, *Carex atherodes*, and *Scirpus fluviatilis*, have long been investigated as promising crop candidates due to their high biomass productivity, distinctive biochemical profiles, broad distribution, and valuable nutritional and medicinal properties. These plants also contribute significantly to water purification processes and flood mitigation. *Typha* is an abundant wetland plant that is evaluated as a new source of natural fiber. *Typha*, a perennial plant, originates from Europe, North America and Africa and is distributed throughout most of the world, including many subtropical regions (Chakma, 2018). Like other bast fibers, harvest is not dependent on climate or perfect growing conditions. The genus *Typha* offers considerable environmental benefits and has been widely utilized for the remediation of soils contaminated with heavy metals such as cadmium, lead, copper, and zinc (Kozłowski, 2012; Karahasan and Bayrak Özbucak, 2015).

In Turkey, no studies have been found on the production of fibers from *Typha* species and their use in textiles. However, this plant is used in some areas such as basket making, roofing material in portable areas, and decoration. Since natural and biodegradable fibers have been given importance in the textile sector in recent years, it is important to evaluate the fibers of these plants in terms of textiles. In addition, it is of great importance for the future that the resources from which natural fibers will be produced in our country are evaluated and brought to the sector. The utilization of natural fibers is particularly important for promoting a circular economy, reducing environmental pollution, and minimizing waste generation.

Biological, Morphological and Ecological Characteristics of *Typha* Plant

Typha is a perennial plant that reproduces by seeds and rhizomes, with a stem that can grow up to 2 m, a leaf width of 1-2 cm, a length of 1-2 m (approximately the length of the stems), and bluish green color, with gnarled roots, rhizomes (Seyithanoğlu 2007), and an upright and thick-stemmed perennial plant (Figure 3). In some sources, it is stated that *Typha* plants grow up to 3-4 m (Hears, 2006). The flowering time is June and July and it can spread up to 2,300 m in altitude (Smith, 2012). Among *Typha* species, *T. latifolia* possesses the broadest leaves, *T. angustifolia* the narrowest, while *T. glauca* and *T. domingensis* exhibit leaves of intermediate width. *Typha* plants are monocotyledonous and monoecious, producing both male and female flowers within a single inflorescence. The inflorescence is structurally divided into two distinct regions: a lower brown cylindrical section corresponding to the female flowers, and an upper yellow spike comprising the male flowers. While some sources call it cat tail because the

mature flower stalks resemble cat tails (Khan, 2021), it is known by different names regionally in Turkey. One of these is “devil candle” (Seyithanoğlu 2007). In *T. latifolia*, which is also widely distributed in Turkey, rhizomes can grow up to 70 cm long and 0.5-3 cm in diameter, and the plant can grow up to 1-3 m tall. The leaves are linear, light green, and possess a flat basal sheath that continues toward the inflorescence. They are 15–25 mm wide and end in a terminal, cylindrical structure resembling a spike. Unisexual flowers contain a pistillate part forming a continuous spike with a diameter of 12–35 mm below the staminate part. Pollen grains occur in tetrads (Setyawati et al., 2015).



Figure 3. A. *Typha latifolia* general view, B. general shape
Şekil 3. A. *Typha latifolia*'nın genel görünümü, B. genel yapısı

It is stated that especially *T. angustifolia* and *T. latifolia* are used in the treatment of various diseases, all parts of the plants are bioreactive, active against gram-negative bacteria, have antioxidant properties and support the immune system. In addition, it is stated that the rhizomes of the plant are edible, rope is produced from its stems and leaves, and is used in the manufacture of mats and baskets (Topaldemir and Taş, 2024). Historically, *T. latifolia* has been used worldwide as building material, basketry, bedding, shoemaking, rope and paper manufacturing and in various herbal applications. The hairs derived from the fruiting spikes of *Typha* have historically been employed for ignition, thermal insulation, treatment of burns, and as stuffing for pillows, mattresses, and various other items.

Today, *Typha* species continue to exhibit considerable untapped potential, with emerging applications including biomass production and use as a contemporary food source (Setyawati et al., 2015). While *Typha* is recognized globally as a natural plant fiber with promising industrial applications (Bajwa et al., 2015; Rezig et al., 2016), it is considered invasive in certain regions, such as Nigeria (Larkin et al., 2012; Sabo et al., 2010).

Extraction of *Typha* Fiber

The efficiency of cellulose extraction is influenced by numerous factors, including the chemical composition of the plant and the specific extraction method employed, which can vary between species. All cellulose extraction techniques share the common principle of removing non-cellulosic constituents—such as lignin, hemicellulose, and pectin—from the fibers, while producing fibers suitable for further processing into nanofibers. Cellulose can be obtained from a diverse array of plant sources, including banana, kenaf, jute, oil palm, abaca, pineapple, sisal, and kapok. The selection of a particular cellulosic source depends on factors such as local availability, intended application, chemical composition, and economic considerations. Various methods are employed to isolate natural fibers from these cellulose-rich sources. Some researchers have isolated the fibers using mechanical processes, while others have used chemical processes to isolate the fibers (Dungani et al., 2016).

Typha fiber, a natural plant-derived material, can be obtained from both the leaves and fruits of the plant. The leaves of *Typha* species also contain a mucilaginous substance, primarily pectin, which binds the fibers together. Common methods for extracting *Typha* fiber from the leaves include mechanical decortication, water retting, and chemical retting. The fiber yield of *Typha* is notably higher than that of many other plant fibers, with approximately 30–40% of mature leaves comprising soft, extractable fiber (Khan, 2021). It is stated that the most commonly used method for fiber extraction from the *Typha* plant is the water soaking method. However, in some studies, it is stated that the results obtained from the water soaking process are not suitable for the *Typha* plant, and therefore it is emphasized that other extraction methods should be used (Chakma, 2018). In the study conducted by Chakma (2018), it is stated that these methods cannot be used efficiently, and similarly, acid and enzyme soaking do not work in the fiber extraction of *Typha* fiber. As a result of his studies, he states that alkaline (KOH, LiOH) treatment for less than 2 hours and < 3.0% concentration is not suitable for proper fiber extraction; however, fibers can be produced in processes carried out with 3% alkali for 2 to 8 hours. Physiological studies conducted on the plant have shown that fiber yield is proportionally affected by different factors; composition of plants such as scale (%) presence of an inner woody core section and plant type: Stemless plants have been shown to provide 4.76% higher yield than plants with 0,0% scaleless, 41,33% hard, 26,57% scaled, 11,59% and 31,90% soft-bodied) (Chakma, 2018).

An ideal textile fiber has several important properties that affect product performance and help select various fibers for all types of end-use in the textile and apparel industry. When fibers are obtained through chemical digestion, it is important to examine their suitability for being a textile material, including morphological structure, physical, mechanical, and thermal analysis (Chakma, 2018). For these reasons, the extraction of

fibers should be evaluated in Turkey's conditions and various fiber extraction methods should be tried to determine the best fiber extraction method. Each plant may have different morphological and structural contents depending on the geographical region where it grows. The water, minerals and some substances (essential oils, alkaloids, tannins, etc.) that plants take from the soil they belong to may differ depending on the geography they are located. This may lead to differences in the extraction method to be applied. For this reason, the methods specified as the best methods in the literature should be tested first and should be put into use and developed if efficiency is obtained. These methods should also be compared with new and traditional methods.

Physical and Chemical Properties of *Typha* Fiber

Typha is a source of lignocellulosic fiber, and its main chemical components are cellulose, hemicellulose, lignin, pectin, and water-soluble matter and the like. Like many other plant fibers, the linkage between cellulose is primarily due to pectin and hemicellulose. It is stated that the pectin content of the fibers is 1.013%, which is comparable to cotton fibers. *Typha* fibers assemble into tufts exhibiting a feather-like morphology, composed of a root, stem, seed, and multiple individual fibers. The porous architecture of these assemblies is derived from the feather-like arrangement of the fiber tufts (Figure 4b) (Khan, 2021). *Typha* leaves and dried fiber extracted from leaves, fiber samples, nonwoven samples, and alkali-treated samples are given in Figure 5.



Figure 4. a. Original *Typha* plant (Rahman et al., 2021), b. *Typha* fiber (Zhang et al., 2018).
Şekil 4.a. Orijinal *Typha* bitkisi (Rahman ve diğerleri, 2021), b. *Typha* lifi (Zhang ve diğerleri, 2018).

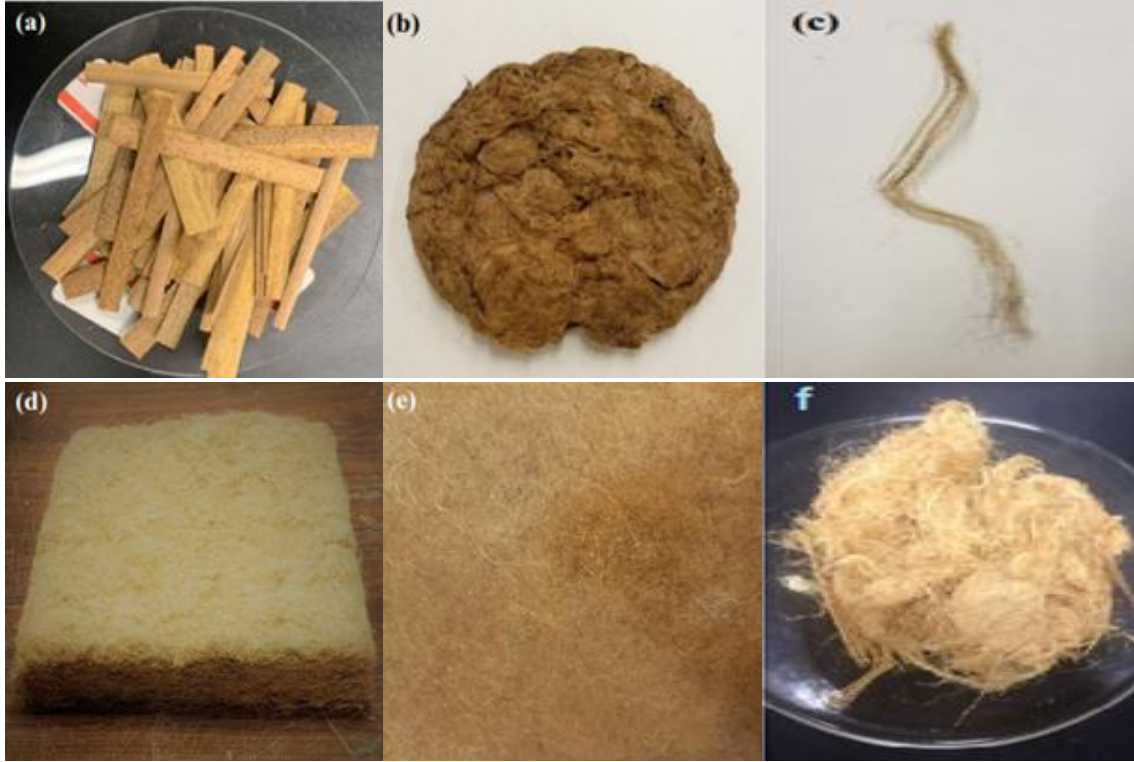


Figure 5. a. Typha leaves; b. Extracted and dried fibers; c. Individualized fiber; d. Nonwoven Typha mat; e. Nonwoven Typha composite (Shadhin et al., 2021); f. Typha fiber treated with 6 hours/3%/95 °C alkaline (Chakma, 2018:148).

Şekil 5. a. Typha yaprakları; b. Çıkarılan ve kurutulmuş lifler; c. Bireyselleştirilmiş lif; d. Dokumasız Typha matı; e. Dokumasız Typha kompoziti (Shadhin vd., 2021); f. 6 saat/%3/95 °C alkali ile işlem görmüş Typha lifi (Chakma, 2018:148).

Typha fiber lacks distinctive microscopic characteristics such as the twisted morphology observed in cotton or the scaly surface typical of wool (Rahman et al., 2021) (Figure 6a.). While the longitudinal surface of *Typha* fiber is not as smooth as that of polyester or other synthetic fibers, it exhibits a relatively rough texture. (Zhang et al., 2018; Rahman et al., 2021). There are dots on each fiber that resemble bamboo. These dots show a smooth feature, but cause the appearance of the single fiber to be irregular (Zhang et al., 2018). The cross-section of *Typha* fiber consists of a large number of small elliptical (polygonal) cells (Figure 6b.), each approximately 4.5-6.0 μm long and 0.70 μm apart due to the presence of smaller channels between the cells (Rahman, 2021; Khan, 2021). There are also larger channels of approximately 3.9 μm wide. Each cell has a lumen of different size, and the largest width and length are reported as $\approx 1.03 \mu\text{m}$ and $\approx 2.0 \mu\text{m}$ (Figure 6c.), respectively (Rahman et al., 2021). A single *Typha* fiber is centrally embedded and extends from both ends in a “ π ”-shaped configuration, creating bamboo-like lumens between adjacent fibers. Individual long fibers typically contain 50–180 of these bamboo-like junctions, with the distance between successive junctions ranging from 51 to 112 μm . The fiber skeleton is coated with a hydrophobic layer and exhibits a crystallinity of 45.41% (Khan, 2021).

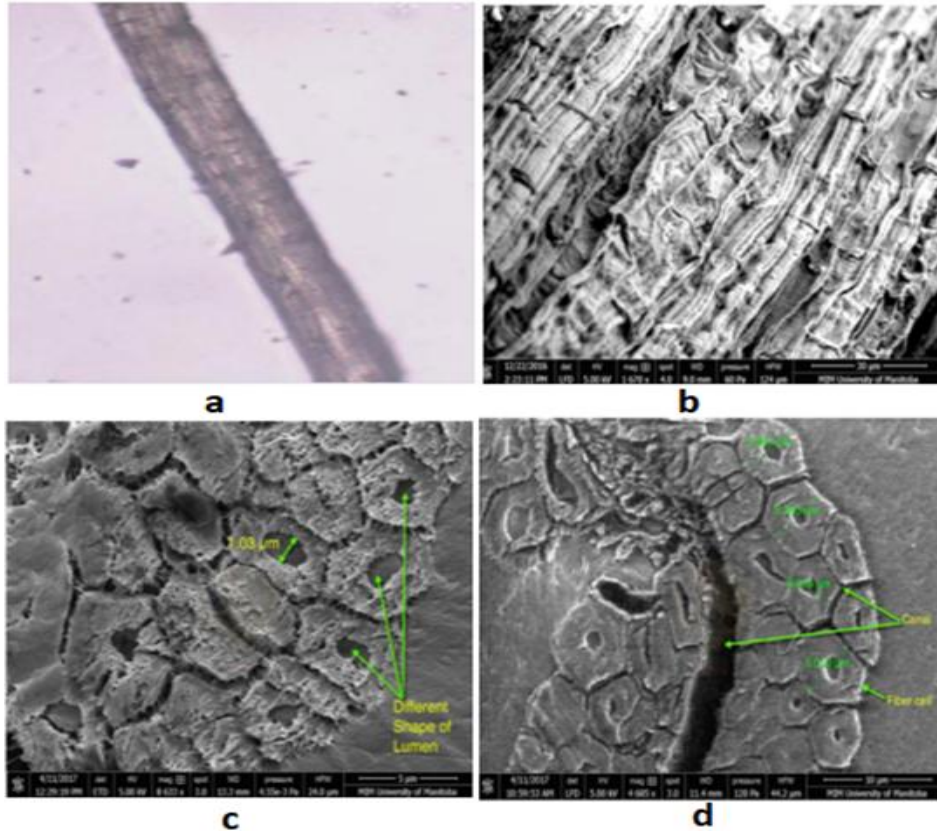


Figure 6. SEM images of Typha fiber: **a.** Typha fiber under electron microscope; **b.** Longitudinal view of Typha fiber showing its granular structure (rectangular recess); **c.** Cross-section of Typha fiber showing different lumen shapes and lumen size; **d.** Cross-section of Typha fiber showing its channel structure (Rahman et al., 2021).

Şekil 6. *Typha lifinin SEM görüntüleri: a. Elektron mikroskobu altında Typha lifi; b. Granüler yapısını (dikdörtgen girinti) gösteren Typha lifinin uzunlamasına görünümü; c. Farklı lümen şekillerini ve lümen boyutlarını gösteren Typha lifinin kesiti; d. Kanal yapısını gösteren Typha lifinin kesiti (Rahman vd., 2021).*

Scanning electron microscopy (SEM) of Typha fiber in longitudinal view reveals two outer surfaces (Figure 6d.) interconnected by a series of ribs, forming a “crenulated” (rectangular recessed) architecture (Rahman et al., 2021; Khan, 2021). These structural characteristics are reported to play a significant role in the adsorption of antibiotics and other chemical compounds, with potential applications in industrial and biomedical fields (Khan, 2021).

The contents of *Typha* fiber and cotton fiber are similar and are a type of cellulose fiber (Zhang et al., 2018). The chemical structure of *Typha latifolia* fiber is mainly composed of 63% cellulose, 8,7% hemicellulose, 40% fiber, 8,9% moisture content, 9,6% lignin and pectin, and 1,4% wax and 2% ash, as well as other water-soluble substances (Sopit, 2007). The chemical compositions of different plant fibers are shown comparatively in Table 2.

Table 2 Chemical (%) composition of different plant fibers (Chakma, 2018)**Tablo 1.** Farklı bitki liflerinin kimyasal bileşimi (%). (Chakma, 2018).

Fiber Source	Cellulose	Hemicellulose	Pectin	Lignin	Wax	Ash	Other
Cotton	92-95.00	5.7	<1.00	-	0.60	-	-
Jute	61-75.50	13.6-20.4	0.20	12-13.00	0.50	-	-
Flax	71.75.20	8.6-20.6	2.30	2.2-4.80	1.70	1.10	-
Ramie	68-76.20	13-16.7	1.90	<0.70	1.70	1.10	-
Hemp	57-77.00	14-22.4	0.90	3.7-13.00	-	0.80	
Sisal	47-78.00	10-24.0	10.00	7-11.00	-	0.6-1.00	
Abaca	56-63.70	17.5	1.00	15.1.00	-	1.10	
Kenaf	45-57.00	21.5	3.0-5.00	8.0-13.00	-	-	
<i>Typha</i> ^a	42.61	-	23.90	5.75	-	12.56	
<i>Typha</i> ^b	51.30	-	-	22.05	4.25	3.20	3.6
<i>Typha</i> ^c	63.00	8.7	-	9.60	1.4	2.0	-

Narrow-leaved *Typha*^a; Tunisia *Typha*^b leaves, *Typha*^c *latifolia*

Compared to agricultural fiber sources, the amount of cellulose (%) of *Typha* fiber is lower than Pineapple, Jute, Flax, and Kapok fibers in terms of chemical properties. It has almost the same ratio with banana fibers and has high ratios in other fiber types. While it has a higher value than Coconut in terms of hemicellulose, it contains similar ratios to Kapok but has lower ratios than all other fibers. While it has higher ratios than Flax and Kapok fibers in terms of lignin content, it has similar percentage ratios to Banana and Sisal fibers. Lignin content is proportionally low compared to other plant fibers (Dungani et al., 2016).

The properties of *Typha* fibers given in Table 3. show that it is advantageous in terms of its processability properties such as spinning and dyeing ability as fiber, as well as its use in clothing and industrial areas. The chemical structure of the fibers indicates that they have limited but improvable spinnability, that their dyeability can be enhanced through appropriate pretreatments, and that they are more suitable for use in the clothing industry in processed or blended forms rather than direct application.

Table 3. Comparison of selected agricultural fibers and *Typha latifolia* fibers in terms of chemical properties (Adapted from Dungani et al., 2016)

Tablo 3. Seçilmiş tarımsal lifler ve *Typha latifolia* liflerinin kimyasal özellikler açısından karşılaştırılması (Dungani vd., 2016'dan uyarlanmıştır)

Types of fibers	Cellulose (%)	Hemicellulose (%)	Lignin (%)
<i>Typha latifolia</i> (Chakma, 2018)	42,61-63,00	8,7	5,75-9,6
Palm oil	44,20-49,60	18,30-33,54	17,30-26,51
Sugar Cane	55,60-57,40	23,90-24,50	24,35-26,30
Banana	60,25-65,21	48,20-59,2	5,55-10,35
Indian Coconut	36,62-43,21	0,15-0,25	41,23-45,33
Corn stalks	38,33-40,31	25,21-32,22	7,32-21,45
Pineapple	70,55-82,31	18,73-21,90	5,35-12,33
Rice straw	28,42-48,33	23,22-28,45	12,65-16,72
Jute	69,21-72,35	12,55-13,65	12,67-13,21
Kenaf	37,50-63,00	15,10-21,40	18,00-24,30
Flax	69,22-71,65	18,31-18,69	3,05-2,56
Sisal	43,85-56,63	21,12-24,53	7,21-9,20
Kapok	65,63-69,87	6,66-10,49	5,46-5,63

Typha is characterized by the stem fiber's strong tensile strength, an elastic spongy texture, and leaves that are resistant to tearing and breaking. These characteristics enhance the fiber's notable load-bearing strength and superior thermal insulation properties. The structure of cellulose, the most prevalent type of plant fiber, primarily consists of pectin and hemicellulose. Amorphous regions with random polymer orientation facilitate higher uptake of water, vapor, or dyes due to their disordered structure. In contrast, crystalline regions, characterized by polymers aligned parallel to the fiber axis, exhibit significant hydrogen bonding. In addition, the crenellated structure increases its absorbency in dyeing. Dyeing is a modification process that gives the material an identity and distinctive appearance, which is an important part of the garment. *Typha* fiber has good dye absorbency due to its crenellated structure that encapsulates reactive dye particles, which helps to increase dye absorbency. It is stated that before the washing process, *Typha* fiber, dye absorption is 92.54% and dye exhaustion is 79.29% (Chakma, 2018). At the same time, this "crenulated" structure can play an active role in industrial and biomedical applications for the capture of antibiotics and other chemicals (Chakma et al., 2017). Reactive dyes have been reported to be effectively applied to *Typha* fiber. The high cellulose content of *Typha* fiber facilitates efficient dye absorption and exhaustion, performing comparably to, or even surpassing, that of cotton (Khan, 2021). For cellulose fibers, the acceptable range of dye fixation in

reactive dyeing is typically 50–90%. *Typha* fiber demonstrates dye absorbency of over 85% prior to washing and approximately 70% after washing, falling within this acceptable range. Based on these dye uptake and color fastness characteristics, *Typha* fiber is considered suitable for textile applications (Chakma, 2018).

The heat fastness of *Typha* fiber is comparable to cotton. *Typha* fibers meet industry and ASTM minimum performance standards for staining and color change (Khan, 2021). The standard rating for color fastness to hot pressing is between 3 and 4.8, which is acceptable in clothing performance specification standards. Results from statistical analyses revealed that wet testing did not produce significant differences in the retention of dry, undyed cotton fabric, consistent with the anticipated behavior of the test material. In contrast, differences in color fastness performance—encompassing both color change and staining—were noted between cotton and *Typha* samples (Chakma, 2018). It is stated that the pH value of *T. latifolia* fiber is 6.7 and has a slightly alkaline property, and it is stated that it is safe to contact directly with human skin due to this property. It has also been revealed that the fiber is resistant to acidity, not alkali (Zhang et al., 2018).

Typha fibers are brittle and short-fibered, the aspect ratio is 2,585.1 and the fiber bundle strength is 26.9 cN/tex. The presence of short fibers is at the level of 30.2%, and this ratio shows that the fiber length is not uniform (Khan, 2021). While it is stated that the fiber length of broad-leaved *T. latifolia* is approximately 50 mm (Chakma, 2018), the fibers of narrow-leaved *T. angustifolia* are stated to have an average length of 19 mm. It is also stated that the fiber length in the fruit is lower than in the leaf. *Typha* has a jute-like stem, and it has been found that the lengths of the fibers collected from the naturally erupting spikes of mature plants vary between 2.25–10.65 mm and the thickness of the fibers varies between 10–15 μm (Khan, 2021).

It was determined that the moisture regain for *Typha* fiber was around 10% at 59% relative humidity and 25°C. These values are comparable to cotton and wool fibers (Khan, 2021). Although the moisture regain of *Typha* fiber differs greatly from wool in proportion, it is stated that there is no significant difference between it and cotton (Rahman et al., 2021). *Typha* fiber demonstrates flammability characteristics in which it neither smokes nor melts when exposed to flame, yet it burns quickly and does not self-extinguish upon removal of the heat source. The reported decomposition temperature of the fiber is 268.7°C. Furthermore, the surface energy of *Typha* fiber is 45.64 mN/m, closely aligning with the surface energies of kapok (49.65 mN/m) and cotton fibers (46.99 mN/m) (Khan, 2021).

A fiber exhibiting greater resistance to heat demonstrates its suitability for textile use. Greater heat stability indicates a fiber's suitability for textile applications. *Typha* fibers have shown superior heat resistance compared to cotton when subjected to direct heating from 0 °C to 300 °C without holding time. However, when heating involves

holding periods, cotton is reported to be more heat resistant than *Typha* fibers (Chakma, 2018). The diameter, moisture regain, burning behavior and thermal properties of *Typha* fiber are similar to commonly used textile fibers such as cotton, wool and polyester. The cellulose content in various bast fibers ranges from 60 to 80% and the cellulose content in cotton is about 90%. Considering the total percentage cellulose and hemicellulose content, it is reasonable to assume that *Typha* fiber, if properly extracted, may have textile properties (Chakma et al., 2017).

Evaluation of the Use of *Typha* Fiber in Textiles and Other Areas

The fiber yield from *Typha* plants ranges between 30% and 50%, depending on the temperature and duration of alkaline treatment. Following a 2-hour alkaline treatment, the average yield (43.24%) was significantly higher ($p = 0.033 < 0.05$) than that obtained after 8 hours (35.78%). Furthermore, studies have demonstrated that *Typha* fiber can be extracted from both the leaves and the sponge tissue of the plant (Rahman et al., 2021).

Several properties of fiber extracted from the leaves of *Typha australis* (Typhaceae) via chemical wetting—including tensile strength, chemical composition, thermal behavior, moisture absorption, and infrared (IR) spectra—were investigated. The study revealed that *Typha* fiber, a lignocellulosic material with approximately 54% cellulose content, 8–10% moisture regain, and a tensile strength of 29 cN/tex, has the potential to serve as a promising alternative to conventional natural textile fibers (Mortazavi and Moghadam, 2009). *Typha* fibers, a natural fiber source, have impressive physical properties. *Typha* fiber, which has higher strength (strength = 0.31 N/tex) compared to wool, can be used in clothing production due to its slightly better strength than cotton (Khan, 2021). In a study investigating the spinnability of *Typha* fiber, blends containing *Typha* were spun using a ring spinning machine. The relatively short fiber length (<50 mm) suggested that short-fiber spinning systems may be more suitable for processing these fibers (Linjala, 2021; Khan, 2021). Moreover, *Typha* fiber exhibits greater hardness than cotton and polyester, which can pose challenges in conventional cotton spinning systems (Khan, 2021). For these reasons, studies on machines to spin *Typha* fiber are insufficient and it is necessary to increase the studies and manufacture machines suitable for spinning.

Typha fibers have some potential properties in terms of textiles due to their diameters ranging from 10 to 14 μm . The average cutting length of 39 to 54 mm is similar to cotton and wool fibers. Since the softness value of *Typha* fiber is at the level of 2.8, it is softer than Brassica, hemp (softness degree 1) and synthetic fiber nylon (softness degree 2). Considering this softness degree of *Typha*, it seems possible to produce with a fiber blend of cotton, wool, nylon or acrylic in various blend ratios (e.g. 70:30, 60:40) to make it suitable for fiber spinning (Chakma, 2018). In addition, studies have indicated

that *Typha* fiber can be processed on a spinning machine alone. Moisture recovery indicates comfort of use. *Typha* fiber exhibits an acceptable moisture recovery range of 9.4% to 12.7%. In addition, a textile fiber needs dyestuff affinity. *Typha* fiber shows good dyeing properties in reactive blue dye and is almost at a similar level to cotton. At the same time, it shows similar thermal properties to cotton fiber in the burning test (Chakma, 2018). The properties of *Typha* fiber and some other fibers are shown in Table 4.

Table 4. Main properties of *Typha* fiber and other fibers (Karahan and Mangut, 2011; Chakma, 2018; Mortazavi and Moghadam, 2009; Khan, 2021, Shadin et al., 2021)

Tablo 4. *Typha* lifi ve diğer liflerin başlıca özellikleri (Karahan ve Mangut, 2011; Chakma, 2018; Mortazavi ve Moghadam, 2009; Khan, 2021; Shadin ve ark., 2021)

Fiber Type Properties	<i>Typha</i>	Cotton	Wool	Flax	Polyester
Fiber length (mm)	2,25-15	13-22	22-40	14-25	Desired fineness according to nozzle diameter
Strength (cN/tex)	29	19-45	12-14	54	47-56
Moisture Absorption Value (%)	9,4-12,7	8,5	16-18	12	0,4
Cellulose Amount (%)	42,61-63	88-96	-	70-85	-
Density (g/cm ³)	1,39	1,55	1,30	1,50	1,39
Surface Properties	Porous structure	Twisted structure	Flaky structure	Transverse broken lines	Smooth surface

The mechanical properties of *Typha* fibers, along with flax, hemp, and cotton fibers commonly used in the clothing and textile industry, are presented in Table 4. *Typha* fiber, which has higher strength than wool, is slightly better than cotton and can be used in clothing production.

In addition, *Typha* fiber has the potential to be used in industrial applications such as composites with its high tensile stress and Young's modulus values (Khan, 2021, Rahman et al., 2021). Due to its low density, buoyancy, and hydrophobic nature, *Typha* fiber has been identified as an excellent natural sorbent (Khan, 2021).

Table 5. Mechanical properties of *Typha* and commonly used textile fibers (Rahman et al., 2021).

Tablo 5. *Typha* ve yaygın olarak kullanılan tekstil liflerinin mekanik özellikleri (Rahman ve ark., 2021).

Fiber type	Tensile stress (MPa)	Tensile strain (%)	Young's modulus (GPa)	Strength (N/tex)
<i>Typha</i>	362,4	3,0	18,93	0,31
Flax	600-1200	1,2-3,0	27,6	0,45
Hemp	690,0	1,6-4,5	70,0	
Cotton	280-840	5,6-7,1	5,5-7,1	0,30

The most widely used sorbents today are synthetic polymers like polypropylene and polyester fibers (Khan, 2021); however, they are neither renewable nor biodegradable and are costly, which significantly restricts their future applications. *Typha* fibers, on the other hand, are proposed as a promising natural alternative for developing oil absorbents. A key factor contributing to their high oil absorption capacity is the presence of open pores within the fibers. It is also stated that *Typha* fibers have a high capacity for the absorption of PAHs (polycyclic aromatic hydrocarbons). In addition, hierarchical porous carbon materials derived from *Typha* fiber have been developed for use in energy storage and conversion. Additionally, *Typha* fiber has been incorporated into textile-based composites with successful outcomes. Studies suggest that it can function as a functional filler or coating in the production of antimicrobial composite materials (Khan, 2021). Many studies have been conducted and are being conducted on *Typha* fiber and fiber. Their areas of use are quite diverse.

Studies have been conducted on *T. latifolia*, which is particularly widespread in Turkey, and its fiber properties have been revealed. In Turkey, no studies have been found on fiber and fiber production from this type of plant. Compared to the materials used in glass fiber reinforcement, The cost of obtaining *Typha* fiber is relatively low, making it an economically viable option. Therefore, studies on the use of *Typha* fiber in composite materials are promising and suitable for use in building construction and manufacturing of automobile parts (Sana et al., 2015). It is also stated that studies on its use in paper production are promising (Sotannde et al., 2020).

Studies on *T. latifolia* fibers have shown that they have good sound absorption properties and this can be explained by their similarity to wool. Fibers from *T. latifolia* can be used to produce *Typha* wool with promising applications as a sustainable sound insulation material. In addition, when *Typha* fiber was evaluated in terms of biodegradability, it was stated in the tests that almost all of the fibers decomposed within four weeks and remained as a thin and delicate layer when the fibers were collected. It was stated that the fibers that did not decay during this period were very fragile (Linjala, 2021).

Typha fibers can be interesting for textile and fashion designers as a natural material, thin yarn or twine can be made from its leaves and original accessories or details can be created with this material. It is a fiber that is primarily more suitable for industrial and filtration purposes. Apart from this, it can also be used as decorative details for clothing and accessory purposes. For instance, a natural element can be incorporated into designs through the use of wicker appliqués or detailed stitching.

Textile and fashion brands can use these fibers in capsule collections focused on sustainability. These collections can reflect an environmentally friendly approach by emphasizing natural materials. It can be used in fashion accessories such as hats, sunglasses, sandals or beach bags. This can be especially popular in the summer months.

The fibers obtained from these plants are used in different designs, especially decoration products, baskets, chandeliers and umbrellas. It is usually not used directly in clothing production. However, it is thought that it can be used in clothing production with different techniques by mixing with other natural fibers.

Conclusion

Typha fibers, which are natural fiber sources, have great importance for both our country and the textile industry due to their unique physical properties. It is clear that these plants, which are naturally abundant in Turkey, will provide great economic gains if used in textile and industrial applications. The fact that there is no production cost in growing the plants and that they can naturally renew themselves quickly provides great advantages. In addition, developments in the textile industry, studies on returning to natural fibers, and searches for biodegradable fabrics make these fibers more valuable. General evaluations about fibers obtained from the *Typha* plant are listed as follows:

- The biodegradability feature includes the capacity of the material to dissolve in nature and transform into organic components, which means that it can participate in a natural cycle process without creating waste. *Typha* fibers are naturally obtained and are biodegradable. At the same time, the *Typha* plant is a fast-growing, abundant, wetland plant that can grow in Turkey and many other regions and is an easily renewable resource. It not only provides visual differences, but also brings an innovative perspective to the textile and fashion industry based on the principle of environmental sustainability.
- There are various chemical extraction processes for the production of *Typha* fiber. Different extraction methods can be applied with water, acid, enzyme and alkaline processes to dissolve lignin and other binding agents and release the fibers.
- When the physical and chemical properties of *Typha* plant fiber are examined, it is seen that it is quite similar to cotton fiber due to its cellulose amount and crenulated morphological structure and has good moisture gain, strength value and dye absorbency.
- *Typha* fiber is of great importance for the textile industry, especially because it has properties similar to cotton fiber. In addition, due to its processability and availability, it is used in many different applications such as antimicrobial composites, automobile parts, building construction applications, sound insulation materials, industrial and filtration materials, and decoration products.

Typha plants, which are a natural fiber source that can be easily found in many areas in Turkey, are economical and sustainable, and have properties suitable for use in the textile sector, are promising in supporting local and regional production potential and responding to the search for new raw materials. In this sense, studies on fiber extraction

from *Typha* should be developed and fiber properties should be investigated. In addition, according to the research results, its use in both the textile industry and other areas should be evaluated and developed. The use and evaluation of resources naturally distributed in our country will be an alternative that can offer innovative solutions for both industrial and commercial applications.

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