

Original Scientific paper

10.7251/AGREN2601074G

UDC 677.141:631.559:631.84

FIBER YIELD OF TWO KENAF CULTIVARS (*HIBISCUS CANNABINUS* L.) UNDER DIFFERENT N-FERTILIZATION LEVELS AND DEVELOPMENT STAGES

Ippolitos GINTSIOUDIS*, Dimitris BARTZIALIS, Kyriakos D. GIANNOULIS, Paulina KASIOLA, Nikolaos G. DANALATOS

University of Thessaly, Dept. of Agriculture Crop Production and Rural Environment,
Laboratory of Agronomy and Applied Crop Physiology, Volos, Greece

*Corresponding author: igints@yahoo.com

ABSTRACT

Kenaf (*Hibiscus cannabinus* L.) is an important fiber crop with applications in textile and composite industries. This study aimed to evaluate the bast fiber and core wood productivity of two kenaf cultivars under different nitrogen fertilization levels at various developmental stages. A split-plot field experiment was conducted in Magnesia, Greece, during the 2023 growing season. Two kenaf cultivars (NH1 and MS8234) were grown under three nitrogen fertilization levels (N0: 0 kg N ha⁻¹, N75: 75 kg N ha⁻¹, N150: 150 kg N ha⁻¹). Destructive sampling was performed at three developmental stages: pre-flowering, flowering, and maturity/harvest. Bast fiber separation was achieved using pectinase enzyme treatment, followed by manual separation and dry weight determination. Bast fiber percentage ranged from 35% at early stages to 30% at maturity, with core wood comprising the remainder. No significant differences in bast fiber-to-core wood ratios were observed between cultivars or fertilization treatments. However, total bast fiber and core wood productivity differed significantly between cultivars, with NH1 producing higher yields (5 Mg ha⁻¹ fibers, 12.3 Mg ha⁻¹ core wood) compared to MS8234 (3.6 Mg ha⁻¹ fibers, 8.4 Mg ha⁻¹ core wood) at harvest. Fertilization significantly increased total biomass production, with fertilized treatments yielding approximately 17.1 Mg ha⁻¹ compared to 11.4 Mg ha⁻¹ for unfertilized controls. The relationship between stem diameter and fiber percentage was weak, ($R^2 = 0.18$), and was not statistically significant.

Keywords: *kenaf, N-fertilization, seed yield, biomass production, arid climate.*

INTRODUCTION

Kenaf (*Hibiscus cannabinus* L.) is a versatile annual fiber crop with numerous applications. Its primary use is as a source of cellulosic fiber for various industries (Austin et al., 2024). Kenaf fibers can reinforce polymer composites, offering comparable properties to synthetic fibers at lower costs (Akil et al., 2015). The plant's bast and core fibers have different chemical and morphological properties,

influencing their behavior in pulp and paper production (Mossello et al., 2010, Monti & Alexopoulou, 2013). Kenaf is used in paper pulp, biocomposites, textiles, biomass energy, and industrial absorbents (Austin et al., 2024). Additionally, its seeds and leaves have traditional medicinal uses in India and Africa (Ayadi et al., 2016). The crop's versatility extends to its potential as a bioenergy feedstock and its seed oil's use in cooking and industrial applications (Ayadi et al., 2016). Given its diverse applications, kenaf production is expected to expand rapidly in the coming decades (Austin et al., 2024). From an environmental perspective, kenaf demonstrates exceptional carbon sequestration capabilities that contribute significantly to climate change mitigation. The high photosynthetic rate of kenaf, enables remarkable CO₂ absorption rates of 21-89 Mg CO₂ ha⁻¹ year⁻¹ depending on agronomic management practices (Santoso et al., 2015). This carbon sequestration potential, combined with the crop's ability to produce substantial biomass within 4-5 months, positions kenaf as a valuable tool for reducing atmospheric CO₂ concentrations while providing renewable raw materials. Despite its environmental and economic potential, kenaf productivity is influenced by various agronomic factors, particularly nitrogen fertilization and cultivar selection. Understanding the relationship between these factors and fiber yield is crucial for optimizing production systems and maximizing both economic returns and environmental benefits. The present study aims to evaluate the bast fiber and core wood productivity of two kenaf cultivars under different nitrogen fertilization levels, providing insights for sustainable kenaf production systems.

MATERIALS AND METHODS

Stem samples were acquired from a field experiment conducted in Velestino in Greece, during the 2023 summer growing season. The experimental site was characterized by clay loam soil with slightly alkaline pH (8.0), organic matter content of 1.2%, available phosphorus of 8.6 mg kg⁻¹, exchangeable potassium of 0.28 cmol kg⁻¹, and electrical conductivity of 513 μS cm⁻¹ at 25°C. The experimental design employed was split-plot with three replications, where the main factor consisted of two kenaf cultivars (NH1 and MS8234) and the sub-factor included three nitrogen fertilization levels: N0 (0 kg N ha⁻¹), N75 (75 kg N ha⁻¹), and N150 (150 kg N ha⁻¹). Each experimental plot had a population density of ≈240,000 plants ha⁻¹. Experimental fields were sown on May 18, 2023, with concurrent basal fertilization of phosphorus (50 kg ha⁻¹), potassium (35 kg ha⁻¹), and nitrogen (40 kg ha⁻¹). Pre-emergence weed control was implemented using either chemical methods or manual removal. No insects requiring control measures were observed during the growing period. Top-dressing fertilization with urea (NPK 46-0-0) was applied on mid-July, according to treatment specifications. Destructive sampling was performed at three developmental stages corresponding to August 23, 2023 (anthesis of MS8234), September 21, 2023 (anthesis of NH1), and October 30, 2023 (physiological maturity and harvest for both cultivars). At each sampling date, plant material from one meter of row length was harvested from each plot and fresh weight was recorded. Three representative plants per plot were selected and transported to

the laboratory for manual separation into constituent organs (stems, petioles, leaves, and reproductive structures). Fresh weights of individual organs were determined, followed by oven-drying until constant weight achievement for dry weight determination. The bast fiber separation protocol involved enzymatic treatment, utilizing pectinase to degrade pectin within fiber cell walls. Dried stem samples were weighed using precision balance and subsequently immersed in aqueous solution containing 500 g pectinase preparation (Pectinase TOUFOOD™) and 1.1 L acetic acid solution (5% CH₃COOH) in 110 L capacity containers to optimize pH conditions. Following a seven-day incubation period, manual separation of bast fibers from core wood was executed. Separated components were oven-dried to constant weight and individual masses were recorded. Stem diameter measurements were obtained per sample using digital calipers. Statistical analysis was performed using analysis of variance (ANOVA) to determine significant differences in bast fiber and core wood percentages and productivity per unit area at $\alpha = 0.05$ significance level using MS Excel™. When significant F-values were obtained, Fisher's protected LSD test was applied to identify significant differences between treatment means. Linear regression analysis was employed to evaluate relationships between stem diameter and fiber composition parameters, with coefficient of determination (R²) values calculated to assess goodness of fit.

RESULTS AND DISCUSSION

The meteorological profile of the experimental site during the 2023 growing season is presented in Figure 1, including mean maximum and minimum temperatures and rainfall per 10-day period. A comparison of these values against long-term climatic data from the Hellenic National Meteorological Service (HNMS) reveals that the growing season commenced with a relatively cool May; the mean maximum temperature of 23.1°C remained approximately 2.8°C below the climatic normal. This trend continued in June (29.9°C), which was 1.3°C cooler than average. This pattern reversed sharply in July, which surpassed the climatic average by 3.4°C, reaching 36.7°C. Similarly, August (34.2°C) remained 1.4°C above average. September aligned closer to the climatic mean (28.3°C), being just 0.3°C cooler. October exhibited mean maximum temperatures reaching 24.2°C, nearly 2°C above the long-term mean of 22.3°C. Overall, the mean maximum temperature for the May–October period was close to the climatic mean, with a thermal peak in July and the lowest values in May. Regarding minimum temperatures, monthly means were consistently higher than their climatic counterparts. May and June (climatic means 11.2 °C and 15.6 °C) were slightly warmer, exceeding the average by 0.9 °C and 0.5 °C, respectively. In contrast, July (climatic mean 18.1 °C), August (17.7 °C), September (14.2 °C), and October (10.2 °C) were significantly warmer, showing positive deviations of 2.7 °C, 2.5 °C, 2.5 °C, and 3.3 °C, respectively. On average, the monthly mean minimum temperature for the entire period was 2 °C higher than the climatic mean. In terms of rainfall, May (29.4 mm) was drier than average (38.1 mm), while June (24.9 mm) matched the climatic norm (24.4 mm). Mid-summer was arid, with July (0.0 mm) and August (6.3 mm) falling well below their respective

means of 19.7 mm and 14.9 mm. In sharp contrast, September recorded an extreme rainfall of 640.3 mm against a typical 33.1 mm, followed by a significantly dry October (14.7 mm) compared to the climatic expectation of 53 mm. Despite the magnitude of the precipitation in September, no obvious negative impact on the crop was observed.

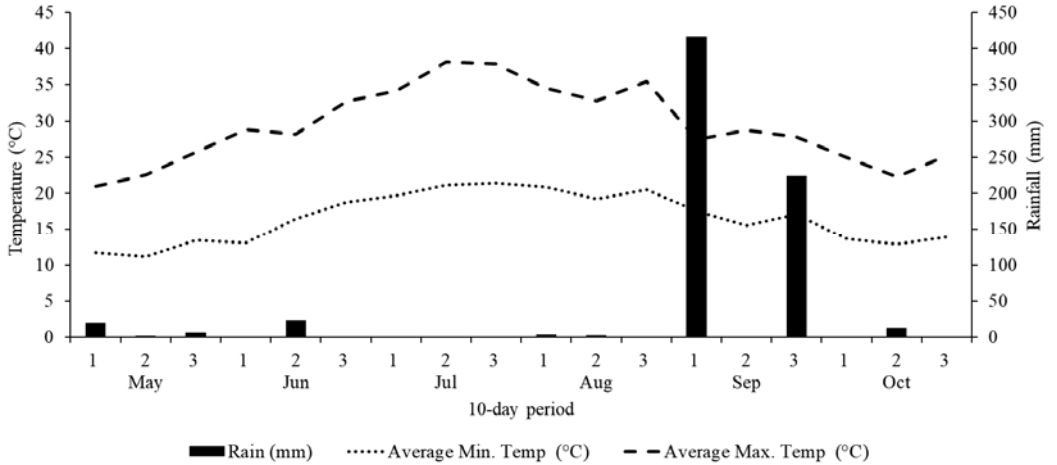


Figure 1. Seasonal variation of mean maximum and minimum air temperatures and total precipitation per 10-day period during the 2023 growing season (May–October) in Velestino.

Bast fiber percentage showed temporal variation throughout the growing season, with values declining progressively from early developmental stages to physiological maturity (Table 1). At the first sampling date, both cultivars exhibited similar bast fiber percentages of approximately 35%, with no statistically significant differences. By the second sampling, bast fiber percentage had decreased to 31% for both cultivars, maintaining statistical equivalence between cultivars, to slightly decline at final harvest to 29.5%, again showing no significant cultivar effect. Xylem, the complementary component of stems, exhibited corresponding percentages of 65%, 69% and 70.5%. Biomass loss due to pectinase treatment and pith weight were negligible. This trend demonstrates that stem composition changes are primarily age-dependent rather than genotype-dependent. Bourguignon et al. (2019) obtained similar results, showing that bast fibers constitute 35-45% of stem volume. However, Morrison et al. (1999) reported that fiber composition varies with plant maturity, with younger plants having different chemical compositions than mature plants, supporting our observed temporal decline. Nitrogen fertilization levels had no significant effect on bast fiber percentage throughout the growing season. Across all three sampling dates, the three fertilization treatments (N0, N75, and N150) maintained statistically similar fiber percentages within each developmental stage. This consistent pattern across fertilization treatments demonstrates that nitrogen availability does not influence the fundamental

anatomical composition of kenaf stems. The temporal decline in bast fiber percentage from 35% to approximately 30% occurred uniformly across all fertilization levels, indicating that developmental processes controlling fiber-to-core wood ratios are independent of nitrogen supply. The lack of fertilization effect on fiber percentage suggests that stem anatomical development follows genetically determined patterns that are not modified by nutrient availability. Our results are consistent with recent studies by Danalatos and Archontoulis (2010) who found no statistical significance between N rates regarding kenaf biomass composition.

Bast fiber productivity exhibited significant cultivar-dependent variation across sampling dates (Table 1). At the initial sampling, no significant differences were observed between cultivars, producing ≈ 2.4 Mg ha⁻¹. However, marked divergence occurred at subsequent samplings, primarily due to differential growth patterns between cultivars. By the second sampling, NH1 demonstrated substantial productivity increase to 4.3 Mg ha⁻¹, significantly exceeding MS8234 which showed modest growth to 3.0 Mg ha⁻¹. This divergence can be attributed to the extended vegetative growth period of NH1, which remained in the vegetative stage until its anthesis at mid-September, favoring continued stem biomass accumulation. Conversely, MS8234 had initiated flowering by August 23, resulting in growth cessation and photosynthate partitioning toward reproductive organs rather than vegetative tissues. At final harvest, bast fiber productivity reached 5.0 and 3.6 Mg ha⁻¹ for NH1 and MS8234 respectively, values that differed statistically significantly ($P < 0.05$). Bañuelos et al. (2002) also found that late-flowering kenaf cultivars generally produce higher fiber yields due to extended vegetative growth periods. Nitrogen fertilization significantly influenced bast fiber productivity, with marked differences observed between fertilization treatments across the growing season. At the initial sampling, no significant differences were detected among fertilization treatments, producing on average 2.4 Mg ha⁻¹ of bast fiber. However, substantial divergence occurred at the second sampling, where the unfertilized treatment (N0) showed limited productivity increase to 2.7 Mg ha⁻¹, while fertilized treatments demonstrated marked enhancement, with N75 and N150 achieving 4.3 and 3.8 Mg ha⁻¹, respectively. This differential response resulted in statistically significant differences between N0 and N150. By final harvest, bast fiber productivity had reached 3.3 Mg ha⁻¹ for unfertilized treatment, compared to ≈ 4.9 Mg ha⁻¹ of fertilized ones, though no significant differences were observed between the treatments. These findings align with previous research showing variable nitrogen response in kenaf. Webber (1996) found that stalk yield tended to increase with N applications up to 168 kg N ha⁻¹, but declined at higher rates, consistent with our observation of similar performance between N75 and N150. The unfertilized treatment consistently underperformed throughout the latter growth stages, achieving approximately 33% lower fiber production compared to fertilized treatments at harvest, although this difference was not statistically significant due to high experimental variability. The delayed response of N0 treatment can be attributed to nitrogen limitation constraining vegetative growth and biomass accumulation. Nitrogen availability is crucial for protein synthesis, chlorophyll formation, and overall plant metabolism,

directly affecting photosynthetic capacity and growth rate. The similar performance between N75 and N150 treatments suggests that 75 kg N ha⁻¹ may represent an optimal fertilization rate for bast fiber production under these experimental conditions. Excessive nitrogen application beyond this threshold did not provide additional benefits, indicating potential nutrient use efficiency considerations for sustainable production systems.

Table 1. Effect of kenaf Cultivar and N-fertilization per sampling date, on bast fiber percentage, bast fiber and xylem productivity.

Sampling Date	Factor	Treatment	Bast Fiber Percentage (%)	Bast Fiber Productivity (Mg ha ⁻¹)	Xylem Productivity (Mg ha ⁻¹)
August 23, 2023	Cultivar	NH1	34% a	2.3 a	4.4 a
		MS8234	35% a	2.5 a	4.6 a
	Fertilization	N0	35% a	2.2 a	4.2 a
		N75	34% a	2.5 a	4.8 a
		N150	35% a	2.4 a	4.5 a
September 21, 2023	Cultivar	NH1	32% a	4.3 b	8.9 a
		MS8234	30% a	3.0 a	6.9 a
	Fertilization	N0	31% a	2.7 a	6.0 a
		N75	31% a	4.3 ab	9.4 b
		N150	31% a	3.8 b	8.3 b
October 30, 2023	Cultivar	NH1	29% a	5.0 b	12.3 b
		MS8234	30% a	3.6 a	8.4 a
	Fertilization	N0	29% a	3.3 a	8.1 a
		N75	30% a	4.8 a	10.7 ab
		N150	29% a	4.9 a	12.1 b

Notes: Values within the same column, sampling date and factor followed by different letters are significantly different ($P < 0.05$, Fisher's LSD test). N0 = 0 kg N ha⁻¹; N75 = 75 kg N ha⁻¹; N150 = 150 kg N ha⁻¹.

Xylem (core wood) productivity followed similar patterns to bast fiber production, demonstrating significant responses to nitrogen fertilization and developmental stage progression (Table 1). During the first two samplings, no significant differences were observed between NH1 and MS8234, with both cultivars producing comparable xylem yields of ≈ 4.5 Mg ha⁻¹ during the first sampling and on average 7.9 Mg ha⁻¹ during the second sampling. However, marked divergence occurred at final harvest, with a substantial 47% advantage for the late-flowering cultivar NH1. The superior xylem productivity of NH1 can be attributed to its extended vegetative growth

period, which allowed continued stem expansion and secondary xylem development while MS8234 had already transitioned to reproductive growth. These findings demonstrate that cultivar selection significantly influences xylem productivity in kenaf, with late-flowering genotypes offering substantial advantages for maximizing core wood yield in fiber production systems. Considering the fertilization treatments, at the initial sampling, no significant differences were observed. However, marked differentiation occurred at the second sampling, where fertilized treatments significantly outperformed the unfertilized control. This differential response continued through final harvest, where xylem productivity reached 8.1, 10.7 and 21.1 Mg ha⁻¹ for N0, N75 and N150 respectively, with significant differences detected between N0 and N150 treatments. The enhanced xylem production under adequate nitrogen supply reflects the importance of nitrogen availability for secondary xylem development and lignification processes. The superior performance of fertilized treatments can be attributed to sustained photosynthetic activity and carbon allocation to structural tissues, particularly during the rapid stem expansion phase. These findings demonstrate that nitrogen fertilization not only enhances bast fiber yield but also substantially increases core wood production, contributing to overall biomass productivity and economic value of kenaf cultivation systems. The relationship between stem diameter and bast fiber percentage (Fig. 2) revealed a weak negative trend across all sampling dates, though the correlation was not statistically significant ($R^2 = 0.18$).

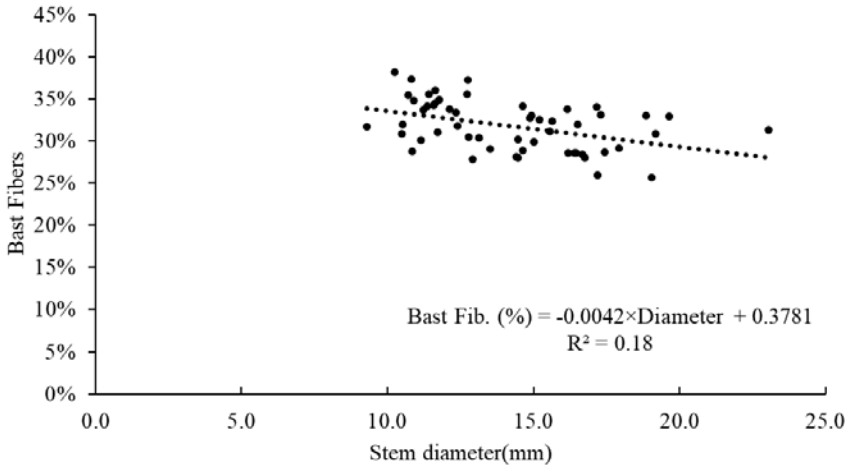


Figure 2. The relationship between stem diameter and bast fiber percentage in kenaf. Stem diameter measurements ranged from 9.3 mm at the first sampling to 23 mm at final harvest, while bast fiber percentage varied from 26% to 38% across all measurements. As stem diameter increased throughout the growing season, there was a tendency for reduced fiber percentage, with larger diameter stems (>17 mm) generally exhibiting fiber percentages below 32%. This pattern can be attributed to

differential growth rates between bast and core tissues, where secondary xylem development outpaces bast fiber accumulation as stems mature and thicken. However, the low coefficient of determination indicates substantial variation in this relationship, likely influenced by factors such as plant age, environmental conditions, and genetic variation between individual plants. The weak correlation suggests that while there may be a biological tendency for fiber percentage to decrease with increasing stem diameter, this relationship is not sufficiently strong to serve as a reliable predictor of fiber content in kenaf production systems.

CONCLUSIONS

This study demonstrated that kenaf fiber composition and productivity are influenced by different factors, with important implications for sustainable fiber production systems. Bast fiber percentage showed consistent temporal decline from 35% to 30% during plant development, a pattern that was independent of both cultivar selection and nitrogen fertilization levels. This indicates that fiber-to-core wood ratios are primarily controlled by developmental processes rather than genetic or nutritional factors. However, total fiber productivity was significantly affected by both cultivar choice and nitrogen management. The late-flowering cultivar NH1 achieved superior bast fiber (5.0 Mg ha^{-1}) and core wood yields (12.3 Mg ha^{-1}) compared to the early-flowering MS8234 (3.6 and 8.4 Mg ha^{-1} , respectively), demonstrating the advantage of extended vegetative growth periods. Nitrogen fertilization proved essential for maximizing biomass production, with fertilized treatments yielding approximately 50% more total biomass than unfertilized controls, though optimal rates appeared to be achieved at 75 kg N ha^{-1} . The weak correlation between stem diameter and fiber percentage ($R^2 = 0.18$) suggests that morphological characteristics cannot reliably predict fiber content. These findings indicate that kenaf production strategies should prioritize late-flowering cultivars and moderate nitrogen fertilization to optimize both economic returns and environmental benefits, while harvest timing should focus on maximizing total biomass rather than altering fiber composition ratios.

REFERENCES

- Akil, H. M., Zamri, M. H., & Osman, M. R. (2015). The use of kenaf fibers as reinforcements in composites. In *Biofiber Reinforcements in Composite Materials*, Woodhead Publishing, Cambridge, UK, 138-161.
- Austin, C. C., Mondell, C. N., Clark, D. G., & Wilkie, A. C. (2024). Kenaf: Opportunities for an ancient fiber crop. *Agronomy*, 14 (7), 1542.
- Ayadi, R., Hanana, M., Mzid, R., Hamrouni, L., Khouja, M. L., & Hanachi, A. S. (2017). *Hibiscus cannabinus* L. - kenaf: a review paper. *Journal of Natural Fibers*, 14 (4), 466-484.
- Bañuelos, G. S., Bryla, D. R., & Cook, C. G. (2002). Vegetative production of kenaf and canola under irrigation in central California. *Industrial Crops and Products*, 15 (3), 237-245.

- Bourguignon, M., Moore, K. J., Lenssen, A. W., & Baldwin, B. S. (2019). Agricultural practices for growing kenaf (*Hibiscus cannabinus* L.) in Iowa: I. Cultivar and plant population effects on biomass yield and composition. *Agronomy Journal*, 111 (3), 1118-1127.
- Danalatos, N. G., & Archontoulis, S. V. (2010). Growth and biomass productivity of kenaf (*Hibiscus cannabinus* L.) under different agricultural practices in central Greece. *Industrial Crops and Products*, 32 (3), 231-240.
- HNMS, Hellenic National Meteorological Service. (2024). Climatological data of Larissa station. Retrieved from <http://www.emy.gr>.
- Monti, A., & Alexopoulou, E. (Eds.) (2013). *Kenaf: A multi-purpose crop for several industrial applications: new insights from the biokenaf project*. Springer-Verlag, London.
- Morrison Iii, W. H., Akin, D. E., Archibald, D. D., Dodd, R. B., & Raymer, P. L. (1999). Chemical and instrumental characterization of maturing kenaf core and bast. *Industrial Crops and Products*, 10 (1), 21-34.
- Mossello, A. A., Harun, J., Tahir, P. M., Resalati, H., Ibrahim, R., Shamsi, S. R. F., & Mohmamed, A. Z. (2010). A review of literatures related of using kenaf for pulp production (beating, fractionation, and recycled fiber). *Modern Applied Science*, 4(9), 21.
- Santoso, B., Jamil, A. H., & Machfud, M. (2015). Kenaf (*Hibiscus cannabinus* L.) benefits in carbon dioxide (CO₂) sequestration. *Perspektif*, 14 (2), 125-133.
- Webber, C. L. (1996). Response of kenaf to nitrogen fertilization. In J. Janick (Ed.), *Progress in New Crops*, ASHS Press, Alexandria, 404-408.