Physical and Mechanical Properties of Sansevieria trifasciata Fibers as Influenced by Gibberellic Acid Treatment

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DOI: https://doi.org/10.51244/IJRSI.2025.120500165

Received: 08 May 2025; Accepted: 15 May 2025; Published: 19 May 2025

ABSTRACT

The environmental impact of synthetic fibers has driven demand for sustainable alternatives like Sansevieria trifasciata, an underutilized plant with potential for textile and composite applications. This study evaluated the effects of GA_3 concentrations (0, 100, 300, 500 µg/mL) and application frequencies (once or twice weekly) on the physical (length, fineness) and the mechanical (breaking strength, elongation) properties of S. trifasciata fibers. Using a completely randomized design, 240 leaf explants were treated for three months in a pot culture experiment in Camarines Sur, Philippines. Fibers were extracted via water retting and tested at the Philippine Textile Research Institute. Single GA_3 applications increased fiber length, with 300 µg/mL producing the longest fibers, likely due to enhanced cell elongation. Twice-weekly applications increased fiber fineness (higher denier), peaking at 100 µg/mL, yielding coarser fibers suitable for robust textiles. Breaking strength was highest in untreated fibers and 100 µg/mL treatments, but 300 µg/mL significantly reduced strength, indicating a trade-off with length. Elongation, a measure of elasticity, was maximized at 100 µg/mL (once weekly), ideal for flexible textiles. The 100 µg/mL concentration optimized fineness, strength, and elongation, while 300 µg/mL favored length, demonstrating GA_3's versatility in tailoring fiber properties. These findings highlight GA_3's potential to enhance S. trifasciata fiber quality, positioning it as a sustainable alternative to abaca in the Philippines. Future research should investigate GA_3 application timing across growth stages and conduct commercial-scale trials to assess scalability and economic viability.

Keywords: Sansevieria trifasciata, gibberellic acid, natural fibers, textile applications, fiber properties

INTRODUCTION

Rapid global industrialization and technological advancements have significantly contributed to environmental degradation, with the textile industry being a major source of pollutants [1]-[4]. Toxic chemicals used in fiber processing often contaminate the environment, prompting researchers and manufacturers to explore eco-friendly alternatives [5]. Eco-friendly textiles, characterized by the absence of hazardous chemicals, biodegradability, and recyclability, have gained attention as sustainable solutions. Consequently, there has been a shift from synthetic to natural fibers, which are derived from plant parts and valued for their renewable and biodegradable properties [6].

In the Philippines, abaca fibers dominate the natural fiber industry [7], yet other fiber-yielding plants, such as Sansevieria trifasciata (commonly known as snake plant), remain underutilized [8]. Commonly grown as an ornamental plant or occurring as a weed, S. trifasciata thrives in a variety of well-drained soils, including sandy or clay types, and requires minimal maintenance [9]. It tolerates a wide range of light conditions, from full sun to shade, and is drought resistant [10]. The plant's leaves emerge from thick, creeping rhizomes and are typically long, erect, lanceolate, and fleshy, measuring 30–120 cm (12–48 inches) in length and 2.5–7.5 cm (1–3 inches) in width [11]. They are characterized by distinctive green coloration with variegated patterns, often featuring grey-green stripes or yellow edges, depending on the cultivar [9].

Research has demonstrated that S. trifasciata leaves contain extractable fibers suitable for textile applications [8] [12]-[14]. These fibers exhibit good tensile strength, fineness, and low elongation, enhancing their

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue V May 2025

potential for composite materials and textiles [13][15]. Studies have shown that incorporating S. trifasciata fibers improves the mechanical properties of composites [16]-[25]. Although S. trifasciata fibers have a tensile strength of 348.6 MPa and lengths up to 1.09 m [13], their shorter length and generally lower strength compared to abaca (100–900 MPa, 2–4 m) [27] limit their competitiveness, necessitating enhancement techniques like GA_3 treatment.

Techniques such as alkali treatment and hormonal applications have been explored to enhance natural plant fiber properties [28]-[33]. Plant hormones, particularly gibberellic acid (GA_3), a diterpenoid carboxylic acid, regulate fiber differentiation and structural properties in plants [34][35]. GA_3 has been used to improve fiber quality in crops like cotton, okra, and ramie [36]-[39]. However, no studies have investigated its effects on S. trifasciata fibers.

This study aims to evaluate the influence of GA_3 on the physical (length, fineness) and mechanical (breaking strength, elongation) properties of S. trifasciata fibers. Different GA_3 concentrations (0, 100, 300, 500 µg/mL) and application frequencies (once or twice weekly) were tested to identify optimal treatment conditions. Enhancing these properties could improve the fibers' suitability for textile applications, potentially positioning S. trifasciata as a viable alternative to abaca in the Philippines.

METHODS

Experimental Site

The experiment, spanning cultivation, GA_3 treatment, and fiber extraction, was conducted from February to November 2021 in a vacant residential lot in Sta. Maria, Presentacion, Camarines Sur, Philippines.

Test Plant

Sansevieria trifasciata plants, sourced from a local residential area in Presentacion, Camarines Sur, were used as the fiber source. Healthy, mature leaves of uniform length were cut into 15-cm sections (explants) [40]. A total of 240 explants were used for propagation and cultivation.

Experimental Design and Treatments

The study employed a completely randomized design (CRD) with three replications, evaluating two factors: gibberellic acid (GA_3) concentration (0, 100, 300, 500 µg/mL) and application frequency (once or twice weekly). The control treatment (0 µg/mL) used distilled water. GA_3 concentrations were selected based on studies demonstrating effective fiber enhancement in crops like cotton and okra [36][38]. Eight treatment combinations (Table 1) were tested, with each treatment comprising 10 explants. Fibers extracted from mature leaves were analyzed for physical and mechanical properties.

Table I Ga_3 Concentration And Frequencies Of Application Treatments Used In The Study

GA_3 concentration	Frequencies of Applications (per week)
Control (Water)	Once
Control (Water)	Twice
100 µg/mL	Once
100 µg/mL	Twice
300 µg/mL	Once
300 µg/mL	Twice
500 µg/mL	Once
500 µg/mL	Twice

Cultural Management

Preparation of Growing Medium: The potting medium, a 1:1 mixture of soil and compost [40], was filled to two-thirds depth in 6 × 6 × 10 inch polyethylene plastic pots. Each pot was labeled using bamboo skewers and laminated cards.

Cultivation of Sansevieria trifasciata: Explants were planted in pots, with 2 cm of the cut end inserted into the medium, following the leaf growth direction [40][41]. Pots were arranged in a CRD on coconut lumber racks.

Hormonal Treatment: One month after shoot formation, when leaf clusters separated, GA_3 solutions (0, 100, 300, 500 µg/mL) were applied via foliar spraying [38] at the specified frequencies. Control plants were sprayed with distilled water. Treatments continued for three months.

Water, Weed, and Pest Management:Pots were irrigated using sprinklers two to three times weekly, adjusted for rainfall [40][41]. Manual weeding was performed weekly. No pest or insect infestations were observed.

Fiber Extraction

Mature S. trifasciata plants, with leaves exceeding 30 cm, were uprooted for fiber extraction. Fibers were extracted using stagnant water retting for 2–3 weeks, until leaves exhibited a slimy texture and easy separation of the outer layer, indicating complete decomposition [13]-[15][42]. This was followed by hand scraping with a knife and ceramic scraper [8][15][43]. Extracted fibers were washed, airdried at room temperature, and sent in bundles to the Department of Science and Technology-Philippine Textile Research Institute (DOST-PTRI) for analysis.

Determination of Physical Properties

Fiber Length: Fiber length was measured using a calibrated tape measure. Thirty fiber bundle specimens per treatment, each comprising approximately 10–15 individual fibers bound together, were laid flat without elongation, and length was recorded in centimeters.

Fiber Fineness: Fineness was determined using a modified ASTM D1577-07 (Reapproved 2018): Option A – Fiber Bundle Weigh method [44], with a Spinlab Clamp Vise and Zweigle Torsion Balance. Fineness (denier) was calculated as: Fineness (denier) = (M × 9000) / (L × N); where M is the mass (mg), L is the length (mm), N is the number of strands in the bundle (10–15 fibers), and 9000 is the yarn length constant. Thirty fiber bundle specimens per treatment were tested.

Determination of Mechanical Properties

Breaking Strength and Elongation: Breaking strength and elongation were evaluated using ASTM D3822/D3822M-14: Single Strand test method [45]. Thirty fiber bundle specimens per treatment, each consisting of a single cohesive bundle of 10–15 fibers, were tested in a Zwick/Roell Tensile Strength Tester Z005 (CRE) with a 25 mm grip-to-grip separation and 5 kN load. Breaking strength (kg-force) and elongation (percentage) were recorded post-rupture.

Data Analysis

Descriptive statistics for fiber fineness, breaking strength, and elongation were provided by DOST-PTRI. Physical and mechanical property means were analyzed using two-way ANOVA to assess the effects of GA_3 concentration, application frequency, and their interaction. Tukey HSD post hoc tests identified significant differences between treatment means.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue V May 2025

RESULTS

This study evaluated the effects of GA_3 concentrations (0, 100, 300, 500 µg/mL) and application frequencies (once or twice weekly) on the physical (fiber length, fineness) and mechanical (breaking strength, elongation) properties of Sansevieria trifasciata fibers. The data were analyzed using two-way ANOVA and Tukey HSD post hoc tests, with key findings summarized below and detailed in Tables II–IV.

Fiber Length

Fiber length ranged from 35.16 ± 4.46 cm (0 µg/mL, twice weekly) to 39.84 ± 4.63 cm (300 µg/mL, once weekly), with single applications consistently producing longer fibers across all GA_3 concentrations (Table II). ANOVA confirmed that both GA_3 concentration and application frequency significantly influenced fiber length ($p < 0.001$ and $p = 0.001$, respectively), with no significant interaction ($p = 0.493$; Table III). Post hoc analysis showed that 300 µg/mL produced significantly longer fibers (39.33 cm, averaged across once- and twice-weekly applications) than 0 µg/mL (36.44 cm, $p < 0.001$) and 500 µg/mL (37.08 cm, $p = 0.007$). The 100 µg/mL treatment (37.71 cm) showed no significant difference from other treatments (Table IV). The high R^2 (0.990) indicates a robust model fit.

Fiber Fineness

Fiber fineness varied from 35.65 ± 4.55 denier (0 µg/mL, once weekly) to 44.62 ± 7.94 denier (100 µg/mL, twice weekly), with twice-weekly applications generally increasing coarseness, except at 500 µg/mL (Table II). ANOVA revealed a significant effect of GA_3 concentration ($p < 0.001$) and a significant interaction between concentration and frequency ($p = 0.006$), but frequency alone was not significant ($p = 0.175$; Table III). Tukey HSD tests indicated that 100 µg/mL (43.87 denier, averaged across once- and twice-weekly applications) produced significantly coarser fibers than 0 µg/mL (38.15 denier, $p < 0.001$), 300 µg/mL (39.50 denier, $p = 0.006$), and 500 µg/mL (40.40 denier, $p = 0.043$), with no significant differences among the latter three (Table IV). The high R^2 (0.971) supports a strong model.

Breaking Strength

Breaking strength ranged from 0.076 ± 0.033 kg-force (300 µg/mL, once weekly) to 0.219 ± 0.118 kg-force (0 µg/mL, once weekly), with twice-weekly applications generally enhancing strength, except at 0 µg/mL (Table II). ANOVA showed significant effects of GA_3 concentration ($p < 0.001$) and the interaction between concentration and frequency ($p < 0.001$), with frequency marginally non-significant ($p = 0.074$; Table III). Post hoc tests revealed that 300 µg/mL (0.110 kg-force, averaged across once- and twice-weekly applications) yielded significantly lower strength than 0 µg/mL (0.181 kg-force, $p < 0.001$), 100 µg/mL (0.191 kg-force, $p < 0.001$), and 500 µg/mL (0.161 kg-force, $p = 0.015$), with no significant differences among the latter three (Table IV). The R^2 (0.771) suggests additional factors may influence breaking strength.

Elongation

Elongation ranged from 4.33 ± 2.52% (300 µg/mL, twice weekly) to 8.45 ± 3.01% (100 µg/mL, once weekly), with single applications generally increasing elasticity, except at 500 µg/mL (Table II). ANOVA indicated significant effects of GA_3 concentration ($p = 0.029$) and frequency ($p = 0.001$), with no significant interaction ($p = 0.137$; Table III). Post hoc tests showed that 100 µg/mL (7.73%, averaged across once- and twice-weekly applications) significantly outperformed 300 µg/mL (5.85%, $p = 0.031$), with no significant differences among 0 µg/mL (6.27%), 500 µg/mL (6.12%), and other concentrations (Table IV). The R^2 (0.765) suggests other factors may affect elongation.

INTERNATIONAL JOURNAL OF RESEARCH AND SCIENTIFIC INNOVATION (IJRSI)
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue V May 2025

Table 2 Fiber Characteristics Under Different Ga_3 Concentration And Application Frequencies

GA_3 concentration	Frequency	Fiber Length (cm)	Fiber Fineness (denier)	Breaking Strength (kg-force)	Elongation (%)
0 µg/mL	Once	37.73 ± 3.25	35.65 ± 4.55	0.219 ± 0.118	7.33 ± 3.12
0 µg/mL	Twice	35.16 ± 4.46	40.65 ± 7.88	0.143 ± 0.089	5.22 ± 5.28
100 µg/mL	Once	38.17 ± 3.46	43.12 ± 5.57	0.177 ± 0.094	8.45 ± 3.01
100 µg/mL	Twice	37.26 ± 3.10	44.62 ± 7.94	0.204 ± 0.106	7.00 ± 3.56
300 µg/mL	Once	39.84 ± 4.63	38.20 ± 8.65	0.076 ± 0.033	7.37 ± 5.27
300 µg/mL	Twice	38.83 ± 4.72	40.81 ± 4.97	0.144 ± 0.094	4.33 ± 2.52
500 µg/mL	Once	38.26 ± 3.52	42.44 ± 8.40	0.128 ± 0.075	6.09 ± 2.94
500 µg/mL	Twice	35.89 ± 2.60	38.37 ± 8.08	0.194 ± 0.102	6.16 ± 3.00

Note: Values are mean ± SD; N = 30 per group.

Table 3 Two-Way Anova Results For The Effects Of Ga_3 Concentration And Application Frequency On Fiber Properties

Dependent Variable	Source	F	df	p-value	Partial η^2
Fiber Length	Gibberellic Acid Frequency Gibberellic Frequency	6.435 12.264 0.803	3 1 3	<0.001 0.001 0.493	0.077 0.050 0.010
Fiber Fineness	Gibberellic Acid Frequency Gibberellic Frequency	6.943 1.853 4.302	3 1 3	<0.001 0.175 0.006	0.082 0.008 0.053
Breaking Strength	Gibberellic Acid Frequency Gibberellic Frequency	9.156 3.223 7.965	3 1 3	<0.001 0.074 <0.001	0.106 0.014 0.093
Elongation	Gibberellic Acid Frequency Gibberellic Frequency	3.061 11.514 1.861	3 1 3	0.029 0.001 0.137	0.038 0.047 0.024

Note: R^2 = 0.990 (Fiber Length), 0.971 (Fiber Fineness), 0.771 (Breaking Strength), 0.765 (Elongation).

Table 4 Tukey Hsd Post Hoc Results For Ga_3 Concentration Effects On Fiber Properties

Dependent Variable	Comparison	Mean Difference	p-value
Fiber Length	0 µg/mL vs. 300 µg/mL 300 µg/mL vs. 500 µg/mL	-2.8900 2.2550	<0.001 0.007
Fiber Fineness	0 µg/mL vs. 100 µg/mL 100 µg/mL vs. 300 µg/mL 100 µg/mL vs. 500 µg/mL	-5.7205 4.3655 3.4635	<0.001 0.006 0.043
Breaking Strength	0 µg/mL vs. 300 µg/mL 100 µg/mL vs. 300 µg/mL 300 µg/mL vs. 500 µg/mL	0.0712 0.0806 -0.0508	<0.001 <0.001 0.015
Elongation	100 µg/mL vs. 300 µg/mL	1.8813	0.031

Note: Only significant comparisons ($p < 0.05$) are shown.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue V May 2025

DISCUSSION

This study elucidates the effects of GA_3 concentration and application frequency on the physical and mechanical properties of Sansevieria trifasciata fibers, revealing optimal conditions for fiber length, fineness, breaking strength, and elongation. These findings highlight GA_3's potential to enhance fiber quality, with implications for textile and composite applications, while also identifying trade-offs that require tailored treatment strategies.

Fiber Length

The longest fibers (39.84 ± 4.63 cm) were achieved with 300 µg/mL GA_3 applied once weekly, with single applications consistently outperforming twice-weekly applications. This likely reflects GA_3's role in promoting cell elongation with controlled hormonal stimulation, as single applications avoid overstimulation that may disrupt growth [35]. The significant effects of GA_3 concentration ($p < 0.001$) and frequency ($p = 0.001$), coupled with a high R^2 (0.990), confirm a robust model, though moderate effect sizes ($\eta^2 = 0.077$ for concentration, 0.050 for frequency) suggest other factors, such as plant age, influence length. Compared to mature S. trifasciata fibers (68.4–109.3 cm after 17–24 months) [12][13], the 9-month-old plants in this study produced shorter fibers, but GA_3 accelerated growth, aligning with its effects on other fiber crops like cotton and ramie [37][39]. These results suggest GA_3 can enhance fiber length in shorter cultivation cycles, improving productivity for textile applications [8][15].

Fiber Fineness

Fiber fineness varied significantly, with the finest fibers (35.65 ± 4.55 denier) in the control (0 µg/mL, once weekly) and the coarsest (44.62 ± 7.94 denier) at 100 µg/mL (twice weekly). The significant effect of GA_3 concentration ($p < 0.001$) and interaction with frequency ($p = 0.006$) indicates that repeated applications promote thicker fibers, likely due to increased cell division [35]. The high R^2 (0.971) supports a strong model fit. Finer fibers (lower denier) are ideal for soft textiles, while coarser fibers suit sturdier fabrics or composites [8][15]. The observed range (35.65–44.62 denier) aligns with prior reports of S. trifasciata fiber fineness (17.65–144 denier) [12][14] and mirrors mixed effects of GA_3 on cotton and okra fibers, where higher doses often coarsen fibers [37][38]. All fineness levels remain viable for industrial applications, but 100 µg/mL (twice weekly) may be preferred for robust textiles.

Breaking Strength

Breaking strength was highest in the control (0.219 ± 0.118 kg-force, once weekly) and 100 µg/mL (0.204 ± 0.106 kg-force, twice weekly), but significantly lower at 300 µg/mL (0.110 kg-force). The significant effects of GA_3 concentration ($p < 0.001$) and interaction with frequency ($p < 0.001$) suggest that twice-weekly applications enhance strength at lower concentrations, while 300 µg/mL may weaken fiber structure due to excessive cell elongation [8]. The lower R^2 (0.771) indicates that additional unmeasured factors, such as fiber chemical composition (e.g., cellulose or lignin content), influence strength. These findings align with GA_3's enhancement of okra and ramie fiber strength at moderate doses [38][39], and the control's strength (0.219 kg-force) falls within reported ranges (0.11–0.38 kg-force) [12][14]. Fibers treated with 100 µg/mL are suitable for durable applications like composites and packaging, while 300 µg/mL may compromise structural integrity [8][15][46].

Elongation

Elongation peaked at 100 µg/mL (8.45 ± 3.01%, once weekly), with single applications generally enhancing elasticity, except at 500 µg/mL. The significant effects of GA_3 concentration ($p = 0.029$) and frequency ($p = 0.001$), with no interaction ($p = 0.137$), indicate consistent benefits of single applications. The lower R^2 (0.765) suggests additional factors, such as fiber morphology, affect elongation. The observed range (4.33–

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XII Issue V May 2025

8.45%) aligns with prior reports (2.1–7.5%) [13][15] and GA_3's enhancement of elongation in ramie and cotton [36][39], though okra showed reduced elongation, indicating species-specific responses [38]. These elastic fibers are well-suited for flexible textiles, with 100 µg/mL optimizing this property.

Comparative Insights

The optimal GA_3 treatments vary by property: 100 µg/mL excels for fineness, breaking strength, and elongation, and performs well for length, while 300 µg/mL maximizes length but compromises strength and elongation. Single applications favor length and elongation, while twice-weekly applications enhance fineness and strength. Significant interactions for fineness and strength highlight complex dynamics, whereas the lack of interactions for length and elongation simplifies optimization. The lower R^2 for strength and elongation suggests unmeasured factors, such as fiber lignin content, warrant further study. Foliar GA_3 likely supplemented endogenous hormones, stimulating cell division and elongation [35], thus enhancing fiber quality. These results position 100 µg/mL (once or twice weekly) as a versatile treatment for textile and composite applications, with 300 µg/mL suitable for applications prioritizing length.

Future studies should explore GA_3 application at different growth stages and use structural analyses (e.g., scanning electron microscopy) to clarify its effects on fiber morphology. Longer treatment durations and commercial-scale trials could further validate S. trifasciata as a sustainable alternative to abaca in the Philippines.

CONCLUSIONS

This study demonstrates that GA_3 concentration and application frequency significantly influence the physical and mechanical properties of Sansevieria trifasciata fibers. A single application of 300 µg/mL GA_3 produced the longest fibers (39.84 ± 4.63 cm), driven by enhanced cell elongation, making it ideal for applications requiring extended fiber length. Conversely, 100 µg/mL GA_3 applied twice weekly maximized fiber fineness (44.62 ± 7.94 denier), suitable for robust textiles and composites. Breaking strength was highest in untreated fibers (0.219 ± 0.118 kg-force) and 100 µg/mL GA_3 (0.204 ± 0.106 kg-force, twice weekly), but 300 µg/mL significantly reduced strength, indicating a trade-off with length. Elongation peaked at 100 µg/mL applied once weekly (8.45 ± 3.01%), enhancing fiber elasticity for flexible textiles. These findings highlight that 100 µg/mL GA_3 optimizes fineness, strength, and elongation, while 300 µg/mL is best for length. Tailored treatments are necessary based on target properties for textile, composite, or packaging applications in the Philippines.

RECOMMENDATIONS

To further enhance S. trifasciata fiber quality, future studies should investigate GA_3 application timing across different growth stages, optimizing dosage (e.g., 100–300 µg/mL) and frequency for specific properties like length, fineness, or strength. Additionally, researchers should compare gibberellic acid treatment with other types of growth regulators, such as auxins or cytokinins, or alternative fiber treatments, such as enzymatic or heat treatments, to evaluate the effectiveness and advantages of GA_3 in enhancing fiber properties. Structural analyses, such as scanning electron microscopy, could elucidate GA_3's effects on fiber morphology. Furthermore, a dose-response study testing a broader range of GA_3 concentrations (e.g., 50–1000 µg/mL) and application methods (e.g., foliar spraying, soil drenching, or immersion) is recommended to identify the optimal treatment for maximizing fiber quality. Researchers should evaluate the performance of GA_3-treated fibers in textile and composite products, including fabrics, ropes, and biodegradable packaging, to confirm commercial viability. Farmers in regions unsuitable for abaca or pineapple cultivation should adopt S. trifasciata with GA_3 treatments (100 µg/mL, once or twice weekly, for fineness, strength, and elongation; 300 µg/mL, once weekly, for length) to promote sustainable fiber production in the Philippines. Pilot-scale trials are recommended to assess scalability and economic feasibility.

ACKNOWLEDGMENT

The author gratefully acknowledges the Department of Science and Technology-Philippine Textile Research Institute (DOST-PTRI) for providing analytical equipment and technical support. Special thanks are extended to the local community in Presentacion, Camarines Sur, for providing Sansevieria trifasciata plants and experimental space. The author also appreciates the guidance of academic advisors of Central Bicol State University of Agriculture – Graduate School in conducting the experiment.

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