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Original Research Article

Blending Residual Biomass of *Phytolacca americana* and *Tradescantia fluminensis*: Paper and Pulp Production and Characterization

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ABSTRACT

Phytolacca americana and *Tradescantia fluminensis* are among the most invasive alien species in Galician riparian forests. Management efforts to control their spread generate large volumes of biomass, which are typically discarded or burned. This study explores the potential of reusing that biomass in papermaking, creating sustainable blends, and supporting circular economy practices. Blends were prepared in five ratios (10 % - 90 %, 30 % - 70 %, 50 % - 50 %, 70 % - 30 %, 90 % - 10 %) and processed according to UNE EN ISO standards. The pulp was refined using a PFI mill at 10 % consistency (ISO 4149:1996), and drainability was measured via the Schopper-Riegler method (ISO 5267-1), increasing from 26ºSR in 90 % P. americana to 38ºSR in 90 % T. fluminensis. However, air resistance was highest in the 50 % - 50 % blend, due to the fiber structure. Grammage showed minimal variation (SD = 0.0068 g/m²), and thickness remained stable (variation = 0.01597 µm). Color and texture varied with composition, revealing potential for innovative and creative paper applications.

KEYWORDS

Invasive alien species, Phytolacca Americana, Tradescantia fluminensis, Papermaking innovation, Physic-mechanical properties, Circular Economy Systems.

INTRODUCTION

The increasing spread of Invasive Alien Plant Species (IAS) poses a critical ecological and economic challenge across the European continent [1], particularly in areas with good growing conditions, such as riparian forests, like those in Galicia, Spain, characterized by being wet and shady spaces. *Phytolacca americana* (American pokeweed) and *Tradescantia fluminensis* (wandering Jew) are two prominent IAS that have aggressively colonized those environments.

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Their growth often outcompetes native flora, disrupts ecosystem functions [2], and reduces local biodiversity [3]. In response, extensive vegetation clearance and control efforts have been implemented in those affected areas. However, these practices typically generate large volumes of biomass waste, which are frequently incinerated or left to decompose, offering limited environmental or economic return [4].

Recent developments in sustainable materials science [5] and circular economy principles have emphasized the potential of repurposing plant-based residues from invasive species as alternative raw materials for industrial processes [6]. One of the most resource-intensive industries with growing demand for alternative fibers is the paper and pulp sector [7], which has traditionally relied heavily on wood-based cellulose, often obtained through environmentally harmful monoculture plantations [8]. The exploration of non-wood fibers is not only ecologically motivated but also aligns with global efforts to decarbonize and diversify raw material sources for paper production [9].

Previous studies have examined the feasibility of using *Tradescantia fluminensis* biomass in papermaking [10], highlighting its structural characteristics and its ability to be integrated with commercial eucalyptus pulp and its high antioxidant content [11]. Although its fibrous network is less defined than traditional sources, its abundance and ease of collection make it an attractive candidate for local, low-impact papermaking. *Phytolacca americana*, on the other hand, presents robust stems and fibrous tissues that suggest high potential for integration into cellulose-based materials. The combination of these two species—each with distinct structural properties—may result in complementary blending effects, enhancing the mechanical or aesthetic properties of the resulting paper. Despite the coexistence of these species in riparian ecosystems and their simultaneous removal during management practices, their combined use as a complementary fiber system has not been sufficiently explored. Therefore, this study addresses a relevant research gap by investigating the potential of blending two invasive species with contrasting morphological characteristics, aiming to enhance both the mechanical and aesthetic properties of non-wood paper while promoting the valorization of locally available biomass.

Reutilizing invasive biomass for paper creation provides a multi-dimensional opportunity. Ecologically, it reduces the burden of waste disposal and supports biodiversity by incentivizing removal efforts. Economically, it transforms non-commercial waste into a value-added product. Culturally and creatively, handmade papers containing natural tones and textures from unbleached fibers provide aesthetic value for art, design, and education [12]. Moreover, using unbleached fibers like those from *Phytolacca americana* introduces organic chromatic and tactile qualities [13], differentiating such papers from industrial products and promoting storytelling around sustainable practices [14].

Finally, this study explores the potential of blending the biomass of both selected species, *Phytolacca americana* and *Tradescantia fluminensis,* to produce novel paper materials. By investigating the physical, mechanical, and morphological properties of these blends, we aim to determine the viability of this dual-species approach in pulp production. Blends were analyzed across various proportions, 90 – 10 %, 70 – 30 %, 50 – 50 %, 30 – 70 %, and 10 – 90 %, to identify optimal compositions in terms of grammage, thickness, drainability, permeability, and visual characteristics. These properties were evaluated according to standardized protocols (UNE-EN ISO), ensuring reproducibility and industrial relevance.

The integration of two distinct invasive biomasses into a single pulp matrix represents a novel contribution to the ongoing research on sustainable materials. Unlike previous studies that focus on single-species invasive biomass or blends with conventional industrial pulps, this work investigates, for the first time, the interaction between two invasive species as a standalone fiber system. This dual-species approach enables the exploration of complementary fiber behaviors and their influence on structural and functional paper properties, contributing novel insights into circular biomass valorization strategies. Furthermore, this paper seeks to go beyond technical feasibility and reflect on the broader socio-environmental implications of using neglected biomass for material innovation. By bridging ecological management with crafted and industrial repurposing, this work contributes to the growing movement toward sustainable circular production systems that recognize waste not as a liability but as a resource.

MATERIALS AND METHODS

The overall experimental procedure followed in this study is summarized in **Figure 1**, which illustrates the sequence from biomass collection and processing to handsheet production and physico-mechanical characterization. In the following sections, the whole process is detailed.

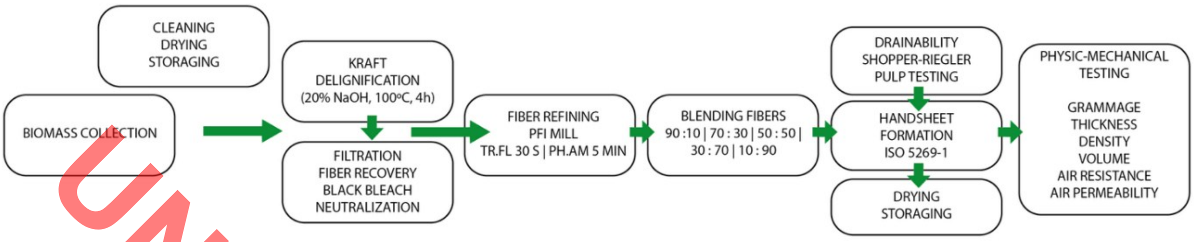

Figure 1. Process flow diagram of the experimental procedure for the production and characterization of paper sheets, including biomass preparation, chemical treatment, fiber refining, blending, sheet formation, and physico-mechanical testing

Selected species and harvesting area

The proposed study was developed within a specific territory in the riparian forest of the Umia River in Ribadumia, Galicia, Spain. This specific area, heavily affected by anthropogenic activities such as vineyards and agriculture, has contained the space of the riparian forest to a thin line of plant species between the river itself and a walking pathway. In this restricted area, pioneer species have proliferated, affecting and changing the autochthonal biodiversity of the river basin. According to Bermudez et al. [15], the most common native species in the area are Alnus glutinosa, Betula pubescens, Fraxinus angustifolia, Fraxinus excelsior, Salix atrocinerea, Populus alba, Malus sylvestris, Quercus robur, Castanea sativa, Corylus avellana, Laurus nobilis, Ilex auifolium, and *Sorbus aucuparia*. On the other hand, identified non-native species in the area of the Umia and Lérez rivers are Acacia dealbata, Acacia melanoxylon, Arundo donax, Phytolacca americana, Cortaderia selloana, Robinia pseudoacacia, and *Eucalyptus globulus*, where we include the *Tradescantia fluminensis* as an increasing presence in the territory. From this range of species, in this study, it has been decided to work specifically with *Phytolacca americana* and *Tradescantia fluminensis* as innovative biomass for papermaking. Previous studies [6,10] demonstrated the possible use of another of the named species for this same purpose, obtaining different paper materials with promising properties.

In the case of *Phytolacca americana* -using Ph.am as an abbreviation-, this species, native to North America, can be found in the Mediterranean region after the 17th century, introduced for its dying properties. As points, this species is considered naturalized in diverse regions, where it is possible to find specific common names for it, like in the case of Galicia, *Tintoreira* (which means, literally, with the capacity to dye). As a perennial herbaceous species, this plant is fast-growing and fast-adapting to different environments, which makes it extremely common to find it. Also, its seeds are usually distributed by birds, which allows it to take space in what is known as Third landscapes [16], like ruderal areas, abandoned urban environments, or the limits of cultivated fields.

On the other hand, *Tradescantia fluminensis* -using *Tr.fl* as abbreviation- is an herbaceous species characterized by creating wide-spreading carpets that take the space of most wet ecosystems. Native to South America, between Brazil and Argentina, this *Commelinaceae* species has rapid propagation and a high resistance to chemicals in controlling efforts. It was introduced and first registered in Galician territories in 1951, when it was included in the catalog of Invasive Plant Species of the Spanish Agriculture Ministry [17].

Biomass treatment and delignification

Once the species were identified and cataloged, samples were collected from the affected areas. Appropriate control measures and safety protocols were implemented throughout the collection process. To process the residual biomass and produce manufactured paper in accordance with UNE-EN ISO standards for paper and cardboard, the following protocol was established:

1. Biomass was collected from the designated plant sources identified in the preliminary study.
2. The collected biomass was thoroughly cleaned to remove impurities and subsequently dried to reduce moisture content.
3. A Kraft delignification treatment was carried out by applying caustic soda (NaOH) equivalent to 20 % of the biomass weight. Distilled water was added in sufficient quantity to fully cover the material. This process was conducted over a period of four hours using a gas cooking station in a controlled environment.
4. After digestion, the biomass was filtered to separate the fibers from the black liquor. The black liquor was safely stored for later pH neutralization procedures.
5. The cleaned fibers were dehydrated again and stored under appropriate conditions for subsequent use.
6. The following standards were applied to ensure consistency and reproducibility in the production of laboratory paper sheet samples:
   UNE-EN ISO 5263-1:2004 — *Pulps – Laboratory wet disintegration – Part 1: Disintegration of chemical pulps*
   UNE-EN ISO 5264-2:2011 — *Pulps – Laboratory beating – Part 2: PFI mill method*
   UNE-EN ISO 4119:1995 — *Pulps – Determination of stock concentration*
   UNE-EN ISO 5269-1:2005 — *Pulps – Preparation of laboratory sheets for physical testing*

Pulp refining and blend preparation

The previous protocol was established to conduct the tests presented in **Table 1**. Based on the findings of previous studies **[10]**, two refining times in the PFI laboratory beater mill were set: 5 min at 1200 rpm for the material from *Phytolacca americana* and 20 s at 1200 rpm for the *Tradescantia fluminensis* pulp. Both biomasses were processed separately in order to preserve their fiber properties.

Table 1. Refining times for each material, blend proportions, and drainability expressed in Schopper Riegler degree

Tests	Materials proportions		Refining times for biomass		Drainability of tests in °SR
	Ph. am	Tr. fl	Ph.am	Tr.fl	
A	90 %	10 %	5 min	30 s	26
B	70 %	30 %	5 min	30 s	26
C	50 %	50 %	5 min	30 s	35
D	30 %	70 %	5 min	30 s	35
E	10 %	90 %	5 min	30 s	38

Once refined, the pulp was prepared based on five different proportions, as presented in **Table 1**. The corresponding quantities of each refined biomass were established as follows: test A (90 % *Phytolacca americana* [Ph.am] – 10% *Tradescantia fluminensis* [Tr.fl]), test B (70 % Ph.am – 30 % Tr.fl), test C (50 % Ph.am – 50 % Tr.fl), test D (30 % Ph.am – 70 % Tr.fl), and test E (10 % Ph.am – 90 % Tr.fl); and consistency was maintained at 10 %, following UNE

EN USO 4119:1996 standard. According to these proportions, the properties of the developed materials changed, suggesting different potential uses and applications.

In relation to the pulp properties, once 10 % of consistency is assured, the drainability Schopper Riegler (ºSR) can be calculated to observe how the pulp in suspension releases water. This is directly linked to the refining times of the samples, along with specific mechanical properties of the fibers.

Handsheet formation and testing

Handsheets were formed using a conventional sheet former with a diameter of 16 cm, following the UNE-EN USO 5269-1:2005 standard. The obtained samples were dried, pressed, and stored to proceed with testing their properties.

Based on the tools and machinery present in the Wood Chemistry Lab at the School of Forestry Engineering, Campus of Pontevedra, Galicia, we decided to perform the following physico-mechanical tests to characterize the samples.

Grammage and weight (UNE-EN ISO 536:2012; UNE-EN ISO 3039:2013). Defined as: the mass of a unit area of paper or board, expressed in g/m².

This property is determined by measuring the mass of a paper or board sample and dividing it by its area. Grammage is a key parameter for characterizing the weight and thickness relationship of paper materials and is essential for quality control in the papermaking and printing industries.

Thickness, specific density, specific volume (UNE-EN ISO 534:2012; UNE-EN ISO 3034:2016). Defining thickness as the perpendicular distance between two surfaces of a single sheet of paper, it is measured under a specific pressure using a micrometer in order to determine the mechanical and printing properties of the paper. Apparent (specific) density is the ratio of the grammage and the thickness of the paper, expressed in (g/cm³). On the other hand, apparent (specific) volume is expressed in (cm³/g) and indicates how much space is occupied by one gram of paper.

Air permeability and air resistance measured according to the Gurley method (UNE-EN ISO 5636-5:2015). Air permeability is considered the volume of air that can pass through a delimited area of the surface of the paper, controlling the pressure and time. In the case of the Gurley method, this is expressed in seconds. Higher Gurley values and air resistance indicate lower air permeability, which is related to the porosity of the material.

RESULTS AND DISCUSSION

Pulp Drainability and Fiber Interactions

As shown in **Figure 2**, visual differences among the paper samples provide additional qualitative confirmation of the interactions between fibers. The sample on the top left, corresponding to 100 % *Phytolacca americana*, displays a lighter and more fibrous texture with noticeable porosity, supporting the lower ºSR drainability readings. In contrast, the bottom right sample, representing 100 % *Tradescantia fluminensis*, appears significantly darker and more compact, indicating a denser sheet structure that aligns with higher ºSR values and Gurley resistance times.

Moving from left to right across the samples A to E, there is a gradual darkening and reduction in visible surface porosity, consistent with an increasing proportion of *T. fluminensis* in the pulp blends. This visual progression reinforces the interpretation that higher concentrations of *T. fluminensis* contribute to more compact fiber networks, which both improve fiber bonding and decrease air permeability.

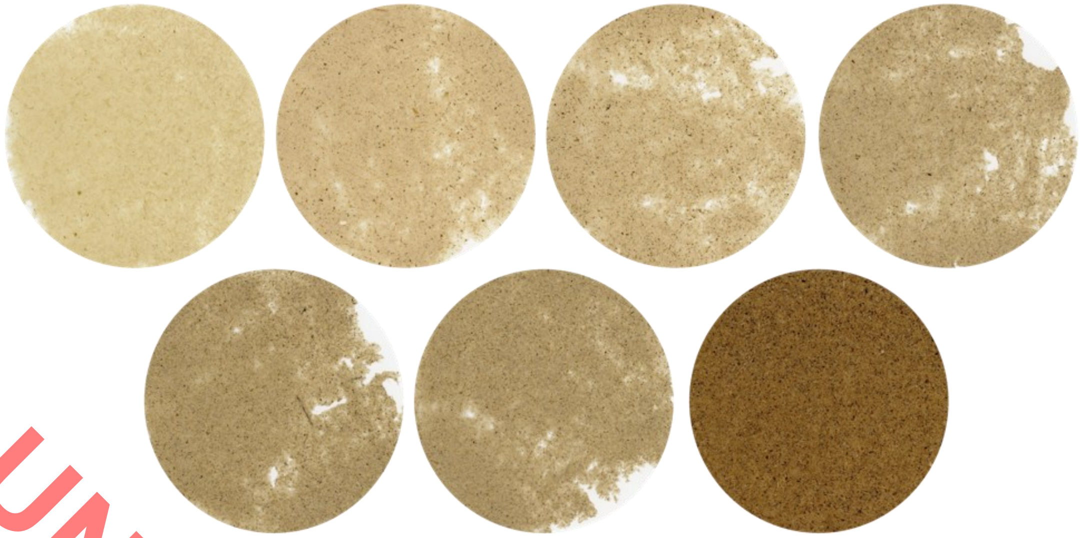

Figure 2. Different paper blends from control tests (100 % Phytolacca americana (top left) and 100 % Tradescantia fluminensis (bottom right) biomass) and, from left to right, tests A, B, C, D, and E

These observations suggest that fiber morphology not only affects measurable physical properties but also impacts the aesthetic and tactile qualities of the resulting paper,

Visualized in **Figure 3**, the Schopper Riegler degree shows a clear upward trend as the proportion of *Tradescantia fluminensis* increases in the pulp blend. Starting from a value of approximately 26 for the 90:10 *Ph. am/Tr. fl* ratio, the ºSR degree stabilizes around 35–38 for blends with higher *Tr. fluminensis* content. This confirms the initial observation that *Phytolacca americana* contributes to faster drainage due to its more open, fibrous structure, while *Tradescantia fluminensis* creates a denser network, slowing water release.

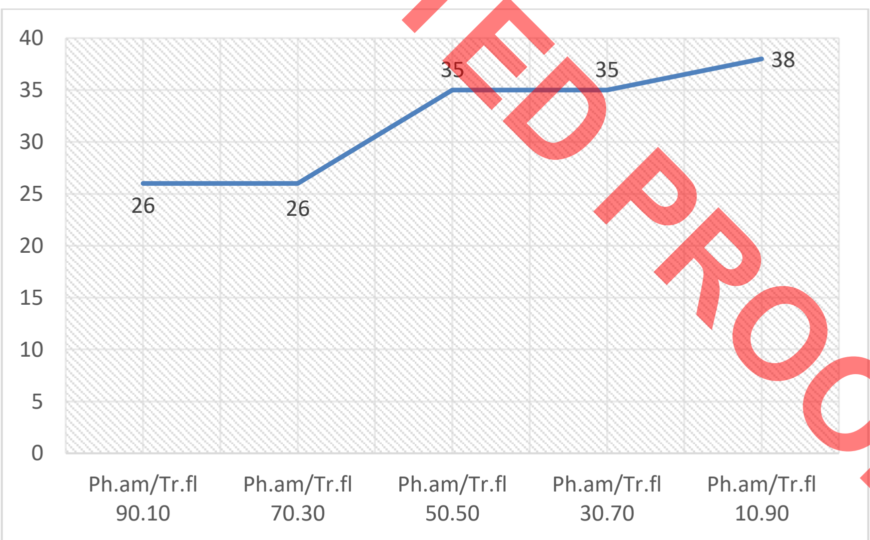

Figure 3. Drainability Schopper Riegler (ºSR) evolution in different blends from tests A-E

In terms of air permeability, represented in **Figure 4**, which inversely correlates with paper density, the material exhibits a non-linear behavior. Intermediate ratios (such as 50:50 and 30:70) demonstrate a stable decrement in air permeability, suggesting that these compositions result in compact structures while keeping the proportion of both biomass sources balanced. This finding implies a synergistic interaction between the two fibers at certain blend ratios, where the long and open *Ph. americana* fibers are effectively bridged by the shorter and denser *Tr. fluminensis* ones, minimizing voids in the sheet.

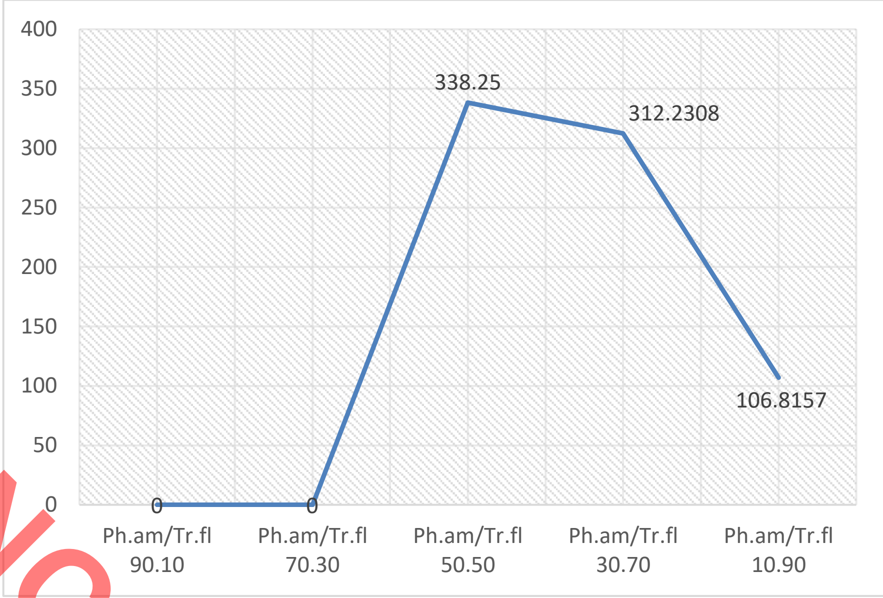

Figure 4. Air Permeability (µm/(Pa.s)) evolution in different blends from tests A-E

Supporting this, the Gurley Air Resistance data (**Figure 5**) reveals a clear increase in air resistance as the Tr. fluminensis content grows. This is most evident in the 70:30 and 90:10 blends (favoring Tr. fluminensis), which exhibit the highest Gurley times, indicating greater difficulty for air to pass through. This rise in resistance confirms the development of a tighter fiber matrix, aligned with the increase in °SR and the visual compactness observed in the paper sheets. In previous studies, it has been demonstrated that *Tradescantia fluminensis* handsheets have a great air resistance capacity, while Phytolacca americana doesn't. For this study, the best conditions are determined in intermediate states due to the balance between both biomass sources and material properties.

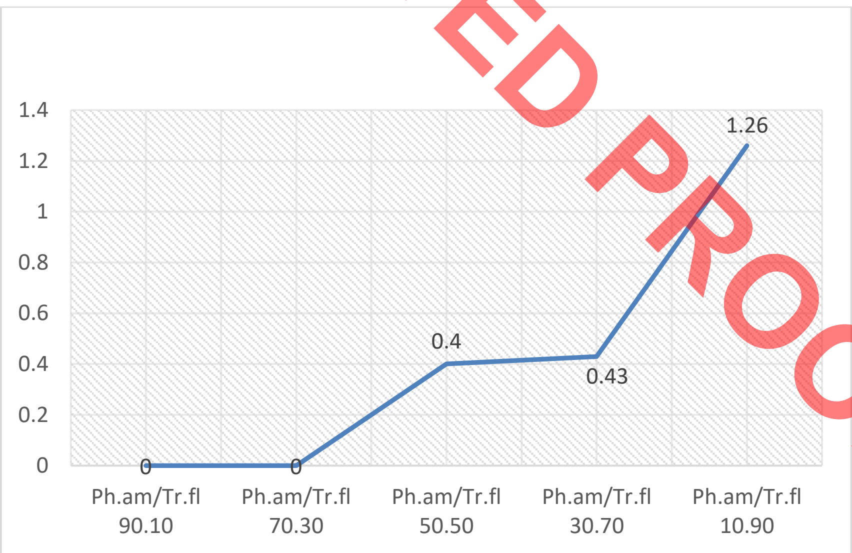

Figure 5. Gurley Air Resistance (s) in 300 cm^3 in different blends from tests A-E

Physical-Mechanical properties

The results presented in **Table 2** demonstrate how variations in biomass composition influence the physical and mechanical properties of the paper sheets. Test A, composed of 90 % *Phytolacca americana* and 10 % *Tradescantia fluminensis*, exhibits the highest weight at 0.51 ± 0.0643 g and a specific density of 0.847 ± 0.084 g/cm³, with the lowest specific volume of 1.181 ± 0.112 cm³/g. This suggests that the long and entangled fibers of *P. americana* promote tighter compaction, resulting in a denser and heavier sheet. As the proportion of *T. fluminensis* increases in Tests B to E, a trend of decreasing weight and density becomes evident. For instance, Test B (70:30) shows a reduction in weight to 0.41 ± 0.0203 g and density to 0.707 ± 0.043 g/cm³, with a corresponding increase in specific volume to 1.415 ± 0.087 cm³/g. This trend continues in Test E (10:90), which reaches the lowest density at 0.667 ± 0.046 g/cm³ and the highest specific volume of 1.498 ± 0.103 cm³/g, indicating that *T. fluminensis*-rich blends produce lighter and more voluminous sheets, likely due to its shorter, stiffer fibers contributing less to structural compaction.

Table 2. Physical-mechanical properties of Tests

Tests	Weight (g)	Gammage (g/m^2)	Thickness (mm)	Specific Density	Specific Volume
A	0.51±0.0643	0.129±0.007	0.152±0.118	0.847±0.084	1.181±0.112
B	0.41±0.0203	0.108±0.004	0.152±0.0001	0.707±0.043	1.415±0.087
C	0.43±0.0133	0.111±0.004	0.152±0.0002	0.731±0.049	1.368±0.089
D	0.45±0.0115	0.121±0.008	0.152 ± 2.12^{-06}	0.792±0.049	1.262±0.082
E	0.45±0.0252	0.102±0.007	0.152±0.00	0.667±0.046	1.498±0.103

Test C (50:50) represents a transitional point with a weight of 0.43 ± 0.0133 g, density of 0.731 ± 0.049 g/cm³, and specific volume of 1.368 ± 0.089 cm³/g, suggesting a moderately compact structure. Notably, Test D (30:70) deviates slightly from the downward density trend, reaching 0.792 ± 0.049 g/cm³ and a lower specific volume (1.262 ± 0.082 cm³/g) compared to Test C, which may indicate a more synergistic fiber interaction at this ratio, where the denser *T. fluminensis* matrix is effectively reinforced by the longer *P. americana* fibers.

The thickness across all samples remains constant at approximately 0.152 mm, with only negligible variation, indicating that observed differences in density and volume are due to internal fiber arrangement rather than variation in sheet formation.

As illustrated in **Figures 6** and **7**, while the grammage of the handsheets consistently declines with increasing *Tradescantia fluminensis* content—from 0.129 g/m² in Test A (90:10) to 0.102 g/m² in Test E (10:90)—the weight follows a similar descending trend, decreasing from 0.51 g to 0.45 g, with a dip to 0.41 g in Test B (70:30). This decline reflects a reduction in the total fiber mass per sheet, likely due to the less fibrous and finer nature of *T. fluminensis*, which contributes less material volume during sheet formation.

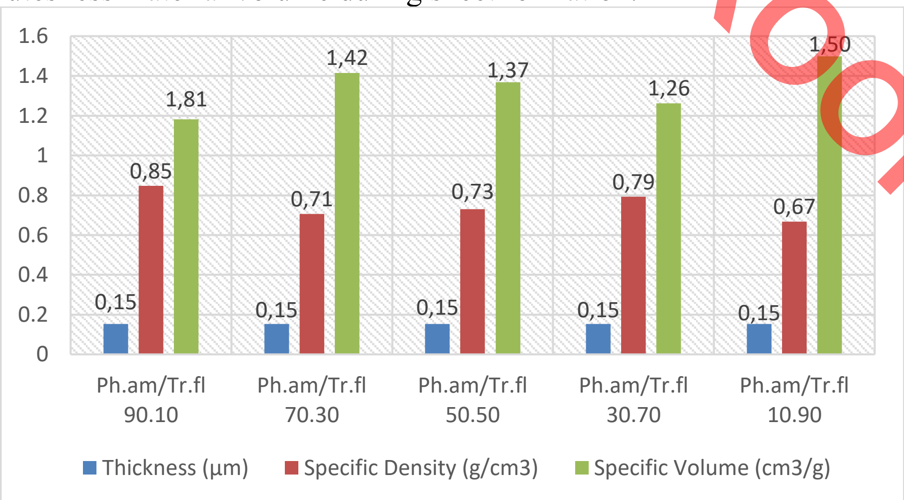

Figure 6. Relation-evolution of Thickness (μm), Specific Density (g/cm³) and Specific Volume (cm³/g) in different blends from tests A-E

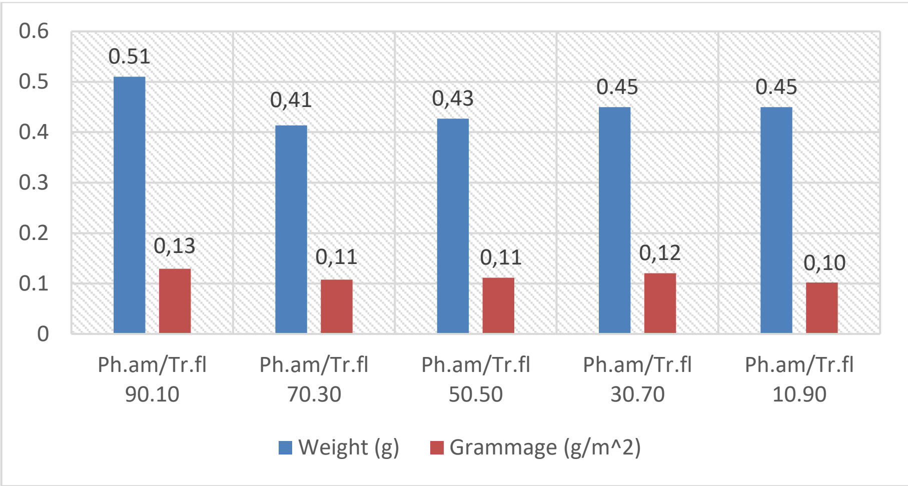

Figure 7. Relation between Grammage (g/m^2) and Weight (g) evolution in different blends of handsheets from tests A-E

Interestingly, despite the reduction in mass and surface loading, thickness remains remarkably consistent across all samples (as shown in **Figure 6**), averaging approximately 152.36 µm, indicating that volumetric differences are not attributed to changes in caliper but to internal sheet porosity and compaction. This uniform thickness, coupled with variations in specific density and specific volume, reinforces the idea that *Phytolacca americana* contributes to a more compact internal structure, while *T. fluminensis* introduces increased void space. The specific density drops from 0.847 g/cm³ in Test A to 0.667 g/cm³ in Test E, while specific volume rises from 1.181 cm³/g to 1.498 cm³/g, clearly visualized in **Figure 6**.

As the percentage of *Tradescantia fluminensis* pulp in the blend is increased, the grammage of the paper tends to decrease, producing thinner surfaces with less fiber (**Figure 7**). This behavior can also be observed in **Figure 6** in relation to specific density and specific volume. As the pulp of *Phytolacca americana* is reduced in the blend, we obtain lower densities and higher volumes, but in the case of intermediate blends of 50-50 % of each material, the properties seem to be balanced. On the other hand, the thickness of the handsheet remains constant at 152.36 µm on average.

Internal structure of different blends

In addition to tests performed in the installations of the Wood Chemistry Lab of the School of Forestry Engineering, the internal structure of the papers was studied to observe their fiber properties and distribution. To do so, Scanning Electron Microscope images were taken at the CACTI (Center for Scientific and Technical Help) at the Universidade de Vigo. Tests demonstrated that the average size of *Phytolacca americana* varies depending on the surface of the paper. As it is possible to appreciate in **Table 3**, we can observe thicker fibers in test A, as it presents the highest percentage of Phytolacca biomass. In each sample, the thickness of fibers decreases as the percentage of this specific biomass decreases.

Table 3. *Phytolacca americana* fibers evolution in different tests

Test	Fiber thickness (µm)
A	13.27±7.37
B	9.64±2.46
C	8.44±3.36
D	8.01±2.46
E	7.08±2.08

On the other hand, as it is possible to observe in **Figures 8**, **9**, and **10**, the paper becomes denser as the amount of Tradescantia fluminensis pulp in the blend increases. This has been proven to be directly related to the air resistance properties of paper.

Although after analyzing the results, it is not possible to determine an ideal ratio for the paper blend, experiments demonstrate that combining the two materials can indeed yield innovative products. Because the blend proportions subtly influence the paper's physical characteristics, each formulation may be better suited to different end-use applications, and more research could be conducted to highlight those desired applications.

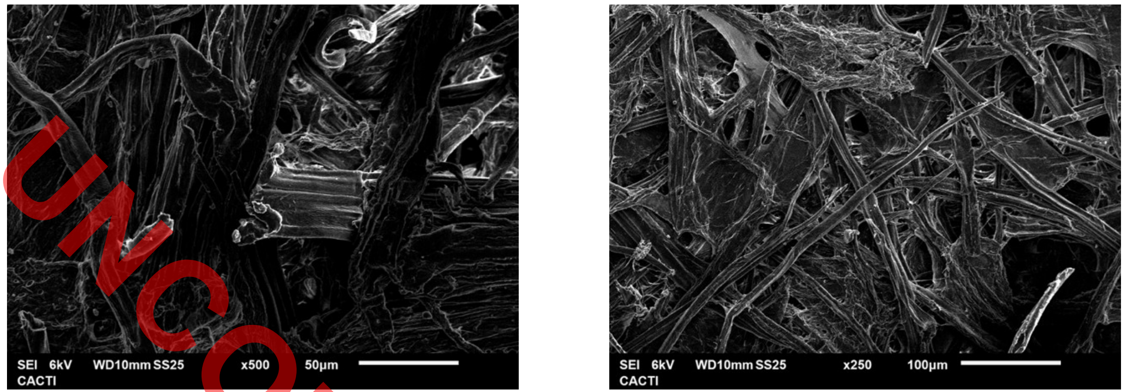

Figure 8. SEM image (Electron Microscope Visualization) of the internal structure of a sample made from (Left) 90 % of *Phytolacca americana* pulp and 10 % of *Tradescantia fluminensis* pulp. (Right) 70 % of *Phytolacca americana* pulp and 30 % of *Tradescantia fluminensis* pulp

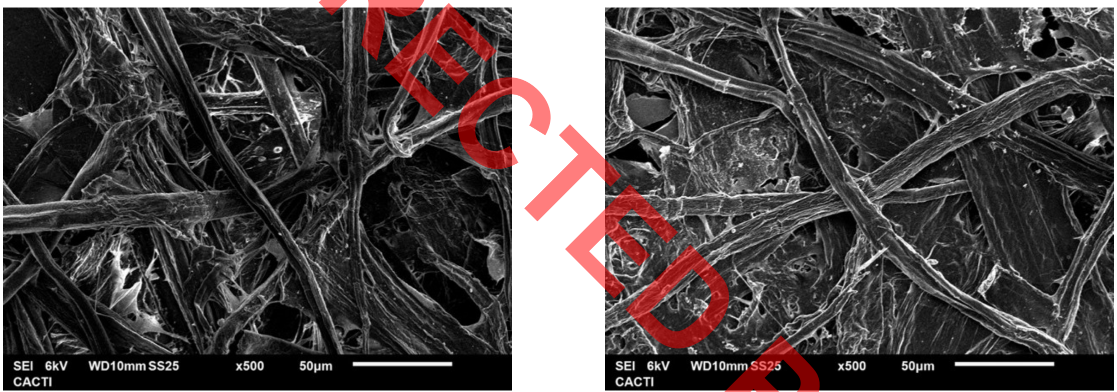

Figure 9. SEM image (Electron Microscope Visualization) of the internal structure of a sample made from (Left) 50 % of *Phytolacca americana* pulp and 50 % of *Tradescantia fluminensis* pulp. (Right) 30 % of *Phytolacca americana* pulp and 70 % of *Tradescantia fluminensis* pulp

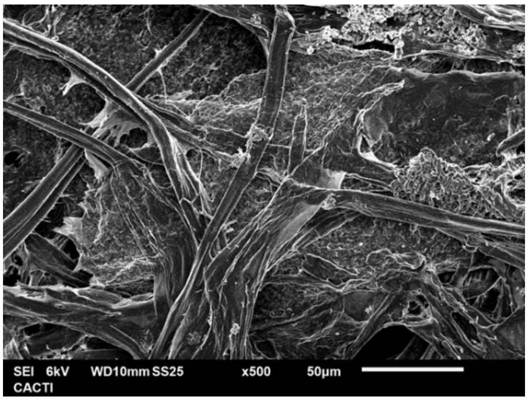

Figure 10. SEM image (Electron Microscope Visualization) of the internal structure of a sample made from 10 % of *Phytolacca americana* pulp and 90 % of *Tradescantia fluminensis* pulp

Implications for sustainability and process scalability

Beyond the technical feasibility demonstrated, the proposed approach presents relevant implications from both environmental and process perspectives. The valorization of biomass derived from invasive alien species such as *Phytolacca americana* and *Tradescantia fluminensis* contributes to reducing the environmental burden associated with their management. In particular, the reutilization of this biomass diverts material from common disposal practices such as incineration or uncontrolled decomposition, while simultaneously supporting ecosystem restoration by creating an incentive for systematic removal in riparian environments [5,6]. By integrating both species in order to complement properties, it is possible to reduce the need for monoculture-originated fibers and to propose that most fibers are suitable for papermaking.

From a resource efficiency standpoint, the use of locally available, non-commercial biomass aligns with circular economy principles by transforming an ecological liability into a value-added raw material. This approach may be particularly relevant at regional scales, where the abundance of invasive species can provide a consistent feedstock for small- to medium-scale production systems in a small collection area [7,14]. In addition, the aesthetic and structural variability observed across different blending ratios suggests potential applications in niche markets such as art, design, and specialty papers, where material uniqueness is highly valued.

However, several challenges must be addressed to consider the scalability of the process. The Kraft delignification treatment employed in this study, involving relatively high chemical loading and processing time, represents a limitation in terms of energy and reagent consumption. Although the laboratory-scale protocol included the recovery and storage of black liquor for subsequent neutralization, further optimization would be required to implement efficient chemical recovery systems at a small industrial scale. Moreover, the distinct morphological characteristics of the two species necessitate differentiated refining conditions, which may complicate process standardization and increase operational complexity.

In relation to these limitations, it is important to acknowledge that the objective of this study is not to develop a fully optimized large-scale production system, but to contribute to a broader rethinking of how materials such as paper can be produced from locally available and underutilized resources. This perspective emphasizes the potential of decentralized and circular production models, where ecological management and material innovation are closely interconnected.

In this context, future research should focus on optimizing pulping conditions to reduce chemical inputs, exploring alternative low-impact delignification methods, and evaluating the overall environmental performance of the system through Life Cycle Assessment (LCA). Additionally, techno-economic analyses would be required to assess the feasibility of scaling up this approach and integrating it into existing pulp and paper local production frameworks.

CONCLUSIONS

This study demonstrates the potential of blending *Phytolacca americana* and *Tradescantia fluminensis* biomass for the production of sustainable paper sheets with tunable physical properties. The interaction between these two fiber types significantly influenced the drainability, structural compactness, and air-related properties of the resulting handsheets. Drainability tests confirmed that increasing the proportion of *T. fluminensis* resulted in higher water retention during sheet formation, while *P. americana* contributed to faster drainage due to its more porous and fibrous structure. Intermediate blends offered an optimal balance of air permeability and resistance, highlighting a synergistic behavior between both fiber types. Physicomechanical characterization showed that while sheet thickness remained constant, variations in weight, grammage, and internal structure allowed for the production of both dense and lightweight papers depending on the blend ratio. Papers with higher *P. americana* content exhibited increased density and weight, while those richer in *T. fluminensis* were lighter and more voluminous. The introduction of pulp from *Tradescantia fluminensis*, a fundamentally dense and binding-rich material, acted as a structural enhancer within *Phytolacca americana*-based pulps. This combination enabled the creation of thinner and lighter sheets with improved air resistance, maintaining performance while reducing material input. These findings open the door for further optimization of fiber consistencies and blend ratios, especially for applications in the creative industries, where aesthetics, sustainability, and material innovation intersect. However, further research would be needed to refine the pulp consistencies and adapt the conventional standards to the specifications of innovative materials. Optimizing these parameters would enable the production of more uniform and stable handsheets, reducing issues like surface holes and structural irregularities, even with lower fiber density.

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