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SUSTAINABLE INNOVATION IN LOCAL COMMUNITIES: USE OF PINE ACICLES SPP. IN HANDMADE PAPER PRODUCTION

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Abstract: The introduction of exotic species of the genus Pinus spp. is widely practiced due to their rapid growth rate, adaptation to different climatic conditions and favorable qualities for wood production. However, the management of these plantations generates large volumes of waste, such as acicles (pine leaves). This study, conducted in the municipality of Canela, RS, used an action-research approach to evaluate the potential of acicles in handmade paper production, promoting empowerment and sustainable development in the Santa Marta community. The research involved collecting the material in the rural area of Tubiana and holding workshops with 250 participants, including women, teenagers and children, at the Padre Franco - Dom Luiz Guanella Social Center. The objectives included testing the viability of acicles as a raw material, analyzing discourses to understand participants' perceptions, evaluating possibilities for expanding the activity and developing technical products to disseminate the results. The methodology included discourse analysis and environmental education practices. The results indicated that the inclusion of acicles is feasible, resulting in good quality handmade paper. Opportunities were identified to exploit the physical characteristics of acicles in the paper industry, although further studies on their chemical properties are needed.
Keywords: Forest waste; Environmental education; Craft production; Social empowerment; Craft workshop.

INTRODUCTION

Modern times demand innovative strategies that promote empowerment and sustainable development in peripheral communities, often marked by complex social challenges. In this scenario, the introduction of exotic species such as Pinus spp. is widely practiced, driven by their rapid growth rate and climatic adaptability (Ceccagno, 2016; Osaki, 1988). However, the management of these plantations results in the generation of large volumes of waste, such as acicles (pine leaves), which are often underutilized and have a potential environmental impact (Ceccagno et al., 2018; Morais *et al.*, 2005).

This article presents the results of an action research project carried out in the municipality of Canela, RS, which explored the use of Pinus spp. acicles in the production of handmade paper. The proposal combines technological innovation with environmental sustainability and community empowerment, promoting a circular economy in local contexts (Kamm; Gruber; Kamm, 2006; Spink; Menegon; Medrado, 2014). The research focused on the sustainable collection of acicles and their incorporation into paper craft workshops held in the Santa Marta community, with the participation of women, adolescents and children.

By integrating the tradition of artisan workshops with the innovative use of acicles, this research seeks to strengthen the pillars of environmental and social sustainability, demonstrating the potential for replicating this approach in other communities facing similar challenges (Ceccagno, 2009; Osaki, 2018).

The local context of Canela, with a consolidated wood production chain, was strategic for the study, allowing the exploitation of forest residues as an input for innovation and social inclusion (Barbosa et al., 2019; Mengue, Beroldt, 2022).

The general objective of the study was to evaluate the potential of acicles as a raw material for handmade paper production, and the specific objectives were to test the technical effectiveness of the material, analyze the participants' speeches, identify opportunities for expansion and develop technical products to disseminate the results.

STUDY AREA

The municipality of Canela, RS, was chosen as the research site because it has a solid connection with the wood production chain, favorable soil and climate characteristics and a geographical location close to large urban centers. The municipality's differential lies precisely in the completeness of its wood chain, which ranges from the production of seedlings for the establishment of monocultures to the international export of furniture and, in the past, federal political incentives established the ideal conditions for the significant development of this production chain.

The practical phase of the action research used the facilities of the Centro Social Padre Franco - Dom Luiz Guanella Institution, located in the Santa Marta neighborhood, in the southwestern region of the municipality of Canela. The choice of institution resulted from the availability of suitable physical space for the experiment, considering factors such as: access, availability of energy and water and good conditions for adapting the space to accommodate the storage, processing, production and warehouse areas.

METHODOLOGICAL PROCEDURES

The action research methodology was adopted to investigate the feasibility of using Pinus spp. acicles in handmade paper production. The approach combined qualitative and quantitative methods to integrate traditional and technological aspects, allowing for a comprehensive analysis of the application of the residue as a raw material.

COLLECTION AND PREPARATION OF ACICLES

The acicles of *Pinus taeda* spp. were collected systematically in Tubiana, a rural area of Canela, RS. The collection area was delimited at 25 m x 25 m, ensuring a constant and sustainable supply. The acicles, in their mature phase, were selected based on criteria such as absence of impurities and good conservation. After collection, the material was transported and stored in an appropriate place for later use in the workshops (Figure 1).

Figure 1 - Storage of acicles at the production site
Source: Authors' personal archive

RUNNING THE WORKSHOPS

The practical part of the study took place at the Padre Franco - Dom Luiz Guanella Social Center, in the Santa Marta neighborhood. The space was adapted to host the activities, with areas for the storage, processing and production of handmade paper. The workshop involved approximately 250 participants divided into groups, with weekly meetings in the morning and afternoon.

ACTIVITY DEVELOPMENT

The artisanal production process followed the steps described:

1. GRINDING AND PREPARATION OF THE BIOMASS:

The acicles were processed manually to facilitate incorporation into the paper pulp (Figure 2).

Figure 2 - Manual processing of acicle reduction

Source: Authors' personal archive

2. PREPARATION OF PAPER PULP:

Recycled paper (Figure 3A) was homogenized with natural additives such as cellulose or starch to improve the characteristics of the final product. In this case, solid-state flocked cellulose fibers were added (Figure 3B).

During this stage, the influence of adding different proportions of acicles to paper pulp on reducing the need for cellulose or corn starch was tested. Trials were carried out varying the proportions, and an experimental ratio of 1 kg of acicles to 40 g of cellulose (equivalent to two tablespoons) was defined, in combination with the pulp of paper. This ratio was sufficient to produce approximately 50 sheets of paper, while maintaining the desired quality of the final material.

Figures 3- Preparation of paper pulp and incorporation of cellulose fiber

Where: A - Homogenization of recycled paper; B - Cellulose fibers flocked in a solid state.

Source: Authors' personal archive

3. MODELING AND DRYING:

The pulp was molded in frames with fine screens (Figure 4), followed by drying in a ventilated environment (Figure 5).

Figure 4 - Shaping the handmade sheet of paper

Source: Authors' personal archive.

Figure 5 - Drying stage of the handmade paper sheet

Source: Authors' personal archive

After the drying process, a visual and tactile inspection of the sheets of paper was carried out to assess the quality of the material produced. This stage included identifying possible variations in texture, thickness or tone, which are inherent to the handmade process. No adjustments were made to correct these characteristics, considering the methodological proposal to value the authenticity and uniqueness of handmade paper in contrast to standardized industrial processes.

ANALYTICAL AND STRATEGIC TOOLS

To support the analysis of the results, the following were used:

- **Discourse analysis**: This was based on Bardin (2011), in order to explore the perceptions and narratives of the participants during the process.

- **SWOT Matrix**: Used to assess the project's strengths, weaknesses, opportunities and threats, guiding the strategies for the workshop.

THEORETICAL REFERENCE

The theoretical framework covers a wide range of authors, including Spink, Menegon and Medrado (2014), who highlight workshops as spaces for co-creation and exchange, Thiollent (2011), who defines action research as a participatory method that involves participants as subjects and objects of the investigation. Barbosa et al. (2019) present the characteristics of the waste investigated (Table 1).

The table presented describes the chemical composition of different *Pinus spp*. residues, including wood, bark, acicle and pine cone, focusing on parameters such as moisture, extractives, holocellulose and lignin, in their soluble and insoluble fractions. The study by Barbosa (2019) investigates these chemical properties, providing relevant information on the use of this waste. Acicula, in particular, stands out in the study due to its high extractive content, which makes it a resinous material with great commercial potential for the production of different compounds. In addition, it has 7.10% moisture and 55.07% holocellulose, placing it in an intermediate position among the other *Pinus* residues in terms of carbohydrate compounds.

Acicula's main distinguishing feature, however, is its high lignin content, with 34.70% total lignin, made up of 5.32% soluble lignin and 29.38% insoluble lignin. This chemical profile gives the acicula remarkable characteristics, especially due to its higher lignin concentration when compared to wood. The significant presence of insoluble lignin suggests that acicula has greater resistance to decomposition, making it a valuable material for applications in sustainable processes, such as the production of filters or biomass. In addition, acicula has great potential to be exploited in biotechnology, composting and other industrial applications that take advantage of its compounds, as highlighted by Sheldon (2014), reinforcing the added value of this waste in the environmental and industrial context.

	Humidity (%)	Extractives (%)	Holocellulose (%)	Soluble lignin (%)	Insoluble lignin (%)	Total lignin (%)
Madeira	5,14	3,63	71,86	0,50	23,62	24,12
Bark	4,61	3,61	49,90	2,45	43,96	46,41
Acicle	7,10	7,37	55,07	5,32	29,38	34,70
Pine cones	10,18	3,61	59,30	1,6	34,95	36,55

Table 1 - Chemical properties of residual *Pinus elliotti var*

Source: Barbosa *et al*, 2019

At this point, it is important to highlight the importance of lignin, the aforementioned composite, which Barbosa *et al.* (2019) refer to as a macromolecule that provides paper with superior strength. The authors also report that this substance can be found in Lignin is abundant in the fibers of various coniferous species and in types of paper, such as brown paper and cardboard, both of which are known for their durability and a certain darker hue indicating that they contain a higher proportion of lignin. According to the authors Kamm and Gruber; Kamm (2006), lignin can be transformed into various high-value by-products, such as natural binders and adhesives, in processing plants such as bio-refineries. Corroborating them, authors Hubbe and Bowdel (2009) write that handmade papermaking has evolved over 2,000 years, influencing modern papermaking technology and re-emerging as a traditional craft and art form, providing insights for modern applications involving cellulosic fibers".

It is also worth mentioning a definition of paper based on Souza (2019), as being a compound of plant origin obtained from the artificial juxtaposition of cellulose fibers. This statement suggests that the chemical composition of paper varies according to the type of plant used, but for the purposes of understanding, it can be considered to be a formula made up of common substances that make up paper and which, when characterized after manufacture, are mostly lignin, cellulose and hemicellulose. Minor constituents include minerals, proteins, fatty acids and resin acids.

The emerging literature on the components of paper, compared to the existing literature on the properties of acicles, suggests that the introduction of acicles can confer additional positive properties to paper (Ceccagno, 2009; Bechara, Reis and Trentin (2014); Ceccagno *et al.*, 2018; Osaki, 2018). Therefore, the convergence between the tradition of artisanal paper workshops and the innovation provided by pine acicle additives takes a step forward towards a more sustainable approach. This integration tends to strengthen the pillars of environmental sustainability and social development, and point to a future where communities can thrive in a balanced way, using the available resources efficiently and respecting the limits of their environment as long as monocultures remain.

RESULTS AND DISCUSSIONS

CHARACTERIZATION OF ACICLES: GETTING TO KNOW THE RESIDUAL

In line with the nature of the waste under analysis and of handmade paper production, the study focused on the details and essential requirements for setting up a workshop, conceived as a research tool, as mentioned by Spink, Menegon and Medrado (2014). This phase involved analyzing the raw material, applying traditional production techniques, as well as exploring possible technological innovations that could harmoniously complement the craft process.

For contextualization purposes, the genus *Pinus* belongs to the *Pinaceae* family, a group of species that have characteristics such as: trees of variable height with a tendency to be tall and monoecious[1], leaves of two types: the scaly and deciduous[2]; and the aciculiform, long and generally appearing in fascicles of 2 to 5 acicles, usually 3, attached to short lateral branches by narrow internodes, defining the insertion of the leaves in bundles. (Lima *et al.,* 1988; Morais *et al*., 2005). Figure 6 shows the stages of acicle maturation.

These materials are produced in large quantities during the species' growth cycle. Some studies have been found on their use in by-products. These by-products are used, for example, in the development of seedlings[3] of corn, lettuce and black tar (Sartor et al, 2009); as energy potential (Muñiz et al., 2014); substrate conditioner (Iceri and Bellote, 2009; Abreu et al., 2010; Ceccgano, 2016); citrus rootstock (Ceccagno, 2009; Ceccagno et al., 2018; Osaki, 2018); essential oil for fungal control (Canonico, 2021); in acoustic panels (Clarin, 2023) and in the covering of driveways (Mengue and Beroldt, 2022; Mengue, Souza and Martins, 2023).

CHARACTERISTICS OF THE PAPER, PRODUCT OF THE WORKSHOPS

The tests carried out showed satisfactory results, producing good quality paper. There was a significant increase in the strength of the sheets after incorporating the acicles, showing the contribution of this material to the structural strength of the paper. However, the sheets produced with acicles added in their natural form, i.e. without any prior processing, showed slightly lower quality, attributed to the partial adhesion of the fibers to the pulp (Figures 7A and 7B). Despite this technical limitation, the results did not compromise the final aesthetics of the material, which maintained its unique and attractive visual characteristics.

Figures 7A and 7B - Images of the sheets of paper with acicles not adhered to the pulp.

Source: Authors' personal archive

Figure 8 shows some of the characteristics of the paper produced during the workshop, made from the careful application of the experimental steps described in the tutorial available at the following link: https://online.fliphtml5.com/mntoi/cnuo/#p=1

As can be seen in Figure 8, the material obtained has attributes such as structural consistency, significant durability and ease of handling, characteristics that make it ideal for use in the development of new products.

1. Monocots are beings that have male and female sexual organs coexisting in the same individual, thus producing both female and male gametes.

2. A deciduous plant is one that loses its leaves in a certain season, usually in the colder months.

3. Seedling - Plant embryo that has already developed and is still enclosed in the seed, or newborn plant.

Figure 6- Stages of acicle maturation

Source: Authors' personal archive

Figure 8 - Paper produced in the workshop

Source: Authors' personal archive

The introduction of *Pinus spp*. acicles in handmade paper production has proven to be an effective strategy for promoting sustainable practices and mitigating environmental impacts. The use of this abundant raw material has been associated with the reduction of forest waste and the creation of a good quality craft product, contributing to the circular economy (Osaki, 1988). In addition, the workshops fostered ecological and social awareness, strengthening environmental preservation practices in a peripheral community (De Andrade; Militão, 2023).

SWOT ANALYSIS

The SWOT analysis highlighted key aspects for the implementation of the paper craft workshop, identifying its strengths, weaknesses, opportunities and threats.

1. Strengths: - Abundant availability of acicles in the region; - Ability to add a different aesthetic component to the paper, promoting environmental awareness.

2. Weaknesses: - Limited infrastructure and gaps in participants' technical skills; - Initial financial restrictions on the purchase of equipment and supplies.

3. Opportunities: - Growing demand for sustainable and differentiated products in the craft market; - Possibility of establishing strategic partnerships with local industries.

4. Threats: - Competition with industrialized products and variability in the seasonal supply of acicola.

The SWOT analysis guided adjustments to the strategies during the execution of the workshops, allowing for continuous improvements and maintaining the relevance of the project (Conforto; Amaral; Silva, 2011).

SUBTEXTS AND DISCOURSE ANALYSIS

Discourse analysis revealed socio-economic and cultural challenges faced by participants. Comments collected during the workshops indicated barriers such as:

1. Structural dependence: Participants expressed fears about autonomy, with statements such as "I just do what I'm told to do, I don't question much."

2. Gender norms: The expectation that certain activities were "men's work" discouraged some women from actively participating.

3. Lack of belonging: Statements such as "I don't know if I really belong here..." reflected the alienation of some participants, often associated with socio-economic status.

These challenges reinforce the need for inclusive strategies to strengthen the social integration and self-confidence of those involved (Spink; Menegon; Medrado, 2014).

SOCIAL AND ECONOMIC IMPACTS

The workshops not only promoted the development of practical skills, but also generated positive impacts aimed at the financial empowerment and environmental awareness of the community.

The production of handmade paper made it possible to sell sheets, with the proceeds going to the participants in the form of food parcels. With regard to environmental issues, there was a noticeable increase in the community's environmental awareness, evidenced by changes in the participants' vocabulary, analyzed in two word clouds.

REPLICABILITY POTENTIAL

The sustainable and artisanal approach has proven viable for replication in other communities. The workshop's flexibility to incorporate local cultural and historical elements was identified as a competitive advantage. In addition, the integration of acicles into the paper biomass revealed technical challenges, such as uniformity in fiber distribution and final paper quality. Despite this, the overall results indicate significant potential for replication in different regional contexts.

PERCEPTION OF COOPERATIVE CREATION

The survey identified interest on the part of 58% of women and 26% of teenagers in forming a paper craft cooperative. The low rates among managers (12%) and monitors (4%) indicate the need to raise awareness about the cooperative model and its advantages.

MAIN CONTRIBUTIONS, IMPACTS AND CHALLENGES OF THE RESEARCH

The research showed that the handmade paper workshop, using *Pinus spp*. acicles, is an innovative initiative with significant impacts in the technical, social, economic and environmental spheres. The use of acicles as a raw material for the production of handmade paper proved to be technically feasible, resulting in a good quality product suitable for the creation of new items. In addition, the process highlighted the potential for reusing forestry waste, helping to reduce the environmental impacts of managing Pinus spp. monocultures. This sustainable process not only reduced the pressure on natural resources, but also offered a practical solution for reusing forestry waste that would otherwise have been discarded.

Socially, the workshop played a significant role in promoting environmental awareness, integrating Environmental Education practices and reinforcing the importance of responsible use of natural resources. It also created an inclusive environment where participants' self-esteem and sense of belonging were strengthened, especially among women in situations of social vulnerability. This social empowerment was essential for the transformation of the communities involved, providing a space for the expression of voices that are often marginalized.

The methodology used also showed potential for replication, and could be adapted to different contexts and communities with ac-

cess to similar waste. The integration of local cultural and historical elements into the handicraft process ensured greater identity and relevance to the production, reinforcing the link between local tradition and environmental innovation.

In addition, the research resulted in important technical products, such as the practical tutorial "**Make your handmade paper from pine cones" and the website (www.alicaodopinus.com),** which document the process and the results achieved, broadening the impact of the initiative and promoting the dissemination of the knowledge generated. These resources make it easier to replicate the workshop in other locations and provide a solid basis for future initiatives.

Despite the significant results, the research revealed some important challenges that need to be addressed to ensure the continuity and expansion of the initiative. One of the main points identified was the need for more in-depth studies into the chemical composition of acicles, especially with regard to their viability in industrial papermaking processes. A more detailed understanding of this composition could expand the use of acicles on a larger scale, benefiting the paper industry. Another important challenge was the limited infrastructure and the influence of hierarchical models deeply rooted in community dynamics, which can hinder the implementation of new production processes.

For the future, it is recommended that detailed chemical characterization be carried out on *Pinus spp.* acicles, with a view to exploring their industrial applications. In addition, it is essential to strengthen strategic partnerships with companies in the paper sector and with public institutions in order to expand the impact of the research. Expanding the workshop model to other communities, with specific adaptations to local realities, is equally important to ensure the effectiveness of solutions in different contexts.

CONCLUSIONS

The research reaffirms the transformative role of initiatives that integrate environmental sustainability and social development. The handmade paper workshop not only reinforced the pillars of sustainability, but also promoted innovation in vulnerable communities, paving the way for more conscious and inclusive production. Based on the results achieved, it is believed that the incorporation of *Pinus spp.* acicles can contribute significantly to more responsible economic and ecological practices, strengthening both environmental preservation and community empowerment.

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