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Development of a new fertilizer material from the shell of the inga feuillei for ecofriendly pens using design thinking

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Abstract*– The writing is inherent to the human being, initially goose feathers were used with ink or reeds to then move to plastic pens, however they are disposable or easily replaced in the face of some loss due to their low cost, but this attracts an increase in environmental pollution as very few plastics are properly recycled. Today, alternatives have appeared to use eco-friendly materials such as paper, cardboard, coconut shell waste and bamboo, however none of these alternatives is eco-friendly under a circular economy where the manufacturer must consider a significant added value. Therefore, using the innovative product design methodology of Design Thinking, we propose a pen with an ergonomic design with a seed at the tip manufactured with a completely organic material such as fertilizer with good properties in macronutrients such as NPK. The result of this research is that the proposed material requires less energy than its current competition to be effectively used as a fertilizer with a significant result since it does not require to be burned to use as a biocarbon or ash and has high ranges in the macronutrients analyzed in the laboratory, in addition to being completely organic and requiring water to initiate its degradation as compostable material.

Keywords—NPK, fertilizer, inga feuillei, design thinking, pen ecofriendly.

I. Introduction

Writing is inherent to the human being; it is a form of expression of a record of our past. Formerly, in China and Japan brushes were used, in the Middle East cane stalks were used, in medieval Europe initially goose down was used separately from ink, with the drawback that spills occurred [1] until the Hungarian-nationalized Argentine journalist Laszlo (Ladislao) José Biro invented the ballpoint pen with his patent in 1938 [2] [3]. Currently, pens are used with the same tip mechanism patented by Biro called pen but with the body of recycled plastic, which has made it a disposable product, that is, even though the product can be disassembled quickly and has an ink charge to recharge, all its parts are discarded together.

In Latin América, 1,600 million pens are discarded annually, considering then the years and frequency with which pens are discarded and that the material from which it is made is a non-biodegradable plastic or difficult to recycle, becomes a significant problem polluting the environment [4].

In the last decade there has been a tendency to decrease the use of products made of plastic because these products, as they come from hydrocarbons, require a long time for their degradation under normal environmental conditions [5] [6]. Despite the increase in this trend, only a small percentage of this plastic waste is recycled [7]. The way to permanently dispose of plastic waste is by using thermal treatments, such as combustion or pyrolysis, which makes environmental pollution with plastic waste a growing concern [8]. For this reason, the development and use of biodegradable materials in various products has increased [9].

In the area of writing, there are several companies with alternatives of products for writing made with eco-friendly organic materials, among the most commercial, bamboo, cardboard and from waste of various products such as coconut shell [10], however without considering an additional added value, since these materials do not have the property of being fertilizers that help the germination and development of a plant. Companies have begun to understand the need for an environmental focus on their products, consumers and suppliers in their products and services [11]

An attractive field for the development of biodegradable products is the field from the residues of food production that were previously seen as a big problem and are now understood as an opportunity for the development of sustainable industrial processes [12] [13] [14]. Peru has an agriculture-based economy with potential for exporting its agricultural products [15]. From 2000 to 2015, agricultural gross domestic product grew on average by 3.3% a year, higher growth compared to countries with similar economies based on agriculture [16]. One of the native species cultivated from Peru along its coast is the inga feuillei, also known as pacay, pacae or guaba [17]. According to the Ministry of Agriculture and Irrigation of Peru, between 2012 and 2016, presents the inga feuillei with a growth rate of 66% and a yield growth of 65%, being the product with

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the highest growth in all agricultural production in the country, with a production in all Peruvian regions and with an emphasis on the north central region [18].

The inga feuillei, is a legume, fruit of a tropical woody tree with a high level of propagation in the open field [19]. The fruit has a shell of 30 to 40 cm long and what is consumed is the white cotton pulp which wraps the smooth black and hard seeds, which is inside the fruit [20], however, during consumption, the shell is discarded without further use.

This document presents a proposal for compostable organic material to be used as a replacement for the pen housing, a product considered for everyday use made of plastic and that is disposable.

II. Methods and Materials

A. *Design methodology*

To realize a new product design the design thinking methodology was used, because Design Thinking is a transdisciplinary method for solving problems and developing new ideas with user-centric solutions to provide various innovative solutions to meet your needs in various situations [21] created by IDEO and Stanford School [22]. According to the IDEO methodology, this methodology has three main parts: Inspiration, Ideation, and Implementation, however in the Stanford method it has five steps: empathize, define, devise, prototype and test [23] [24].

B. *Participants*

A total of 268 university students participated in this project on the condition that they are students who use pens to register classes or make diverse notes having at least one year of admission before a pandemic, in other words, to guarantee a minimum use of pens, participants were asked to have at least one year of face-to-face classes at the university. This is because students who entered during the pandemic, to make their annotations, use the computer or write electronically.

C. *Collection of data*

Due to the pandemic and sanitary restrictions in Peru during the data collection in the empathizing stage, this was done through the Google Forms platform.

D. *Ethical considerations*

All the results of the participants were collected anonymously, and the students were also informed that they could withdraw from the study at any time for any reason and that their participation was not compulsory, but voluntary.

III. Results

For this research project the Stanford method was taken of five steps. Which we proceed to describe:

A. Design Thinking Methodology

1) Empathize: Due to the pandemic, for this first phase, the Moodboard technique was used, where photographic images have been placed so that users can relate them to a possible solution.

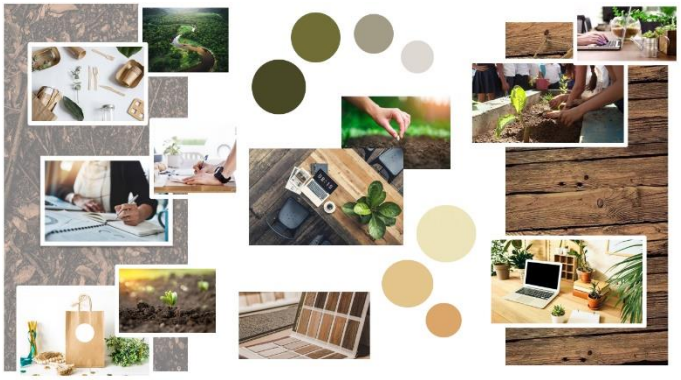

Fig. 1 Moodboard using in this research project with Design thinking

On the table 1 and Fig 2 show the results of the survey of participants which is the material they consider could have a better effect on reducing environmental pollution.

As seen, the most requested material is wood or some similar with 37.7%, followed by recycled fabric with 14.9%.

TABLE I
TYPES OF MATERIALS PROPOSED BY PARTICIPANTS

Materials	Quantity	Percentage
Wood or similar	101	37.7 %
Metal	29	10.8 %
Recycled plastic	10	3.7 %
Clay	13	4.9 %
Ceramics	28	10.4 %
Paper	14	5.2 %
Cardboard	9	3.4 %
Glass	19	7.1 %
Recycled Cloths	40	14.9 %
Others	5	1.9 %

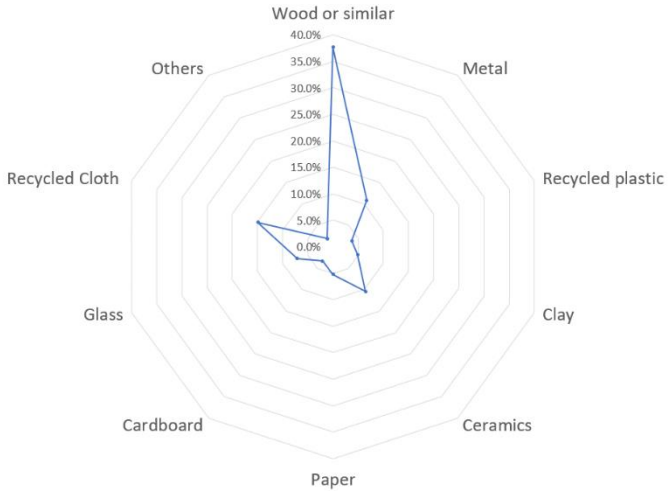

Fig. 2 Radar graph of the results of materials that users propose to use for an eco-friendly pen

In addition, participants had the freedom to write various characteristics that they require in an eco-friendly pen, as for example, comments related to wood were diverse as the ease of the wood in being worked and the finish that can have, the elegance of working a product in wood and that can take different colors if it is varnished, a natural product that has a rustic touch that symbolizes the environment.

2)Define: In the case of using wood, it is necessary to consider the deforestation that this could produce when changing plastic material for wood, Peru is the second country with the largest extension of Amazonian humid forests with an area of 67 million 932 thousand 915 hectares of Amazonian forest, However it presents a loss of 137 thousand 976 hectares only in 2021, and with a historic loss, only in 2020 in the last 20 years of 203 thousand 272 hectares of forest, concentrated extremely high in the whole jungle but with emphasis on the central forest [25].

It was decided to develop a material, similar to biodegradable organic wood with an environmental approach, however, to give added value to existing pens, it was decided to build to counteract deforestation from teaching students the awareness that pens do not pollute but can give life.

According to the needs of the participating users, these were grouped into four categories, which were decomposed into various possible solutions: shape (2), materials (05), binders (03) and additional ecofriendly characteristics (03) creating a matrix in Table 2.

TABLE 2
PROBLEM DESCOMPOSE INTO CATEGORIES AND POSSIBLE SOLUTIONS

Category		Description	
A	Shape	1	Straight
		2	Following the shape of the hand
B	Materials	1	Pineapple bark
		2	banana peel
		3	pecan shell
		4	carrot skin
		5	Inga feuillei
C	Binder	1	No one
		2	Organic paint
		3	Organic binder
D	additional characteristics	1	Lookout ink
		2	Seed
		3	Fertilizer

Resulting in a matrix with 90 possible solutions.

3) Ideate: As well as generating ideas, it is important to evaluate them. For the brainstorming, three different ideas were raised by each researcher and the technique of choosing the two best solutions from the other researchers was used, so that the idea that was most voted is the chosen one. With this criterion it was possible to decide to develop a new organic material from the combination of the crushed shell of the inga feuillei and an organic binder, in addition to coated with a thin layer of a natural adhesive such as the crayfish that provides a tough, fibrous and hard material, for the manufacture of the body of pens. In addition, two additional ecofriendly features were included, first, that the material allows a seed to be placed on the tip of the pen as seen in Fig. 3, adhered with transparent colapez that allows the visualization of the seed, allowing the recognition of the type of seed for its correct insertion into the soil and that the material has characteristics of fertilizer.

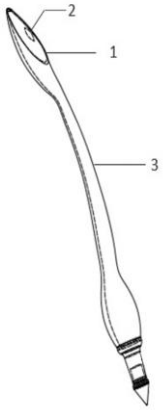

Fig. 3 Design of the body of pen with the material type fertilizer proposed. The parts of the pen are: 1. Colapez as natural adhesive, 2. The seed and 3. The body of the pen [26].

In addition, this new ergonomic design was registered as industrial design at the National Institute for the Defense of Competition and Protection of Intellectual Property of Peru – Indecopi.

Before proceeding with the prototyping to give the shape of the pen, measurements of the macronutrients Nitrogen (N), Phosphorus (P) and Potassium (K) of the material were made to determine if it is considered as a fertilizing material [27]. Table 3 shows the results:

TABLE 3
NPK MACRONUTRIENT RESULTS FROM THE PROPOSED MATERIAL

Phosphorus - P [mg/kg] or [ppm]	Potassium – K [mg/kg] or [ppm]	Nitrogen – N [mg/kg] or [ppm]
918.76	1,260.60	3,142.41

The conditions for obtaining the NPK results of the proposed material can be seen in the table 4.

TABLE 4
CONDITIONS TO OBTAINS NPK MACRONUTRIENT RESULTS

Environmental conditions	
Temperature	20.5 °C
Relative humidity	51%
Methodology used for each macronutrient	
Nitrogen	Nitrogen / Kjeldahl
Phosphorus	Phosphorus Available/ Olsen modified, NaHCO3, 0.5 M
Potassium	Potassium Available/ Atomic Absorption

4) Prototype and Test: The process for the manufacture of the pen begins by filling the single mold with the previously agglutinated material and proceeds to heat it at low temperatures in order to dehydrate the mixture and not burn it, then varnish the pen with a thin layer of gelatine that gives consistency and prevents premature wear when handled during its first writing function. Different process if compared to the injection of plastic pens in which a mold is used and against mold or also called a divided mold, the plastic is heated while it is moved by the screw of Archimedes and injected with pressure to the mold.

In addition, the seed at the top of the pen remains in its position, without germination, during the first function as a pen, since it is encapsulated by a second layer of fish that is placed to protect it from moisture and at the same time attach it to the tip of the pen. After the pen is no longer used for writing, you want to use it as fertilizer, you must dissolve the protective layer of the seed. This can take advantage of the water required for the degradation of the body of the pen and help the seed come into contact with soil moisture and the environment.

At this phase, several prototypes were made, which are improved with user feedback. As shown in Fig. 4. showing the first prototype.

Fig. 4 First prototype made

Fig. 5 shows one of the tests that users did when practicing writing with the first prototype proposed.

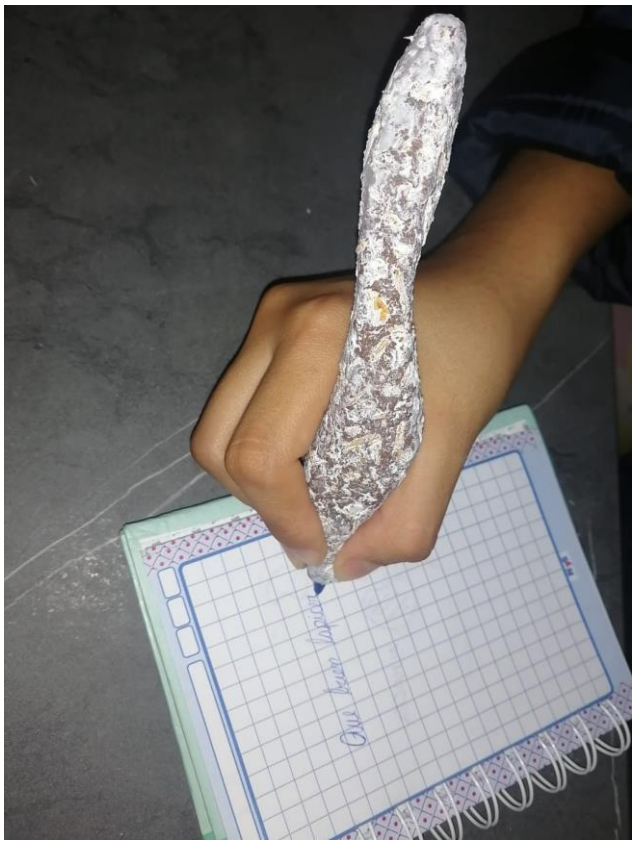

Fig. 5 Tests with the first prototype

Fig. 6 and Fig 7 show the second prototype made after the iteration after the user feedback from users, where a pen with a better-defined shape with respect to the contour of the hand and a better grip can be seen, in addition to the seed on the tip of the pen attached with the gelatine but without a good surface finish.

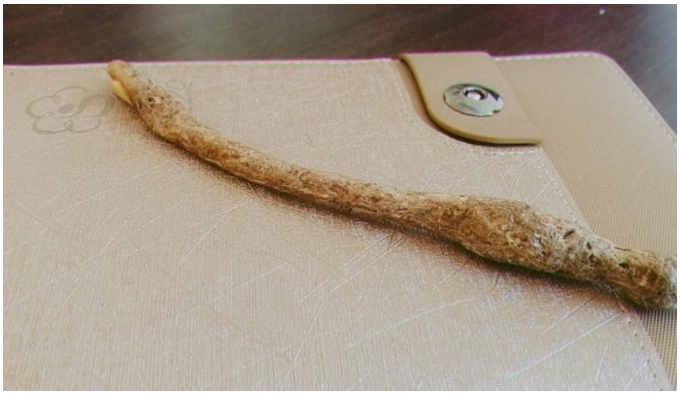

Fig. 6 Prototype of the ecofriendly pen with the proposed material after second iteration.

Fig. 7 Testing of the ecofriendly pen prototype after the second iteration

Because the material proposed for the body of the pen has similar physical characteristics to wood, it allows improvements to its surface finish using the abrasion method.

During the process of the design thinking methodology, three iterations were made to reach the required shape in the design, resulting in the pen as seen in Fig. 8.

Fig. 8 Eco friendly final pen prototype with proposed material

A. Diagram of the use of pen as fertilizer material

Fig. 9 shows in a block diagram how the proposed pen is used after its useful life as a writing tool.

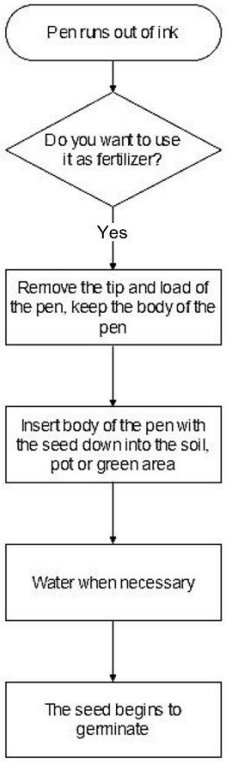

Fig. 9 Diagram of blocks for the use of pen as fertilizer material

IV. Discussions

Macronutrients depend on the type of soil, for example, agricultural soil must have a higher range of nutrients than forest soil [28], as well as cultivation, however there are minimum ranges for most agronomic and forage crops: in phosphorus, a very low level is less than 16 ppm and above the optimum is greater than 50 ppm, on the other hand, in potassium for most crops, a very low level is less than 61 ppm and a level above the optimum is greater than 175 ppm, whereas Potassium for pasture code has very low values with less than 21 ppm and above the optimum at values greater than 100 ppm [29], and in nitrogen ammonia nitrogen concentrations are 2 to 10 ppm [30].

The literature mentions the effects of fertilizers depending on the temperature, humidity and type of product cultivated, a next step of this research is to verify the effect that this material has on crops that have greater need of fertilizers in Peru.

In the case of pens made of cardboard, there is no study made directly with this material to find its macronutrient content, however if there is an investigation where its NPK content is analyzed by burning it cardboard briquettes to get its ashes, however the result is that its content is lower than required by the standard UNE-EN ISO 16967:2015 [31], to be considered fertilizer [32].

In the case of eco-friendly pens made from coconut husk waste [1], this material is used as a fertilizer when it is converted into a biochar and has an outstanding participation with the Nitrogen macronutrient, but without presence with Phosphorus or Potassium [33].

Like both previous cases, in order to use bamboo as a fertilising material, it must be used as a biochar with a positive effect on Phosphorus, with a result of 2.50 ppm of Phosphorus compared to 918.76 of the material proposed in this research [34], so for a positive result it is necessary to have more mass of bamboo biochar to present positive results as fertilizer [35].

V. Conclusions

The material presents higher than optimal results in the amount of ppm of the 3 macronutrients, however, nitrogen stands out in a ratio of 2.5 times the amount of ppm of potassium and 3.42 times that of phosphorus. This favors the plant since nitrogen is fundamental in plant formation, growth and production, as well as the formation of chlorophyll.

The most commonly used materials with which ecofriendly pens are made, such as bamboo, cardboard and coconut shell waste, are not used directly as fertilizer, but in the form of ash or biocarbon, For this, they should be combusting at high temperatures with low oxygen content (pyrolysis) using a lot of energy. Quite the contrary, in the case of the material proposed in this research, in the procedure of preparation of the material, it is necessary to dehydrate it using a lower energy to dry the mixture with the organic binder, and to be used as fertilizer, this does not need to be burned, on the contrary, it is used directly by placing it on the ground and adding water for its degradation.

In subsequent research, the application of this material in various types of crops is expected depending on the needs it requires for fertilization in order to provide an alternative of a product, not only fertilizer type, but it has a first use in a everyday product as a replacement for using plastic.

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