Chapter

# Use of Recycled Cellulose Fibers to Obtain Sustainable Products for Bioeconomy Applications

*Petronela Nechita*

## Abstract

Knowing the negative impact of plastic materials from agriculture sources on the environmental pollution, in this chapter, some of research activities carried on the utilization of secondary cellulose fibers (from recovered papers and boards) and other lignocellulosic materials on obtaining of sustainable composite materials are presented. The aim was to obtain the (bio)composite materials with applications in manufacturing processes of biodegradable nutritive pots used in the production of vegetable seedlings. The tests were developed on a pilot plant designed to obtain the pots from a mixture of secondary cellulose fibers, red peat, and other additives. These materials were characterized in terms of biodegradability and growth and development of tomatoes and lettuce seedlings. For all the compositional versions studied, the specific indicators of seedlings growth and development have recorded values that allow a normal growth of plants similar to the use of plastic pots or biodegradable pots available on the import market.

**Keywords:** biodegradable nutritive pots, cellulose fibers, peat, recovered papers, seedling, biodegradable potential, biodegradable rate, wet strength, dry strength, bioeconomy

## 1. Introduction

In the most technological processes, current trends are geared toward the identification of alternative solutions for the rational use of raw materials by replacing the petroleum-based materials with negative environmental impact with those from renewable resources, biocompatibles, and highly recyclables in order to obtain sustainable products according to the circular economy concept.

The negative impact on the environment of plastic pots used in agriculture has convinced many consumers that this is an unsustainable practice and has determined them to explore and identify the “green” alternatives to obtain the new materials, biodegradable, eventually recyclable and based on renewable resources with low pollution for soils and plants [1, 2].

Nowadays, the plastic pots, containers, and trays are widely used in industrial greenhouse and private farms. In 2002, there were 1.678 billion pounds of plastics used in the agricultural sector [3].

After their utilization, these are dumped in landfills where they are very slowly degraded. The total flow of agricultural plastic waste reaches ca. 400,000 tonnes per year, and plastic pots and trays constitute about 16,000 tonnes (www.greenfacts.org). In this respect, the biodegradable pots represent a good alternative to plastic materials [4].

Generally, the plastic pots are light, cheap, and durable, and their walls are relatively impermeable. The last feature contributes to reducing the water consumption by the plants cultivated in such pots. Nevertheless, the salts and nutritive elements in their walls are not concentrated, and the recycling of the used plastic pots is still an unsolved problem [5].

Recently, alternative containers based on natural raw materials, impregnated with various components, such as slow-releasing fertilizers, fungicides, insecticides, and plant growth regulators that are released during plant growth, are gaining entry to the market and could enhance the efficiency of the production system. Industry and researchers are continuously working together to develop and fine-tune sustainable alternative containers to suit emerging grower and customer requirements [6, 7].

The researches in the field of biodegradable pots are focused into groups:

- biodegradable plastic pots; and
- cellulose fibers pots

The researches in the field of biodegradable plastic materials are very intense and generally are economically stimulated to become alternatives to nondegradable materials [8]. Nevertheless, biocontainers are considerably more expensive and their cost ranges from 10 to 40%, which is more than their plastic counterparts [9]. Furthermore, these are only partially degradable and their degradation products do not exhibit the ecological safety [10, 11, 12].

In particular case of seedling biodegradable pots, it is required that beside the lack of toxicity, their degradation products should have nutritive properties for plants and contribute to soil quality improvement [13].

In this context, when the reuse and recycling are the first options in the concerns of sustainable management of production processes, cellulose fibers (primary and secondary) are considered to be the raw materials with great availability between the existing vegetal and renewable resources, presenting the important advantages compared with synthetic, inorganic, or mineral fibers.

The use of cellulose fibers has been explosive over the last decades, being directed both to the production of paper products (paper and cardboard) but, more and more as auxiliaries in many economical fields, such as: obtaining of (bio) composite materials with applicability in the construction materials industry, automobiles, aeronautics, electronics, agriculture, etc., medicine, pharmaceutical applications, or the food industry.

Considerable progress has been reported in the development of nano or microfibrilated cellulose with large-scale applications in medicine (cardiovascular implants, prostheses, etc.), and also in the field of biorefinery, the concept and basic process of the future of the cellulose and paper industry, which provides integrated solutions for the complex exploitation of plant biomass for energy production and the extraction of chemicals based on "green chemistry" concept.

*The biodegradable pots based on cellulose fibers* are composite materials obtained from mixtures of cellulose fibers and peat on wire or vacuum dewatering process using specials molds [14].

The main drawback of these materials is their low strength, especially wet strength. However, the researches in this field are focused on increasing the dry and wet strength without affecting their biodegradation capacity [15, 16].

This chapter highlights the use of cellulose fibers in composite materials with application in agriculture to obtain the biodegradable nutritive pots for seedling manufacturing.

## 2. Utilization of cellulose fibers to obtain the biodegradable nutritive pots with applications in the seedlings production

The cellulose is the most available polymer in nature that can be converted into (bio)composite materials or (bio)chemicals as alternative to petroleum-based products [17].

Among the biodegradable and nutritive pots, the pots based on peat and cellulose fibers are most widely used. They can be either embedded into soil together with plants or digested [18, 19]. The advantages of using the nutritive pots in the seedling manufacturing process are based on the fact that, comparing with existing plastic pots, these are biodegradable, have good water and air permeability and high ability of plant roots to penetrate the pot walls. Furthermore, these types of pots do not generate the waste after use and their degradation products are adequately fertilizers that contribute to soil bioremediation [20]. In their walls, the nutritional and biostimulative elements can be incorporated. These have an important role for improving the plant prophylaxis.

The other advantages are presented as follows:

- increasing the work productivity in the seedling production by elimination of collecting, selection, storage, cleaning and sterilization stages that exist for the plastic pots;

- reducing the costs for seedlings production—due to the fact that these are planted in soil together with biodegradable pots;

- improving the seedling quality—the walls of biodegradable pots have incorporated all the nutritive elements necessary for growing of plant roots (i.e. cellulose fibers, peat, protective and stimulative additives) and allow water retention and air penetration; these are very important parameters to ensure the oxygen flow;

- reducing the duration of seedling production with about 14–21 days comparing with existing conditions, which contribute to obtain a better production efficiency;

- obtaining 100% biodegradable fully organic products (cellulose fibers, peat, etc.);

- eliminating recycling and waste management totally—at soil contact, these pots are converted in humus that improves the soil fertility.

The applications of nutritive and biodegradable pots in seedling manufacturing are varied, starting with vegetables and flowers, medicinal plants, ornamental shrubs, or various forest species until the production of vine cuttings [21].

The nutritive biodegradable pots belong to new generation of transplantation media being designed to fulfill the following functions:

- resilient support of seedling for a variable period depending on the cultivated plant;

- biologically active material that releases nutrients and biostimulators during germination and seedling growth;

- support with a structure that is totally degradated during a life cycle of plants transplanted in soil, and the degradation products must be nontoxic for soil, biodegradable, and can to contribute to soil bioremediation.

Therefore, obtaining biodegradable nutritive pots is based on the principles of sustainable development, considering the entire life cycle of the product [22]:

- utilization of natural raw materials, renewables and recyclables (recycled cellulose fibers, lignocellulosic waste);

- using of additives for strength properties of composite structures, based on natural polymers, biodegradables, and nontoxic;

- all of these additives ensure the adequate level of nutrients for plants growth and their the degradation products of the nutritive and biodegradable pots are good soil fertilizers.

As a result of these aspects and in the context of integration of the horticultural production with other industrial fields (i.e., processing and recycling of cellulosic fibers), the experimental programs were managed to obtain the biodegradable nutritive supports (pots) based on peat and secondary cellulose fibers. These pots were tested with promising results for obtaining tomatoes and lettuce seedlings [23].

### 2.1 The composition of biodegradable nutritive pots

The properties of composite structure are highly influenced by the distribution and interactions between raw materials during wet forming and fibrous network consolidation by pressing and drying.

The mechanical strength properties are most important for a composite structure because indifferently by their use, this must meet specific characteristics such as shape, stiffness, and strength.

The fibrous materials are the main raw material for the biodegradable nutritive pots, having a decisive role to obtain the composite structure with adequate strength properties without compromising their biodegradability.

In this context, the most used fibrous materials are: kraft pulp for achieving the structure strength; secondary cellulose fibers from different types of recycled papers as fine material for forming and reinforcing the structure; peat consisting of vegetal materials, including wood fibers, in different stages of degradation, which gives the structure porosity, absorption, and water retention capacity as well as the nutritional properties.

Therefore, the characteristics of composite material may vary depending on the levels and properties of the fibrous raw materials.

After the analysis of the sources of fibrous materials based on their utilization in the composition of biodegradable and nutritive pots, for our experimental program, the following fibrous components have been identified: secondary cellulose fibers (from recycling of corrugated board boxes) and surface peats.

Based on the laboratory tests performed on the choice of the ratio between fibrous components, a value of 70/30 peat/secondary cellulose fiber ratio was identified as optimal.

This ratio allows obtaining:

- a product with a proper strength of the support for a variable period depending on the cultivated plant;
- a high content of biologically active material, which releases the nutrients and biostimulators during germination and plant growing;
- a pot with permeable structure for water and oxygen and penetrable by the plant roots, which is completely degradated over a life cycle of plants transplanted in soil.

A content over 80% peat has as a result decreased the dewatering rate as well as the dry and wet strength of nutritive biodegradable pots.

Regarding the cellulose fiber quality, it is recommended to have a high content of long fiber fraction that ensures a better bonding capacity and reinforcement of the pot structure.

The physical-mechanical properties that are important for seedling pots are bursting and tensile strength (bursting index and breaking length). These properties are recommended to be evaluated in dry and wet state [24]. Another important property is the structure porosity that is determined by air permeability measurement. All these characteristics of composite material were tested on hand sheets (400 g/m$^2$) obtained in the laboratory by Rapid-Köthen method with different percent of fibrous components (peat and cellulose fibers). The values of dry and wet strength of laboratory hand sheets with different contents of peat are presented in the **Figures 1** and **2**.

It is important to mention that the optimization of these strength parameters is very difficult to obtain only from fibrous composition, because some requirements on resistance indexes are somewhat in opposite; for example, to obtain the composite material as pot shape, high resistance indexes (both for tensile and bursting strength) are necessary; during seedling manufacturing, a high wet strength for composite materials is necessary; after soil transplantation of seedling and pot, a lower bursting strength as the plant roots to easily penetrate the composite material structure is necessary.

The tensile and bursting strength in dry state are influenced by total interfiber bonding energy and fiber length. Therefore, at high grammage, it is difficult to

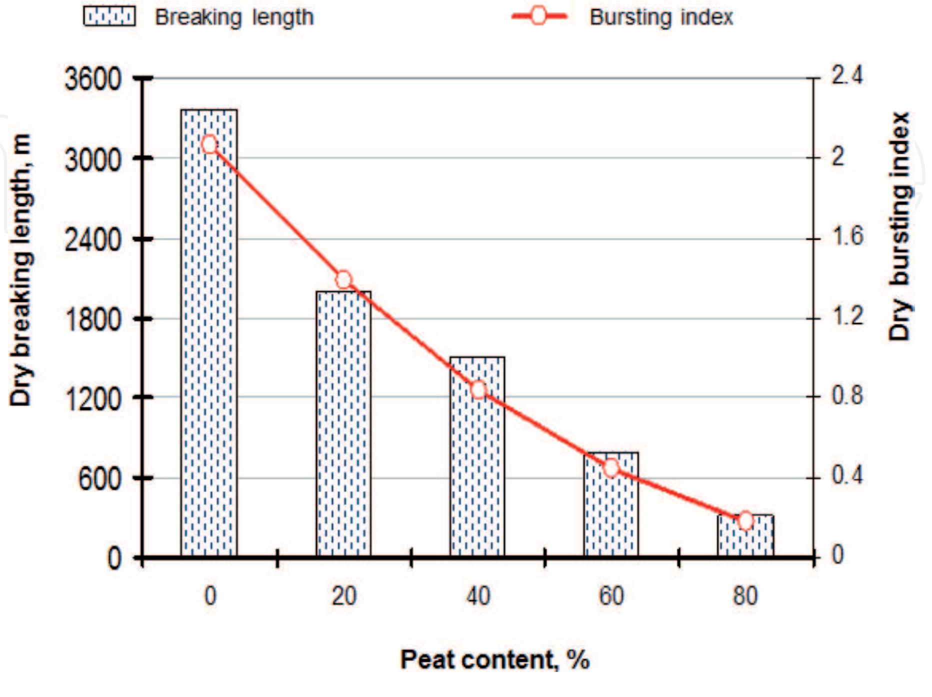


**Figure 1.**
*The influence of peat content on dry breaking length and dry bursting index for the laboratory hand sheets of composite material (23°C and 50% RH).*

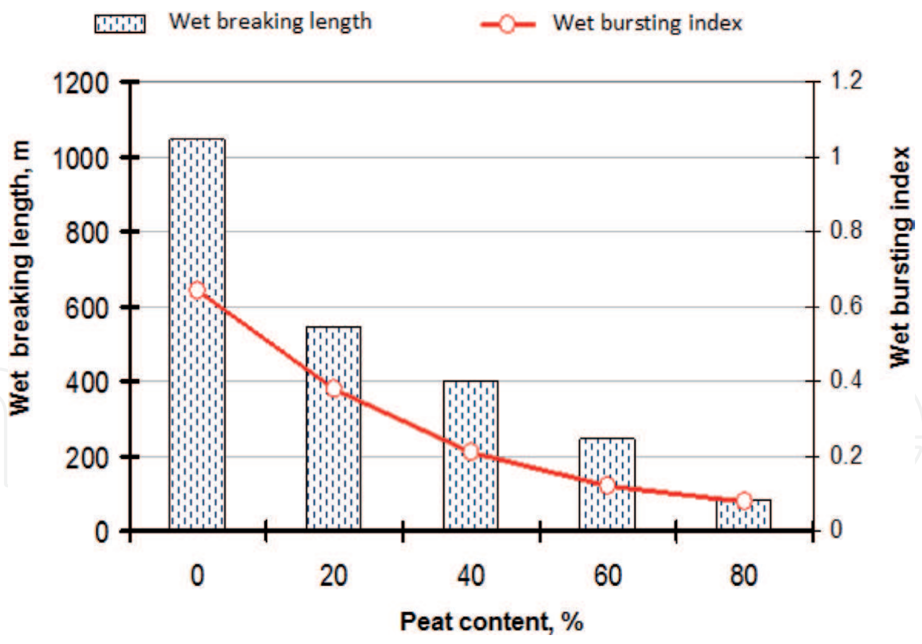


**Figure 2.**
*The influence of peat content on wet breaking length and wet bursting index for laboratory hand sheets of composite material.*

obtain a fibrous structure with better breaking length than bursting strength. In this context, the solution is to exploit the fact that long and rigid peat fibers reduce the interfiber bonding energy. This will have a higher impact on the bursting strength that is more influenced by the fibers length (**Figures 1** and **2**).

The wet strength retention of fibrous composite structures (percent of fraction from dry strength that remains when the structure is saturated with water) is obtained by introducing, in the composite structure, the specific additives that protect the interfiber bonds by blocking the access of water when this is wetted for different durations. The wet strength retention (%) can be at different levels (10–40%), and mechanical wet strength of the composite structure is directly influenced by dry strength and level of wet strength retention [25].

Aiming to obtain the appropriate wet strength retention of composite structure, a polyamide-polyamine-epichlorohydrin (Kymene 611) resin was used in the fibrous composition. This additive has a high efficiency for improving wet strength and a good degradation capacity. Furthermore, this resin, in accordance with environmental safety, is being used in the composition of tissue papers or cellulosic food packaging.

*Breaking length and wet strength retention*: At different contents of Kymene 611, the dry breaking length increases linearly with resin content (approx. 150 m/1%). The optimum content of resin for 40% value of wet strength retention is between 4 and 6% (**Figure 3**).

Based on these experiments, the content of Kymene resin was considered as optimum at 6%, when the wet strength retention level is over 35%.

*Bursting index and wet strength retention*: Dry bursting strength increases linearly with the content of Kymene (approx.10%/1%) (**Figure 4**).

Unlike the wet strength retention reported as breaking length that starts to decrease at 4% Kymene content, the wet strength retention reported as bursting strength starts to decrease at 6% Kymene content.

The dry bursting index for the tested samples has a maximum value for 6% Kymene content. The wet tensile and bursting strength of the composite material are directly influenced by their values in dry state as well as by wet strength retention level.

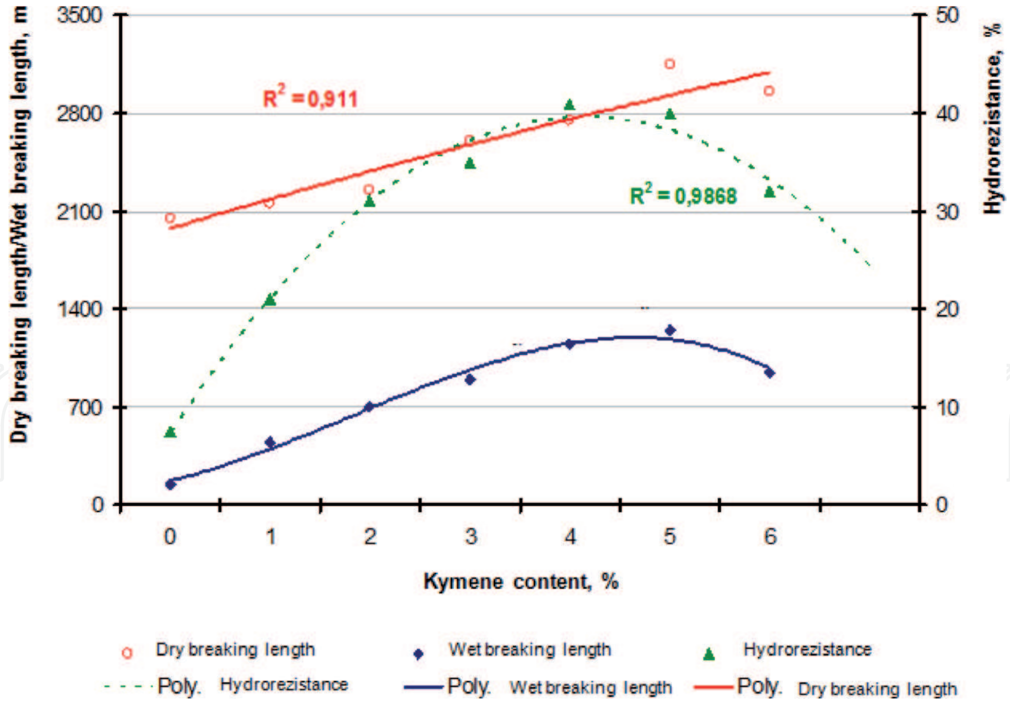


**Figure 3.**
*Breaking length and wet strength retention at different contents of polyamide-polyamine-epichlorohydrin resin.*

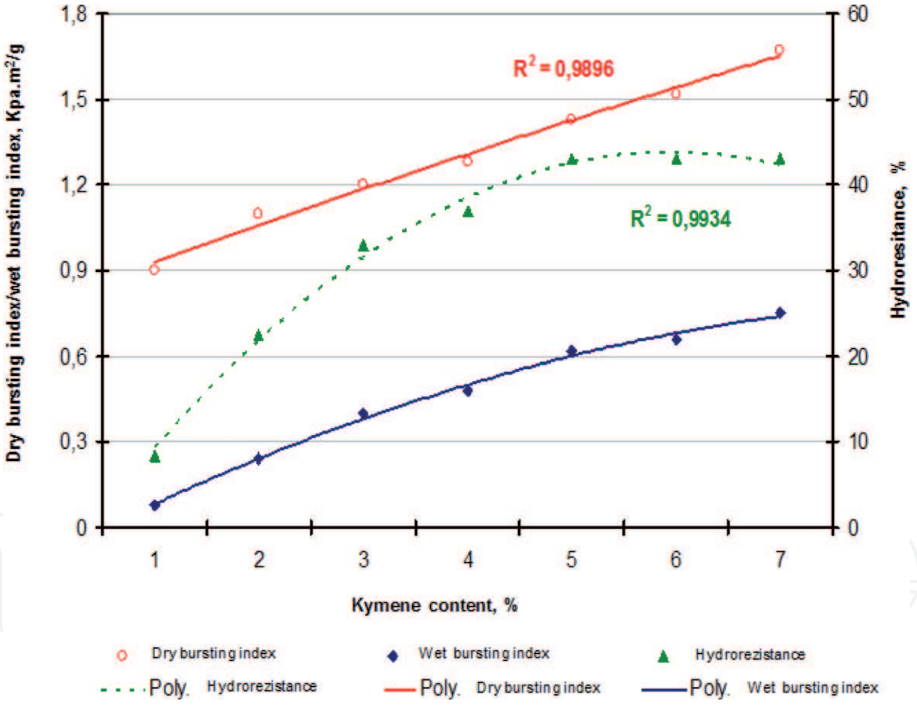


**Figure 4.**
*Bursting index and wet strength retention at different contents of Kymene 611.*

The dosage of resin for wet strength can be a means for retention of the components control, contributing also to increase of the additive efficiency as nutrient intake.

### 2.2 The influence of fibrous composition and additive content on the structure of nutritive biodegradable pots

Generally, the porosity is an important property that characterizes the structure of fibrous composites. This property influences the other characteristics of composites such as air permeability, liquids filtering, and water absorption. The porosity of composite structure was evaluated by air permeability measurement, which means the air volume that passes through a sample with known surface, under given time and pressure. The moisture content at equilibrium was evaluated beside air permeability.

The increasing peat content as a result has increased the porosity of the composite structure, evaluated by air permeability. Due to the high capacity of water retention of peat, the composite structure exhibits an increased moisture content (**Figure 5**).

The permeability of the composite structure is mainly influenced by the peat content. A lower influence is obtained with the increase of the resin content, also (**Figure 6**).

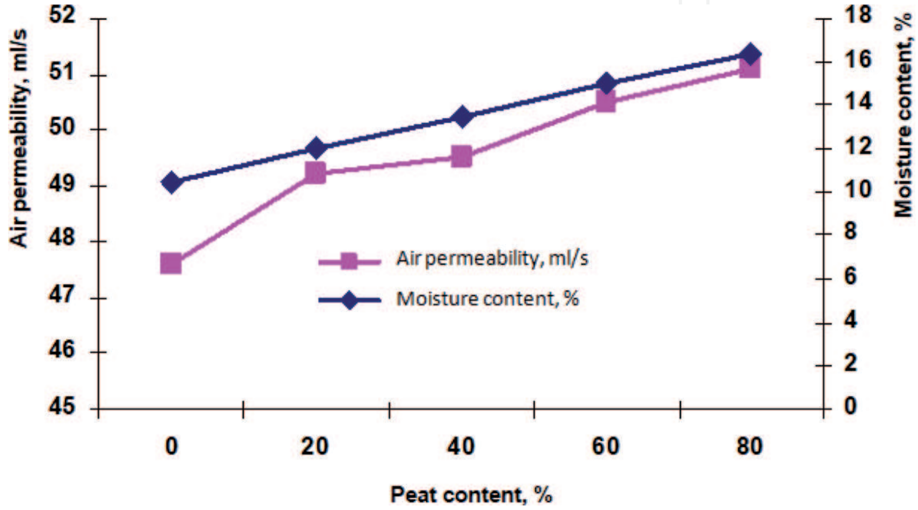


**Figure 5.**
*The influence of peat content on air permeability and equilibrium moisture of composite structures.*

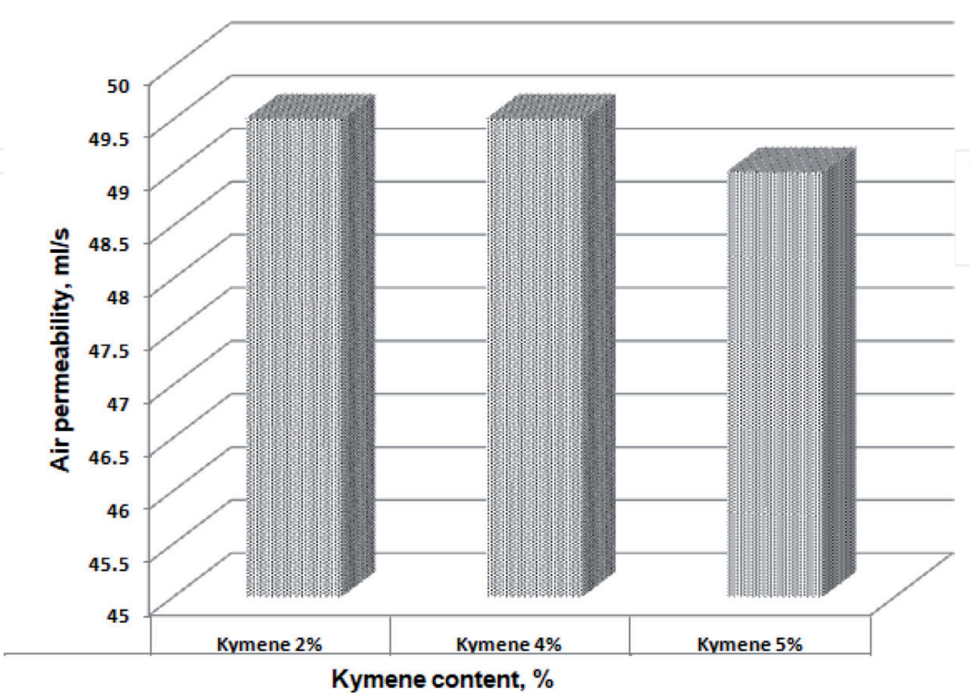


**Figure 6.**
*The effect of resin content on the air permeability.*

### 2.3 The level of nutrients in composition of biodegradable nutritive pots

A high content of peat in the composition of biodegradable pots involves an ideal medium for development of seedling roots, while providing a nutritional reserve. This fibrous component allows circulation of air and water ensuring the oxygen flow. The peat cannot be a permanent source of nutrients for a long time. In this respect, the ways of retaining nitrogen from urea or ammonium phosphates, phosphorus from potassium or ammonium phosphate, potassium and microelements such as molybdenum, boron, manganese, copper, and zinc, were analyzed.

For an additional contribution of mineral salts and nutrients in the composition of biodegradable pots, it was established that a part of the peat to be replaced with a mixture of waste from grape processing (skins and bunches of grapes, dried and ground), keeping the proportion of peat in the range of 50–70%.

All of these additives were introduced in the mass of composite materials aiming to obtain an optimal ratio of nutritive elements (N, P, K).

The chemical and natural auxiliaries identified to be introduced into the composite material structure are:

- urea and dibasic ammonium phosphate—for nitrogen and phosphorus release;
- borax and ammonium molybdate—for release of boron and molybdenum microelements;
- zinc sulfate and copper sulfate for zinc and copper release;
- potassium nitrate for the release of potassium;
- mixture of waste from grape processing (peelings and bunches) for additional mineral salts.

The nutritional properties of biodegradable composites are improved by incorporating bioactive substances in their structure (walls). Furthermore, a peat content of about 50–70% contributes to accelerating biodegradation rate of composite pots. A content of 70% peat in the composite structure facilitates the accessibility of seedling roots toward nutritive elements within the optimum range of pH. Exceeding the proportion of peat in the composition of the nutritive pots (over 70%) raises high problems during the formation process of their fibrous structure.

## 3. Experimental program for obtaining the biodegradable nutritive pots

In our experiments, three compositional versions (M1, M2, and M3) of biodegradable nutritive pots dedicated to produce seedling material were obtained using the formation and dewatering system through die molding. The obtained nutritive pots were dried in a laboratory oven at 105°C temperature [26].

### 3.1 Materials preparation

The composition of those three versions of nutritive pots is presented in the **Table 1** and their preparing stages in **Figure 7**.

After separation of coarse materials, the peat was dried at 105°C and defibrated using a homogenization device (Lhomargy type) for 4–5 min at 2000 rpm. Recycled

| Materials | M1 (%) | M2 (%) | M3 (%) |
|---|---|---|---|
| Peat | 70 | 55 | 70 |
| Waste from grapes processing | — | 15 | — |
| Secondary cellulose fibers | 30 | 30 | 30 |
| Wet strength resin (Kymene 611) | 6 | 6 | 6 |
| Chemical additives | 2 | 2 | — |

**Table 1.**
*The compositional versions of nutritive pots obtained in the experimental program.*

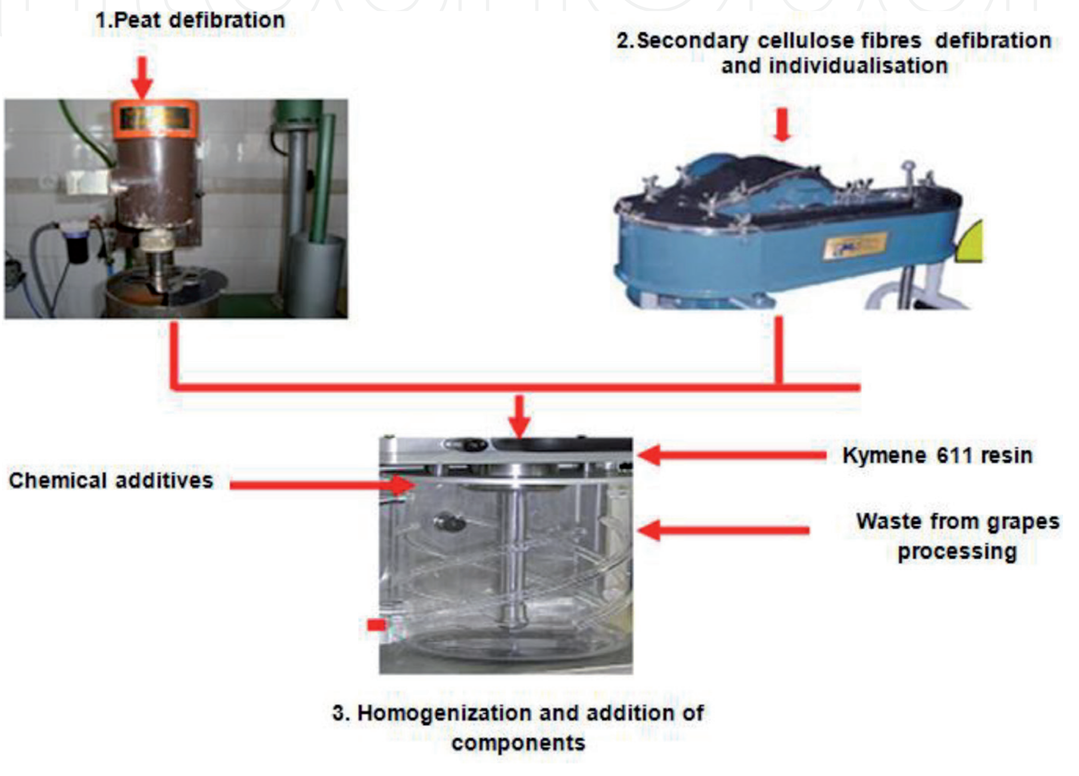


**Figure 7.**
*The stages of fibrous material preparing.*

papers from corrugated board boxes were defibrated in a laboratory Hollander until 35–40°SR. The fibrous components (peat and cellulose fibres) are mixed using a homogenizer where the Kymene 611 resin is added. The consistency of the fibrous mixture is adjusted at 0.8–1.0%.

### 3.2 Formation and dewatering of biodegradable nutritive pots

Fibrous suspension corresponding to each compositional version was transferred to a laboratory pilot plant where the die molding and dewatering of biodegradable nutritive pots took place as is described in **Figure 8**.

For each compositional version, about 150 pieces of nutritive pots have been obtained, and technical parameters during formation and dewatering processes are presented in the **Table 2**.

All composite structures have an adequate wet strength and fibrous network integrity (after formation and dewatering). This allowed manual take-up of nutritive pots and their introduction into drying equipment, where free-air drying was carried out.

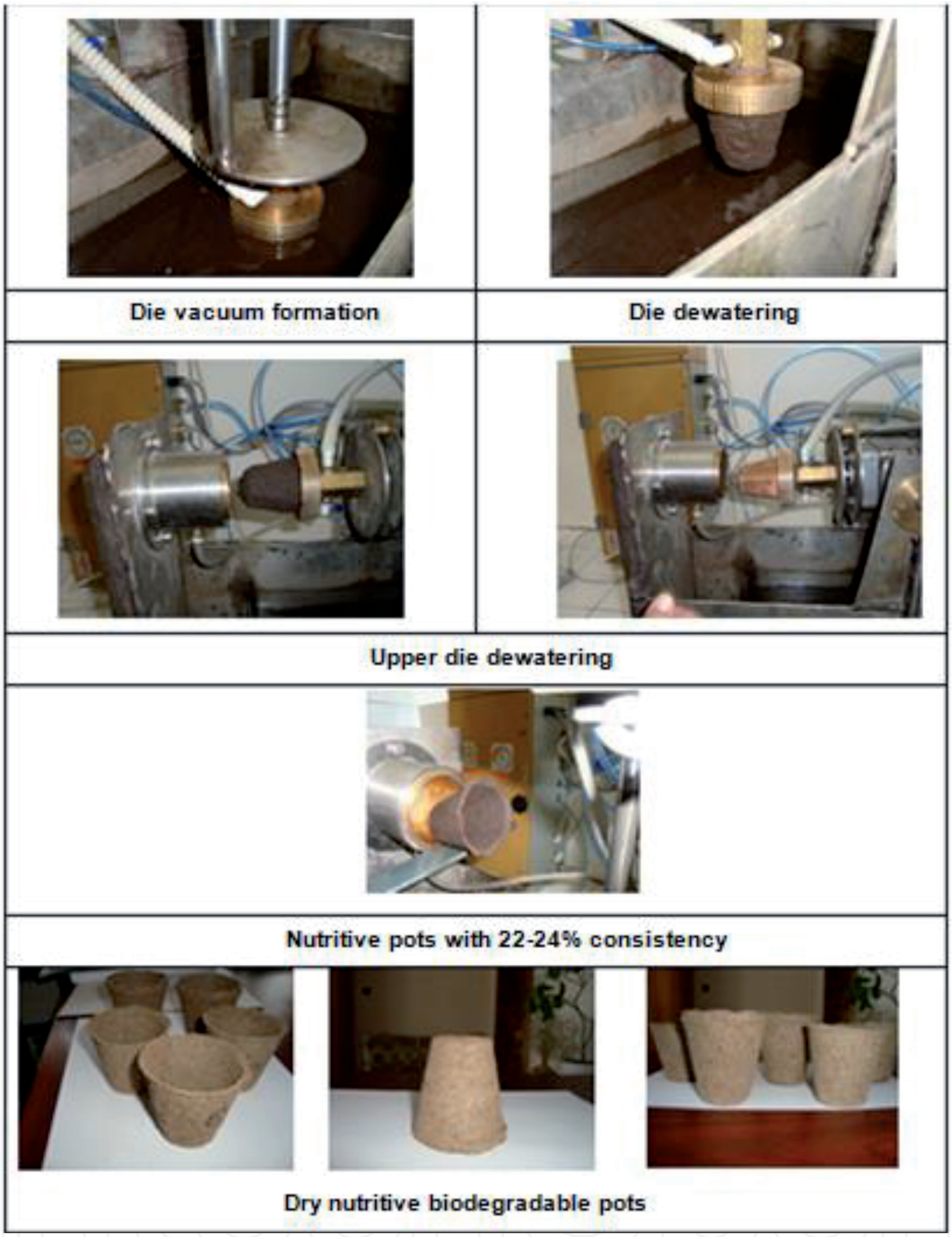


**Figure 8.**
*Formation and dewatering of biodegradable nutritive pots [27].*

### 3.3 Drying of nutritive pots

The nutritive pots were dried at 105°C for 60–80 min in a laboratory oven (**Figure 9**).

### 3.4 Assessment of mechanical strength properties of nutritive biodegradable pots

The mechanical strength properties were measured using a specific device for strength evaluation, whose construction was developed to simulate the specific shape and individual stresses to which biodegradable nutritive pots are subjected [27].

| Parameter | Value | | | Observations |
|---|---|---|---|---|
| | M1 | M2 | M3 | |
| Consistency of fibrous material, % | 1.2–1.4 | 1.2–1.4 | 0.9–1.1 | |
| Formation consistency, % | 22–24 | 22–24 | 22–24 | After die formation |
| Weight of wet pot, g | 32–34 | 34–36 | 24–28 | After die formation |
| Weight of dry pot, g | 7.5–8.0 | 8.0–9.0 | 6.5–7.5 | After drying at 105°C |
| Time of die formation, s | 12–15 | 15–16 | 15–17 | |
| Dewatering time, s | 60 | 60 | 60 | |
| Consistency of white water, % | 0.0397 | 0.0351 | 0.0320 | |
| Ash content of white water, % | 41.43 | 30.34 | 21.72 | |
| Number of nutritive pots | 150 pcs. | 150 pcs. | 150 pcs. | |

**Table 2.**
*Technical parameters during formation and dewatering of nutritive biodegradable pots.*

**Figure 9.**
*Drying of biodegradable nutritive pots.*

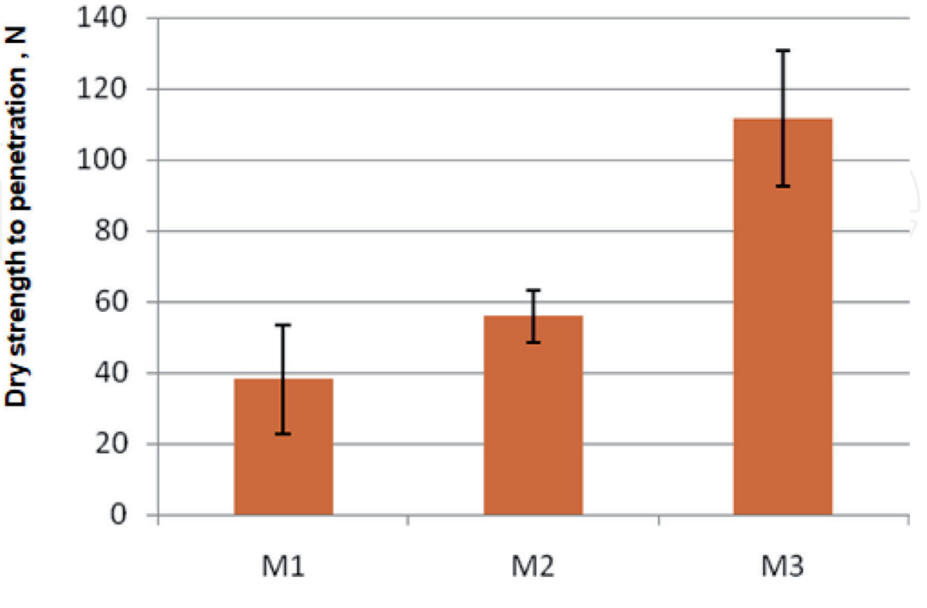


**Figure 10.**
*Dry strength of biodegradable nutritive pots.*

Strength tests were carried out both on samples conditioned in the standard atmosphere (23°C, moisture 50% RH) and wetted by immersion in water at 23°C for 15 minutes.

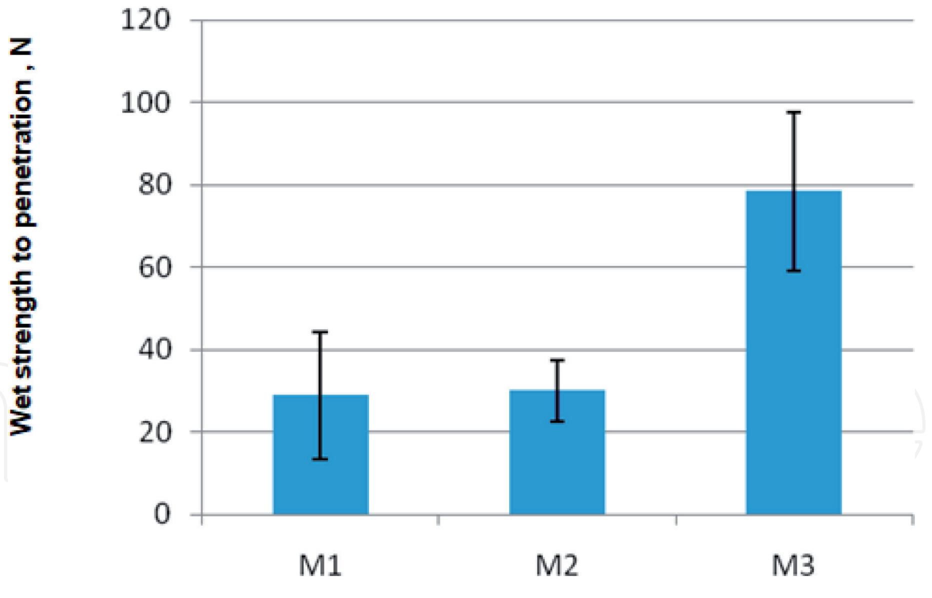


**Figure 11.**
*Wet strength of biodegradable nutritive pots.*

In **Figures 10** and **11**, the results obtained after the strength tests of those three versions of biodegradable nutritive pots are presented.

As it can be observed, the M3 version exhibits the best strength properties, both in dry and wet state. Values obtained for the M3 pots were of two and three times higher than those registered for the M1 and M2 versions. It seems that in case of the M1 version, the nutrient charge as salts affected resin retention and crosslinking, as it is known that resin adsorption on fibers decreases significantly, at the same time, increasing the valence of metallic ions and their stock concentration [28, 29, 30]. In case of the M2 version, the charge of residue from grape processing breaks the continuity of the fibrous network and introduces fine and colloidal anionically charged material. Nevertheless, in both cases (M1 and M2), the obtained strength exceeds the strength requirement for handling and transport in the seedling manufacturing process.

### 3.5 Assessment of nutritive pots biodegradability during seedling manufacturing process

To assess the biodegradability of nutritive pots, the cellulosic degradation rate was determinated [31, 32]. Based on this evaluation method, the nutritive pot samples (dried at 105°C) were incubated in a nutritive substrate commonly used for producing seedlings. During incubation, the nutritive pots were introduced in a previously weighed synthetic bag, in order to totally recover the fibrous material contained in it. During the entire experimenting period (141 days), the effective substrate moisture was maintained in the range of 60–65% relative humidity, and temperature in the range of 24–28°C. The biodegradation rate (degradation degree) was calculated as weight loss of initial and after soil incubation of pots.

The *capability to create a favorable environment for developing a typical microflora for soil and culture substrates* was evaluated by microflora respiration intensity, having in view that microflora are involved in cellulosic material degradation [33]. The experiments were carried out on both experimental nutritive pots and the current process for the production of lettuce (*Lactuca sativa,* var. Capitata) and tomatoes (*Lycopersicon esculentum*) seedlings [27].

Analyzing the obtained results (**Figure 12**), it is observed that during the experimental program, the pots from M1 version showed the lowest biodegradation

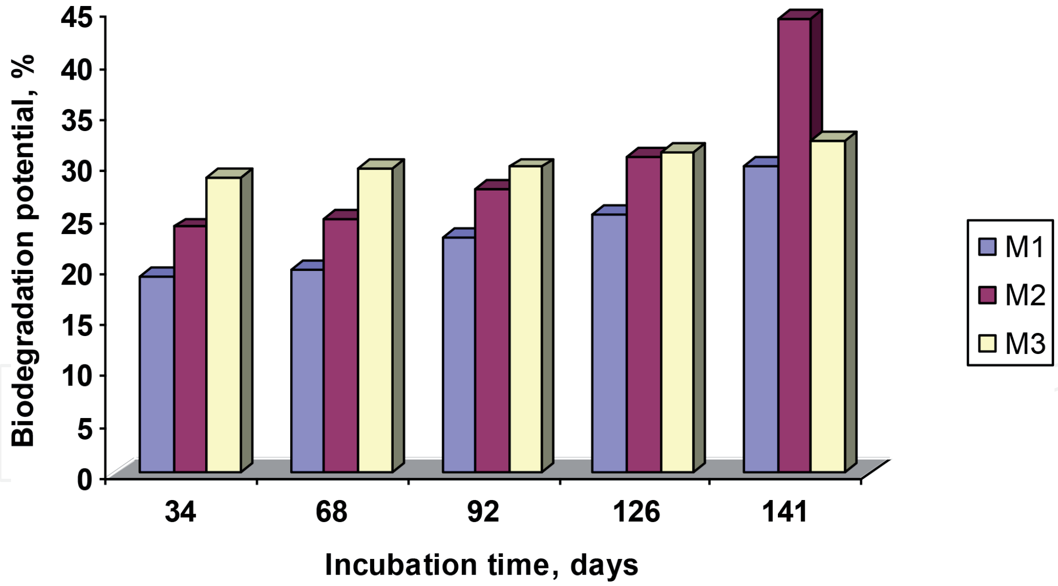


**Figure 12.**
*Biodegradation potential of nutritive biodegradable pots [27].*

| Pot version | Effective biodegradation rate (%) | | Daily biodegradation rate (%) | |
|---|---|---|---|---|
| | Tomatoes | Lettuce | Tomatoes | Lettuce |
| M1 | 16.484 | 12.391 | 0.32 | 0.34 |
| M2 | 15.351 | 13.657 | 0.30 | 0.38 |
| M3 | 16.312 | 13.008 | 0.32 | 0.36 |

**Table 3.**
*The biodegradability of nutritive pots with cultivated seedling.*

potential; though at the first analysis time (after 34 days), the M3 version pots showed a higher degradation rate (28.76%) than the M1 and M2 pots. In the last analysis period (after 141 days), the biodegradation potential was the highest for the M2 version pots (44.19%); this behavior can be explained by the fact that the pots obtained with this composition contained a lower amount of fibrous material (85%) compared with the M1 and M3 pots; in the composition of these pots, the waste from grape processing acts as a filler, increasing the distance between fibers and reducing bonding forces in the fibrous network. The obtained results are correlated with the wet strength of the M2 version pots, also.

Regarding the effective biodegradation rate measured during seedlings manufacturing process (tomatoes—*Lycopersicon esculentum* and lettuce—*Lactuca sativa*), the obtained results showed that all of three tested versions of pots behaved differently according to the seedling type (**Table 3**). Therefore, in case of tomatoes seedlings (after 51 days), the M1 pots exhibited the highest biodegradation rate (16.48%) and the M2 version showed the lowest rate (15.35%). When the lettuce seedlings are produced, the highest biodegradation rate was obtained in M2 (13.65%) and the lowest in M1 (12.39%).

The reason is that tomatoes naturally have a stronger root system than lettuce, though the latter develops its roots faster. As a result, the rhizosphere effect is more intense for tomatoes, and biodegradation conditions are modified both in the culture substrate and in the pots.

Analyzing the average daily biodegradation rate, it is noticed that this is more intense when pots are not planted with seedling compared to seedling production

| Pot version | Height of plant (cm) | Length of roots (cm) | Plant/roots ratio | Number of leaves | Leaves frequency (no./plant height) | Roots volume ($cm^3$) |
|---|---|---|---|---|---|---|
| | | | **Tomatoes** | | | |
| M1 | 20.3 | 18.1 | 1.12 | 6.6 | 0.32 | 10.0 |
| M2 | 14.2 | 23.8 | 0.60 | 5.4 | 0.38 | 7.0 |
| M3 | 14.0 | 16.8 | 0.83 | 4.6 | 0.32 | 8.4 |
| Jiffy pot | 24.8 | 21.8 | 1.13 | 7.2 | 0.29 | 10.2 |
| | | | **Lettuce** | | | |
| M1 | 5.3 | 9.6 | 0.55 | 6.6 | 1.24 | 9.6 |
| M2 | 5.0 | 9.8 | 0.51 | 6.2 | 1.24 | 8.6 |
| M3 | 4.6 | 7.4 | 0.62 | 6.4 | 1.39 | 8.8 |
| Jiffy pot | 5.1 | 5.1 | 1.00 | 7.0 | 1.37 | 9.5 |

**Table 4.**
*Comparative morphological characteristics of seedlings planted in biodegradable pots with different compositions.*

**Figure 13.**
*Tomatoes and lettuce plants obtained using the experimental nutritive biodegradable pots.*

when the pots benefit by rhizosphere effect of seedling. In these circumstances, there are differences between the two types of tested seedlings. Therefore, the daily biodegradation rate of lettuce seedling is with 0.02–0.08% higher than tomatoes seedling. This is based on the existence of an initial rate of roots growth which is more intense in lettuce than tomatoes.

From the results presented in the **Table 4** and **Figure 13** regarding the growth and development of lettuce and tomatoes seedlings, it can be observed that for all the studied versions, the growth indicators have values that allow the framing within the favorable limits according to the data from specialty literature. The mass indicators show accumulations that have allowed normal growth. The experiences have shown that for both the lettuce and tomatoes, the type of pots used for seedling and transplanting strongly influences the number of leaves and roots volume. By visual appreciation, it has been found that the good development of the seedlings is also related to the good penetration of the roots through the walls of the pots, even if their effective biodegradation was quite small. This aspect is mainly related to the mechanical properties of the nutritive pots, especially the penetration resistance. It is also observed that the morphological properties of the plants raised in the experimentally pots are comparable to those of the plants developed in currently existing Jiffy pots.

## 4. Conclusions

In our experimental programs, three compositional versions of biodegradable nutritive pots based on 50 and 70% peat, 30% recycled cellulose fibers, and organic and mineral nutritive materials between 0 and 2% were tested; these biodegradable nutritive pots were tested on production of lettuce and tomatoes seedlings.

The results on mechanical strengths (wet and dry) demonstrated the importance of fibrous composition and chemistry relative to the formation and integrity of biodegradable nutritive pots for the seedling production process.

The additional nutrients (mineral or organic) stimulate the pulp degradation; therefore, the pots containing both chemical (for nutrient contribution) and natural (waste from grape processing) additives—M2 version—showed the highest biodegradation potential.

For all the studied versions of pots, the specific indicators of plant growth have values that allow them to be framed within the limits of favorability, ensuring a normal growth of plants.

The obtained results are promising and the biodegradable nutritive pots based on lignocellulosic materials can be used in the seedlings manufacturing process; based on their composition, these products can be considered a good reserve of organic materials for soil. These materials are nontoxic and biodegradable, according to the provisions of European Directives, concerning reduction of environmental pollution with plastics from agricultural sources. Furthermore, it represents a real opportunity to stimulate transition towards a circular economy.

## 5. Future recommendations

The experiments will be continued with testing of biodegradable pots on other types of seedling as well as for optimization of wet strength additives content aiming to ensure an adequate biodegradation according with the duration of seedling development.

## Acknowledgements

The author thanks for support of Research and Consultancy Centre for Environmental and Agriculture “Lunca” from Dunărea de Jos University of Galați, Romania.

## Conflict of interests

The author declares no potential conflicts of interest with respect to the research, authorship, and/or publication of this chapter.

## Author details

Petronela Nechita
Department of Environmental, Applied Engineering and Agriculture,
"Dunărea de Jos" University of Galați, Romania

*Address all correspondence to: petronela.nechita@ugal.ro

## References

[1] Carrión C, Abad M, Maquieira A, Puchades R, Fornes F, Noguera V. Leaching of composts from agricultural wastes to prepare nursery potting media. Acta Horticulturae (ISHS). 2005;**697**:117-112

[2] Hurley S. Postconsumer Agricultural Plastic Report. California Integrated Waste Management Board; Published by California Environmental Protection Agency; 2008

[3] Levitan L, Barros A. Recycling agricultural plastics in New York state. In: A Research Report Prepared for the Environmental Risk Analysis Program. Ithaca, New York: Cornell University; 2003

[4] Treinytea J, Grazulevicienea V, Bridziuviene D, Svediene J. Properties and behaviour of starch and rapeseed cake based composites in horticultural applications. Estonian Journal of Ecology. 2014;**63**(1):15-27. DOI: 10.3176/eco.2014.1.02

[5] Welleman JCC. Fytocell, an increasingly popular substrate. Acta Horticulturae (ISHS). 2005;**697**:195-198

[6] Evans MR, Taylor M, Kuehny J. Physical properties of biocontainers for greenhouse crops production. HortTechnology. 2010;**20**(3):549-555

[7] Nambuthiri S, Schnelle R, Fulcher A, Geneve R, Koeser A, Verlinden S, et al. Alternative containers for a sustainable greenhouse and nursery crop production. Agriculture & Natural Resources. 2013;**1**(11)

[8] Seiichiro I, Hongkang Z. Products Based on Corn Gluten Meal and Other Agro Byproducts, World Conference and Exhibition on Oilseed and Vegetable Oil Utilization. Istanbul, Turkey; 2006

[9] Robinson T. Containers evolve to satisfy industry, retailer, and consumer needs. GMPro. 2008;**28**(1):35-40

[10] Environment Australia. Biodegradable Plastics – Developments and Environmental Impacts, Ref: 3111-01/ October 2002, Prepared by NOLAN-ITU Pty Ltd in Association with ExcelPlas Australia; 2002. pp. 37-40

[11] Yue C, Hall CR, Behe BK, Campbell BL, Dennis JH, Lopez RG. Are consumers willing to pay more for biodegradable containers than for plastic ones? Evidence for hypothetical conjoint analysis and nonhypothetical experimental auctions. Journal of Agricultural and Applied Economics. 2010;**42**(4):757-772

[12] Camberato D, Lopez R. Biocontainers for Long-Term Crops. Greenhouse Grower; 2010. Available from: https://www.greenhousegrower.com/production/pots-trays/biocontainers-for-long-term-crops/

[13] Abaecherli A, Popa VI. Lignin in crop cultivations and bioremediation. Environmental Engineering and Management Journal. 2005;**4**(3):273-292. DOI: 10.30638/eemj.2005.030

[14] United States Patent, No. 6,490,827 B2. 2002

[15] Kirchhoff MM. Promoting sustainability through green chemistry. Conservation and Recycling, Resources. 2005;**44**:237-243

[16] Bobu E. Improving the effectiveness of papermaking chemicals by controlling the aggregation mechanisms. In: PIRA International Conferenece- Scientific and Technical Advances in Wet End Chemistry. 2004; 1-12 May, Nice, France

[17] Zhu S, Wu Y, Cheng Q , Yu Z, Wang C, Jen S, et al. Dissolution of cellulose with ionic liquids and its application: A mini-review. Green Chemistry. 2006;**8**:325

[18] Maljanen M, Sigurdsson BD, Guðmundsson J, Skarsson H, Huttunen JT, Martikainen P. Greenhouse gas balances of managed peatlands in the Nordic countries ñ present knowledge and gaps. Biogeosciences. 2010;**7**:2711-2738

[19] Verhoeven JTA, Setter TL. Agricultural use of wetlands: Opportunities and limitations. Annals of Botany. 2010;**105**:155-163

[20] Ingram DL, Nambuthiri S. Using plantable containers for selected ground-cover plant production. Hortscience. 2012;**47**(9). (Supplement) SR–ASHS Annual Meeting—February 3-6, 2012

[21] Maljanen M, Sigurdsson BD, Guðmundsson J, Óskarsson H, Huttunen JT, Martikainen PJ. Greenhouse gas balances of managed peatlands in the Nordic countries, present knowledge and gaps. Biogeosciences. 2010;**7**:2711-2738

[22] Evans MR, Taylor M, Kuehny J. Physical properties of biocontainers for greenhousec rops production. HortTechnology. 2010;**20**:549-555

[23] Wang X, Fernandez T, Cregg B, Fulcher A, Geneve R, Niu G, et al. Performance of alternative containers and plant growth and water use of *Euonymus fortune*. Hortscience. 2012;**47**(9):S2.(Abstr.)

[24] Taylor M, Evans M, Kuehny J. The beef on biocontainers: Strenght, water use, biodegradability and greenhouse performance. OFA Bulletin. 2010;3:923

[25] Orliac O, Rouilly A, Silvestre F, Rigal L. Effects of various plasticizers on the mechanical properties, water resistance and aging of thermo-moulded films made from sunflower proteins. Industrial Crops and Products. 2003;**18**:91-100

[26] Nechita P, Bobu E, Ciolacu F, Dobrin E, Biocomposites from renewable resources – biodegradable nutritive support for containerized seedling manufacturing. 2009; National Research Programme, BIOSUN project - Contract no. 51-090, stage 3

[27] Nechita et al. Biodegradable pots for planting. BioResources. 2010;**5**(2):1102-1113

[28] Ampulski RS, Neal CW. The effect of inorganic ions on the adsorption and ion exchange of Kymene 557H by bleached northern softwood Kraft pulp. Nordic Pulp & Paper Research Journal. 1989;**2**:155-163

[29] Roberts JC. Wet-strength additives. In: Roberts JC, editor. Paper Chemistry. 2nd ed. Blackie Academic & Professional; 1996. pp. 104-107. Available from: https://www.springer.com/la/book/9780751402360

[30] Yoon SH. Adsorption kinetics of polyamide-epichlorohydrin on cellulosic fibres suspended in aqueous solution. Journal of Industrial and Engineering Chemistry. 2006;**12**(6):877-881

[31] Ştefanic G. Probleme de agrofitotehnie teoretică şi aplicată. 1999;**XXVIII**(Supplement):45-50

[32] Bourtoom T. Plasticizer effect on the properties of biodegradable blend film from rice starch.Chitosan. Songklanakarin Journal of Science and Technology. 2008;**30**(Suppl. l):149-155

[33] Szegi J. Cellulose Decomposition and Soil Fertility. Budapest: Akademiai Kiado; 1988. pp. 65-68