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AMARANTH, A MODEL FOR THE FUTURE BIOREFINERY OF WHOLE PLANTS

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ABSTRACT

Amaranth is an annual herb native to temperate and tropical regions. It is a promising raw material for the biorefinery of whole plants. Looking at the large amounts of starch, proteins and squalene inside its seeds, the latter could find applications in many fields like the food, cosmetics and material industries. This study specifically investigated the possible uses of stems for material applications. Stems are composed of a bark on their periphery (90% w/w) and a pith fraction in their middle (10%). A fractionation process was developed for separating mechanically and continuously these two fractions. Due to their low density (47 kg/m³), pith particles could be used as thermal insulating materials inside buildings. For its part, grinded bark was successfully used for the manufacture of fiberboards using hot pressing. Looking at its usage properties, the optimal hardboard produced appeared as a viable option for replacing current commercial wood-based materials.

KEYWORDS

Amaranth, biorefinery, whole plant, stem, material applications

INTRODUCTION

Amaranth is an annual herb native to temperate and tropical regions. For a very long time, various amaranth species have been grown for food in Asia, Central and South America, and Africa. It was cultivated by Native Americans for the nutritional properties of its seeds, the latter being very digestible and also an interesting source of starch and proteins. For the future, amaranth appears as a promising raw material for the biorefinery of whole plants, all parts of the plant being potentially usable for different food and non-food applications.

Firstly, the seeds contain 7-8% lipids, this fraction being particularly rich in squalene of vegetal origin (5-6%), a triterpene acting as an essential intermediate in the biosynthesis of cholesterol, steroid hormones and vitamin D for humans. Squalene could be used as food supplement or in cosmetics (Ott et al., 2015). Proteins represent 15% of the amaranth seeds mass. Seeds could be a food source of first rank in the formulation of bread flours as a protein reinforcement. Amaranth proteins are also known for their biocidal activity and as antioxidants (Caselato-Sousa and Amaya-Farfán, 2012). In addition, they would be potentially usable for their emulsifying capacities (surfactants for food or in cosmetic creams) or for their adhesive properties in the panel industry. Amaranth seeds also contain a large amount of starch (up to 55%). After its plasticization/gelatinization (plus the denaturation of proteins) through a thermo-mechano-chemical pre-treatment using the twin-screw extrusion technology, amaranth seeds could thus be possibly transformed into thermoplastic granules for injection-moulding applications.

Secondly, stems are composed of a bark (*i.e.* a woody part or ligneous fraction) on their periphery and a pith fraction in their middle. This study especially aims to investigate the possible uses of stems for material applications.

RESULTS

Wild plants from the *Amaranthus cruentus* variety were manually harvested in November 2017 near Auch (Gers, France). Then, the structure of stems was studied from ten samples, and the pith fraction was estimated to 10% w/w. Due to the difference in density between bark and pith fractions, a fractionation process associating grinding and blowing steps made possible the continuous separation between bark and pith.

As for sunflower and corn, amaranth pith particles have an alveolar structure, and they reveal a very low bulk density (47 kg/m³ for 4-16 mm particle size), making them a promising raw material for the thermal insulation of buildings. On the other hand, the chemical composition of amaranth bark was very close to that of sunflower bark. It revealed high cellulose content (44%), lignins, hemicelluloses and water-soluble compounds representing 20%, 18% and 15%, respectively, of its dry mass. Thus, it has a real potential in the field of composite materials, especially for the production of dense fiberboards, *i.e.* hardboards (HB), through hot pressing. The latter would be usable in furniture, lignins inside amaranth bark potentially contributing to the board water resistance.

A cohesive HB was obtained with success from grinded amaranth bark (4 mm), using next conditions: 200 °C temperature, 19.6 MPa pressure, and 5 min moulding time. For such board, no external binder was added, thus illustrating the adhesive ability of some chemicals inside bark, especially free sugars, hemicelluloses and possibly lignins. Flexural strength at break, elastic modulus and thickness swelling were 13.2 MPa, 2.1 GPa and 143%, respectively (Table 1).

The usage properties of HB were much improved when adding an external binder. Three different natural binders were used successfully, with 20% and 40% addition: two protein-based binders (*i.e.* a deoiled coriander cake (C) and a protein isolate from sunflower cake (S)), and a starch-based one (*i.e.* deoiled amaranth seeds (A)). Best properties were obtained when adding 40% S: 18.2 MPa flexural strength (+38%), 2.4 GPa elastic modulus (+14%), and 82% thickness swelling (-42%) (Table 1). Such optimal board could present a viable, sustainable alternative for current commercial wood-based materials such as oriented strand board (OSB), particleboard (PB) and medium-density fiberboard (MDF), with high cost-effectiveness.

Table 1. Density, mechanical properties and water resistance of fiberboards produced from amaranth bark using hot pressing (200 °C temperature, 19.6 MPa pressure, and 5 min moulding time).

| Board number | Binder type | Binder content (%) | d | Shore D (°) | σ_f (MPa) | E_f (GPa) | TS (%) | WA (%) |
|--------------|-------------|--------------------|------|-------------|--------------------|-------------------|------------------|------------------|
| NB | No binder | 0 | 1.23 | 74.1 | 13.2 (± 2.4) | 2.1 (± 0.4) | 143 (± 11) | 124 (± 8) |
| C1 | C | 20 | 1.23 | 74.7 | 18.1 (± 1.5) | 2.4 (± 0.3) | 123 (± 12) | 113 (± 14) |
| C2 | C | 40 | 1.29 | 78.1 | 20.3 (± 2.1) | 2.6 (± 0.4) | 110 (± 9) | 103 (± 3) |
| S1 | S | 20 | 1.38 | 73.6 | 19.1 (± 1.4) | 2.9 (± 0.3) | 109 (± 22) | 106 (± 28) |
| S2 | S | 40 | 1.38 | 74.5 | 18.2 (± 1.6) | 2.4 (± 0.2) | 82 (± 9) | 76 (± 3) |
| A1 | A | 20 | 1.25 | 75.8 | 18.8 (± 1.7) | 2.7 (± 0.5) | 136 (± 10) | 124 (± 7) |
| A2 | A | 40 | 1.24 | 75.7 | 18.5 (± 2.3) | 2.0 (± 0.4) | 132 (± 20) | 132 (± 11) |

d, density; *Shore D*, surface hardness; σ_f , flexural strength at break; E_f , elastic modulus; *TS*, thickness swelling after 24 h immersion in water; *WA*, water absorption after 24 h immersion in water.

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Amaranth, a model for the future biorefinery of whole plants

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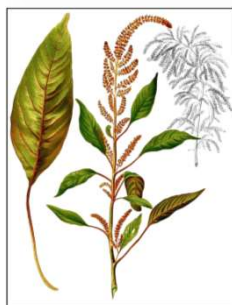
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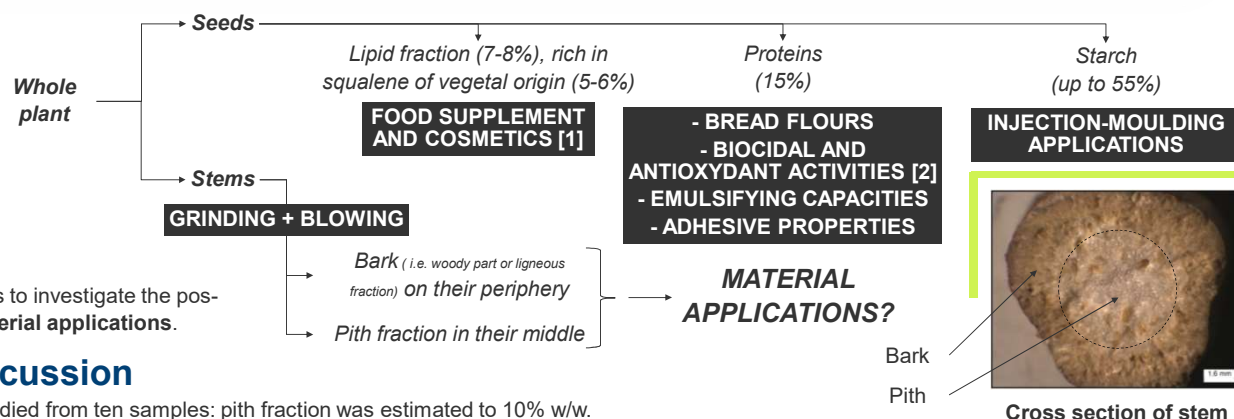
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Introduction



- ▶ *Amaranthus cruentus*, an annual herb native to temperate and tropical regions (cultivated for the nutritional properties of its seeds).
- ▶ For the future, amaranth appears as a promising raw material for the biorefinery of whole plants, all parts of the plant being potentially usable for different food and non-food applications:



Amaranthus cruentus

- ▶ This study especially aims to investigate the possible uses of stems for **material applications**.

Results and discussion

- ▶ Structure of stems was studied from ten samples: pith fraction was estimated to 10% w/w.
- ▶ Difference in density between bark and pith fractions ⇒ Continuous separation possible through (i) **grinding** and (i) **blowing** steps.
- ▶ Alveolar structure for the pith particles ⇒ Very low bulk density (47 kg/m³ for 4-16 mm particle size) ⇒ Promising raw material for **thermal insulation**.
- ▶ High lignocellulose content for the bark particles (**Table 1**) ⇒ Potential for the production of dense fiberboards, *i.e.* **hardboards (HB)**, through **hot pressing**.
- ▶ A cohesive HB was obtained with no external binder added (NB) ⇒ Adhesive ability of some chemicals inside bark (free sugars, hemicelluloses and lignins).
- ▶ Usage properties of HB much improved when adding an external binder: C, deoiled coriander cake; S, sunflower protein isolate; A, deoiled amaranth seeds.
- ▶ **Best properties obtained when adding 40% S (S2) ⇒ Viable, sustainable alternative for current commercial wood-based materials (OSB, MDF, etc.).**

Tableau 1. Chemical composition of amaranth bark (% of dry matter).

| Component | Cellulose | Hemicelluloses | Lignins | Minerals | Water-solubles |
|-----------|------------|----------------|------------|-----------|----------------|
| Content | 43.6 ± 0.7 | 17.6 ± 0.4 | 20.3 ± 0.6 | 9.3 ± 0.3 | 14.8 ± 0.9 |

Tableau 2. Density, mechanical properties and water resistance of fiberboards produced from grinded amaranth bark (4 mm) using hot pressing (200 °C temperature, 19.6 MPa pressure, and 5 min moulding time).

| Board number | Binder type | Binder content (%) | d | Shore D (°) | σ _f (MPa) | E _f (GPa) | TS (%) | WA (%) |
|--------------|-------------|--------------------|-------------|-------------|----------------------|----------------------|---------------|---------------|
| NB | No binder | 0 | 1.23 | 74.1 | 13.2 ± 2.4 | 2.1 ± 0.4 | 143 ± 11 | 124 ± 8 |
| C1 | C | 20 | 1.23 | 74.7 | 18.1 ± 1.5 | 2.4 ± 0.3 | 123 ± 12 | 113 ± 14 |
| C2 | C | 40 | 1.29 | 78.1 | 20.3 ± 2.1 | 2.6 ± 0.4 | 110 ± 9 | 103 ± 3 |
| S1 | S | 20 | 1.38 | 73.6 | 19.1 ± 1.4 | 2.9 ± 0.3 | 109 ± 22 | 106 ± 28 |
| S2 | S | 40 | 1.38 | 74.5 | 18.2 ± 1.6 | 2.4 ± 0.2 | 82 ± 9 | 76 ± 3 |
| A1 | A | 20 | 1.25 | 75.8 | 18.8 ± 1.7 | 2.7 ± 0.5 | 136 ± 10 | 124 ± 7 |
| A2 | A | 40 | 1.24 | 75.7 | 18.5 ± 2.3 | 2.0 ± 0.4 | 132 ± 20 | 132 ± 11 |

d, density; Shore D, surface hardness; σ_f, flexural strength at break; E_f, elastic modulus; TS, thickness swelling after 24 h immersion in water; WA, water absorption after 24 h immersion in water.



Photographs of fiberboards produced

Conclusion

- ▶ *Amaranthus cruentus*, a promising raw material for the **biorefinery** of whole plants!
- ▶ Large amounts of starch, proteins and squalene inside its seeds: possible applications in the food, cosmetics and material industries.
- ▶ Stems, composed of (i) a **bark** on their periphery (90% w/w), and (ii) a **pith fraction** in their middle (10%): usable for **material applications**.
- ▶ Possibility to separate mechanically and continuously these two fractions thanks to a fractionation process developed recently.
- ▶ Low density for pith particles: usable as **thermal insulating materials** inside buildings.
- ▶ Grinded bark successfully used for the manufacture of **fiberboards** using **hot pressing**.
- ▶ **Optimal hardboard (S2) ⇒ A viable option for replacing current commercial wood-based materials (usable in furniture, etc.)!**

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