



Assesment of Particle Size on the Physico-mechanical Behavior of Waste Low-Density Polyethylene/*Delonix regia* Seed Composite

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Abstract. *The excessive and widespread usage of single-use plastics has led to a growing concern over the accumulation of non-biodegradable waste in natural environments, posing a serious threat to global ecosystems. Incorporating agricultural residues into polymer composites as reinforcements presents a sustainable alternative, offering benefits such as low cost, ease of processing, reduced environmental impact, lightweight characteristics, and biodegradability. This research investigates how the particle size of *Delonix regia* (D.regia) seed waste influences the physico-mechanical properties of a composite made from waste low density polyethylene (wLDPE). The study found that increasing the particle size of the filler led to a gradual reduction in tensile strength, elongation at break, flexural strength, and density of the composite by 15.75 %, 75.93 %, 24.08 % and 14.08 % respectively. Conversely, larger filler particles enhanced the composite's hardness and impact resistance by 56.16 % and 76.07 % respectively. Additionally, water absorption increased with particle size, with the highest uptake observed in composites containing the largest particles and lowest in composites containing smallest particles.*

Keywords: *Composites; Agro-waste; Waste low-density polyethylene; *Delonix regia*; Physico-mechanical properties.*

Type of the Paper: Regular Article.

1. Introduction

Plastic has become an important material in our daily life due to its varying usage in different sectors like engineering, building, electronics, and the like. Plastic has the highest documented usage in the packaging industry due to its excellent properties, including durability, flexibility, and cost-effectiveness [1–3]. If current trends continue, the world could be producing around 34 billion tons of plastic by 2050. Alarmingly, approximately 12 billion tons of that material may not be recycled or properly managed, instead ending up in landfills or polluting our environment. Plastic waste has led to the reduction of oxygen intake by mankind and caused a high amount of environmental pollution. Compared to other widely used materials like glass, paper, aluminum, and ceramics, plastics tend to be recycled far less frequently, despite their massive consumption. According to research, about 9 % of plastic waste was recycled, and 79 % believed to have been

accumulated in the environment [1,3–5]. Scientists have identified plastic waste recycling as a promising approach, with numerous methods extensively proposed for its implementation [6]. Low density polyethylene (LDPE), a member of the polyethylene family, is a thermoplastic polymer extensively utilized in the packaging sector. Its widespread application, particularly in sachet water packaging, commonly referred to as “pure water,” is attributed to its favorable characteristics, including high toughness, flexibility at low temperatures, excellent electrical insulating capacity, and ease of forming [7].

Recent research has increasingly focused on repurposing discarded plastics into composite materials that support sustainable development [8]. Composites are engineered by combining two or more distinct phases of materials to produce a system with enhanced mechanical and functional performance [9]. Polymeric composites have attracted significant interest for their capacity to combine the advantageous traits of multiple components, yielding enhanced properties ideal for applications in industries such as automotive, construction, aerospace, and beyond [10]. The integration of agricultural residues as reinforcement in polymer composites has become a subject of interest due to their eco-friendly nature, biodegradability, cost-effectiveness, renewability, low density, and wide availability [11]. Composite materials made from plastic and agricultural waste offer a smart alternative to our environmental problems due to the biodegradability, cost-effectiveness, compostability, and enhanced stiffness associated with this polymeric composite material [12].

Delonix regia (*D.regia*) also known Flamboyant Flame Tree belongs to the *Fabaceae* family. This tree features a short, stout trunk with smooth, gray bark and a distinctive, pleasant scent. It is especially noted for its feathery foliage and striking orange-red blossoms that appear in the summer months. As the flowers fade, pods develop, containing the seeds. The pods initially are green and flexible but gradually harden, turning dark brown and woody as they mature. The seeds of *D.regia* often contribute to environmental litter, as the pods burst open and drop to the ground, especially during the dry season [13–15].

Numerous studies have explored the incorporation of food and agricultural by-products as reinforcing agents in polymer composites. These reinforcements are derived from a wide range of plant-based residues, including husks from wood, rice, coconut, pineapple, and sunflower, as well as various nutshells such as those from almonds, oil palms, argan, groundnuts, walnuts, hazelnuts, cashews, and beetles. Additionally, agricultural leftovers like wheat straw, corncob, rapeseed stalks, and sunflower stalks, along with other fruit and plant components, have also been utilized [16,17]. The selection of these materials is typically influenced by their local availability, the specific requirements of the end-use application, and the broader objective of managing surplus biomass efficiently.

The use of *D.regia* seed particles as reinforcement in polymer composites was first investigated by Awoyera and Adesina [18]. Their research focused on assessing the tensile behavior of the developed materials, employing a monovariate regression model structured around a full factorial experimental design with a single variable tested at five levels. The models developed revealed that the weight percentage (wt%) of *D.regia* particles significantly influenced both tensile strength and strain. While the findings were valuable, the real-world applicability of their model might be constrained. Later studies, including those by Achukwu et al., Umaru et al [13,19], expanded on this work by exploring the incorporation of *D.regia* seeds or pods as reinforcement in polymer matrices. These studies demonstrated that the resulting composites are suitable for applications in household items and construction materials. A notable limitation across many of these studies, however, is the reliance on thermosetting polymers, which are not recyclable, as opposed to thermoplastics that offer greater sustainability through recyclability.

While interest in sustainable composites made from waste plastics and natural fillers continues to grow, research specifically focused on incorporating *D.regia* seed particles into LDPE composites remains limited. In particular, there is a lack of detailed investigation into how the particle size of *D.regia* filler affects the physico-mechanical performance of such composites. Also in this part of the world only a few research work has been performed on the use of *D.regia* as agricultural filler in composite material to increase the biodegradability of such plastic material. This study aims to fill that gap by producing composites using *D.regia* seed particulates as reinforcement within a waste LDPE (wLDPE) matrix. The influence of varying particle sizes on key physico-mechanical properties was systematically examined. By exploring this relationship, the study not only evaluates the potential of *D.regia* as a viable natural filler but also contributes to addressing the environmental challenges posed by plastic waste. Through the integration of agricultural and plastic waste, this research proposes a sustainable pathway for transforming waste into value-added materials, promoting both environmental remediation and economic benefit.

2. Materials and methods

2.1 Sample Procurement and Preparation Protocol

Waste pure water sachets (wLDPE) were sourced within the ICSA Hall, Ahmadu Bello University, Zaria. They were washed, dried, and cut into smaller particle sizes. Dried *D.regia* seeds were obtained from Ahmadu Bello University, Zaria main campus. The dried *D.regia* pods were manually split to release the seeds, the seeds were dried, grind using a mechanical grinder, and the resulting seed particles were sieved using sieves of 150 μm , 300 μm , 500 μm , and 600 μm mesh size (Fig. 1).



Fig 1. *D.regia* Seeds and LDPE bags (pure water Sachet)

2.2 Composite Fabrication

The compounding process was carried out using a co-rotating compounding machine at a processing temperature of 150 °C to ensure uniform mixing of the materials (Fig. 2). The composite formulation consisted of 85 % waste low-density polyethylene (wLDPE) and 15 % *D.regia* seed particles, with each batch incorporating fillers of varying particle sizes. The compounded material was then transferred into a metal mold with dimensions of 12 cm × 12 cm and a thickness of 3 mm. Compression molding was performed at 150 °C under a pressure of 2.5 MPa for 5 minutes. After molding, the samples were cooled to room temperature and subsequently cut into appropriate dimensions for physico-mechanical testing (Fig. 3).



Fig 2. A compounding and compression moulding machine



Fig 3. Cut samples to undergo Physico-mechanical Testing

2.3 Physico-mechanical property tests

2.3.1 Tensile property test

The fabricated composite specimens underwent tensile testing in line with the ASTM D638 standard, using a 100 KN capacity Universal Testing Machine (Model: ZL-8006A) (Fig. 4). The test specimens were shaped into standard dumbbell profiles, measuring 100 mm × 15 mm × 3 mm. Each specimen was firmly mounted between the machine's grips and subjected to a uniaxial tensile load until failure occurred. During testing, both the elongation at break and the maximum load at failure were recorded. To ensure reliability and repeatability, each test was performed three times per sample, and the mean values were used for analysis.

$\text{Tensile strength} = \frac{F}{A}$ F = Force (Newton) A = Cross-sectional area (mm²)	(1)
$\text{Strain} = \frac{\Delta l}{l}$	(2)
$\text{Elongation at break} \times 100 \%$	(3)



Fig 4. Universal material Testing Machine (100 KN capacity)

2.3.2 Flexural property test

The flexural behavior of the composite specimens was evaluated following ASTM D790 guidelines, employing a Universal Materials Testing Machine (Model: Cat. NZ261, 100 KN capacity) (Fig. 5). Test pieces with dimensions of 100 mm × 30 mm × 3 mm were supported horizontally on two points, while a centrally positioned loading nose applied force at a uniform rate until the samples either fractured or attained their maximum deflection. To improve data accuracy, each measurement was performed in triplicate, and the average values were considered for further analysis. The flexural strength was computed using the equations given below:

$\text{Flexural strength} = \frac{3PL}{2bd^2}$	(4)
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P = Force/ Load (KN)

b = Width (mm)

d = Thickness (mm)

L = gauge length (mm)

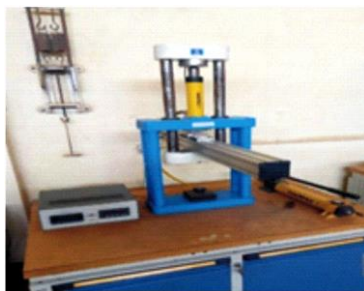


Fig 5. A Universal Materials Testing Machine

2.3.3 Impact Strength Test

The impact resistance of the composite materials was evaluated by the ASTM D256 standard using a Charpy impact testing machine (Model: HD96QD, Serial No.: CHARPY412-07-15269C) equipped with energy capacities of 15 J and 25 J. Test specimens with dimensions of 100 mm $\times$ 15 mm $\times$ 3 mm were mounted on the testing platform, and a controlled impact was applied using a pendulum drop mechanism. The energy absorbed by the material during fracture was recorded for each test. To ensure accuracy and repeatability, each test was performed three times, and the average values were reported.

2.3.4 Hardness Test

Vickers hardness of the composites was determined with an MV1-PC tester (S/N 07/2012-1329) following ASTM E92 (Fig. 6). Samples sized 30 mm $\times$ 30 mm $\times$ 3 mm were subjected to controlled indentations; impression measurements were then used to calculate the Vickers hardness numbers.



Fig 6. Vickers hardness tester (MV1-PC)

2.3.5 Density Test

To determine the density of the composites, a simple calculation based on their weight and size was employed. Small rectangular pieces, each 30 mm long, 30 mm wide, and 3 mm thick, were weighed at ambient temperature using a sensitive analytical balance. The size of each piece was measured with a digital vernier caliper, and its volume was obtained by multiplying the three dimensions. The density was then worked out by taking the weight of the sample and dividing it by its volume.

$\rho = \frac{M}{V}$	(5)
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ρ = density (g/cm³)
 M = mass (g)
 V = volume (cm³)

2.3.6 Water Absorption Test

For the water absorption test, dried composite samples with dimensions of 30 mm × 30 mm × 3 mm were first weighed and recorded as M_1 (g). These samples were then immersed in a container filled with distilled water at room temperature for a period of 30 days. At daily (24-hour) intervals, samples were removed from the bath, dried with a clean towel, and reweighed (M_2 in grams). Water absorption (%) was calculated from these measurements using the formula shown below.

$\text{Water Absorption}(\%) = \frac{M_2 - M_1}{M_1} \times 100$	(6)
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3. Results and Discussion

3.1 Tensile Strength

Fig. 7 displays the tensile strength of the composite material at various filler particle sizes of 150, 300, 500, and 600 μm . A noticeable trend was that the tensile strength of the composites decreased as the particle size increased from 150 μm to 600 μm . This reduction in strength can be attributed to the fact that smaller particles have a larger surface area, allowing for better dispersion and stronger interaction between the filler and the polymer matrix. This interaction enhances the transfer of stress between the matrix and the filler. However, as the particle size grows, the hydrophilic nature of the filler leads to weaker bonding with the hydrophobic polymer, creating voids within the composite. These voids reduce the material’s ability to transfer stress effectively. This behavior aligns with the observations of Umaru et al., Gozdecki and Wilczyn’ski, Zykova et al. [19–21], who also noted a decrease in tensile strength with increasing filler particle size.

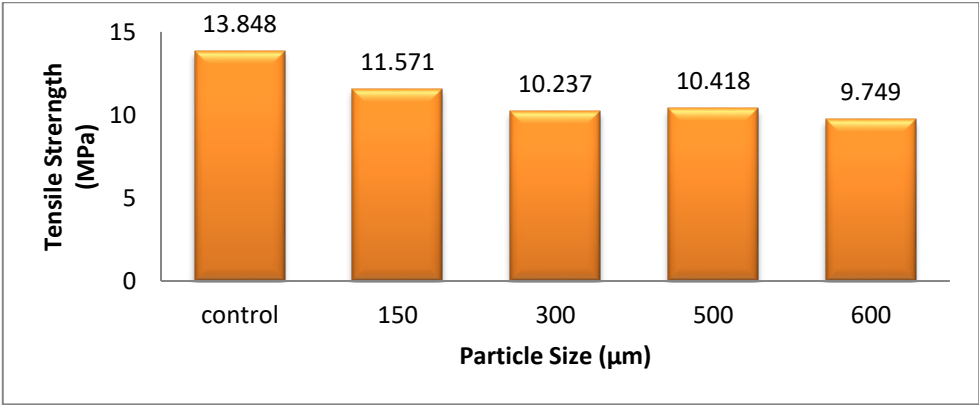


Fig. 7. Tensile Strength Response of wLDPE/*D.regia* Composites to Varying Filler Particle Sizes

3.2 Elongation at Break

The results for elongation at break are presented in Fig. 8, It was observed that the elongation at break of the composite decreased as the filler particle size increased from 150 μm to 600 μm . This decline can be attributed to the reduced surface area of larger particles, which limits effective interfacial bonding between the filler and the polymer matrix. As a result, the larger particles are less capable of aligning within the matrix to absorb and distribute applied stress, leading to reduced flexibility and ductility. In contrast, smaller filler particles possess a greater surface area, promoting stronger filler-matrix interaction and facilitating more efficient stress transfer. This contributes to higher elongation at break values. Furthermore, increased particle size can lead to filler agglomeration within the matrix, which impairs uniform stress distribution and reduces the overall flexibility of the composite. These findings are consistent with the trends reported by Umaru et al., Zykova et al., Onuoha et al. [19,21,22], who also observed a decrease in elongation at break with increasing filler particle size.

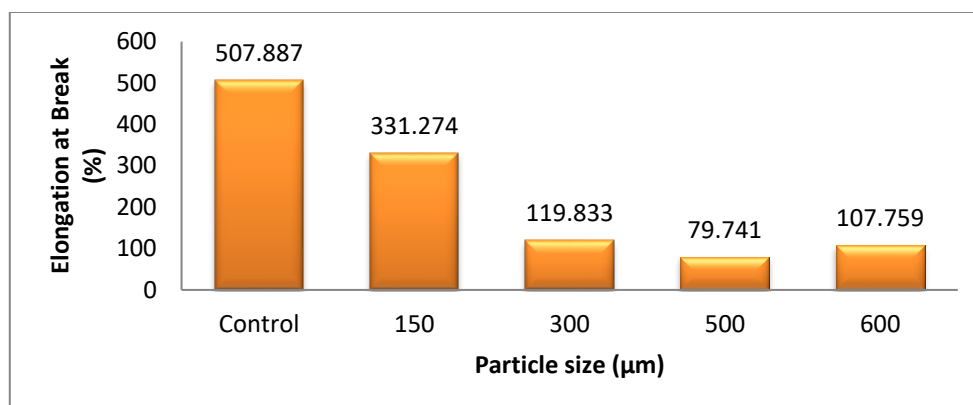


Fig. 8. Elongation at Break Behavior of wLDPE/*D.regia* Seed Composites as a Function of Filler Particle Size

3.3 Flexural Strength

Fig. 9 illustrates the flexural strength of the composite material at varying filler particle sizes of 150, 300, 500, and 600 μm . The results show an increase in flexural strength for composites containing filler particles sized 150 and 300 μm . However, a decline in flexural strength was observed for composites with filler sizes of 300, 500, and 600 μm . The improvement seen with finer particles is likely due to their larger surface area, which promotes better dispersion within the polymer matrix and stronger filler-matrix interaction, thereby facilitating more efficient stress transfer. Conversely, the observed decrease in strength at larger particle sizes may be related to imperfections introduced during the mixing process. Similar trends have been documented by Umaru et al., Onuoha et al., Lawal et al. [19,22,23].

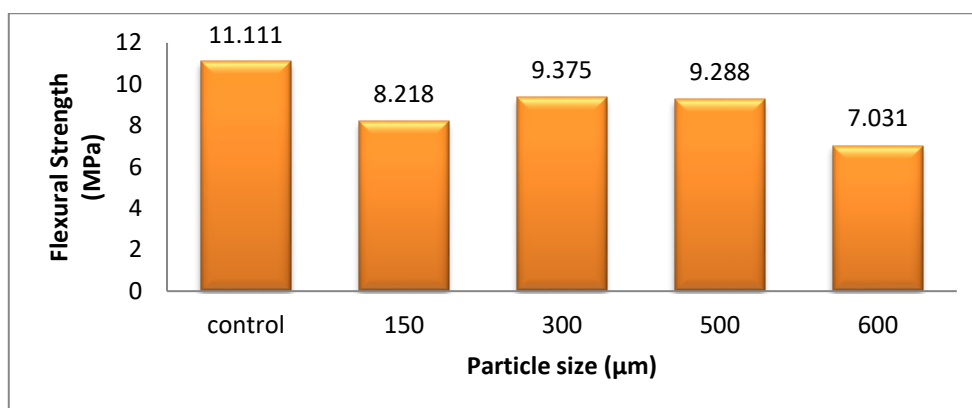


Fig. 9. Flexural Strength Variation of wLDPE/*D.regia* Seed Composites with Different Filler Particle Sizes

3.4 Impact Strength

Fig. 10 illustrates the influence of filler particle size on the impact strength of the composite material. The results show that the composite containing 150 μm filler particles exhibited the lowest impact strength, whereas the composite with 600 μm particles demonstrated the highest impact strength. The improvement in impact strength with increasing particle size is likely due to the larger fillers being less evenly dispersed throughout the matrix. Instead, these larger particles tend to accumulate near the composite surface, where they can absorb and dissipate impact energy before it reaches the polymer matrix. This mechanism enables the filler particles to act as crack stoppers or deflectors during impact, thereby enhancing the composite's resistance to fracture. Similar observations have been reported by Eze et al., Government et al. [12,24] in their studies on comparable composite materials.

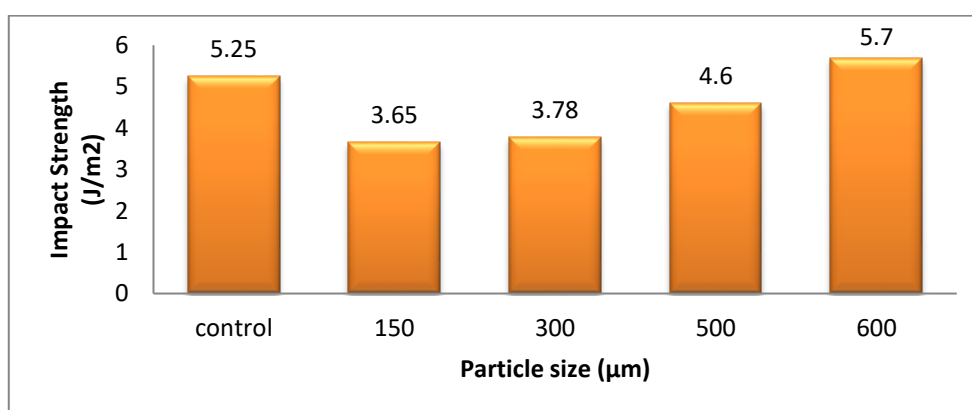


Fig. 10. Variation of Impact Strength in wLDPE/*D.regia* Seed Composites with Different Filler Particle Sizes

3.5 Hardness test

Fig. 11 shows the relationship between filler particle size and the hardness of the composite

material. The data indicate that hardness progressively increases as the filler particle size expands from 150 μm to 600 μm . This enhancement in hardness is likely linked to the tendency of larger filler particles to cluster near the composite's surface due to uneven distribution within the polymer matrix. Such agglomeration at the surface results in greater resistance to indentation forces, thereby elevating the overall hardness of the material. These findings align with similar observations reported in previous studies by Bosan et al., Achukwu et al., Umaru et al. [11,13,19].

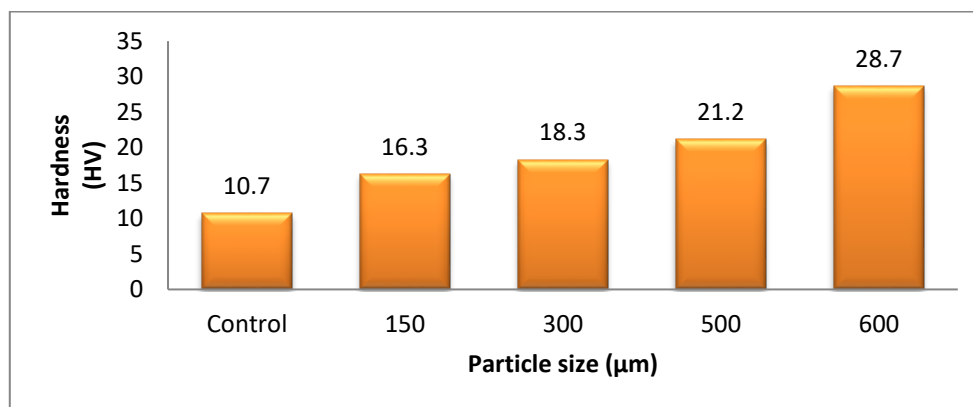


Fig. 11. Hardness Response of wLDPE/*D.regia* Seed Composites to Different Filler Particle Sizes

3.6 Density

Fig. 12 depicts the impact of filler particle size on the density of the composite material. The results demonstrate a decline in composite density as the filler particle size increases. This decrease is likely due to the diminished contact surface area between larger filler particles and the polymer matrix, which weakens interfacial adhesion and promotes the formation of voids within the composite. The presence of these voids increases the composite's overall volume, thereby reducing its density. Consequently, the larger particle sizes contribute to less efficient packing and poorer dispersion, which together reduce matrix-filler interaction and lead to a lower composite density. Similar findings were observed by Umaru et al. [19] in composites fabricated with *D. regia* seed particles and unsaturated polyester resin.

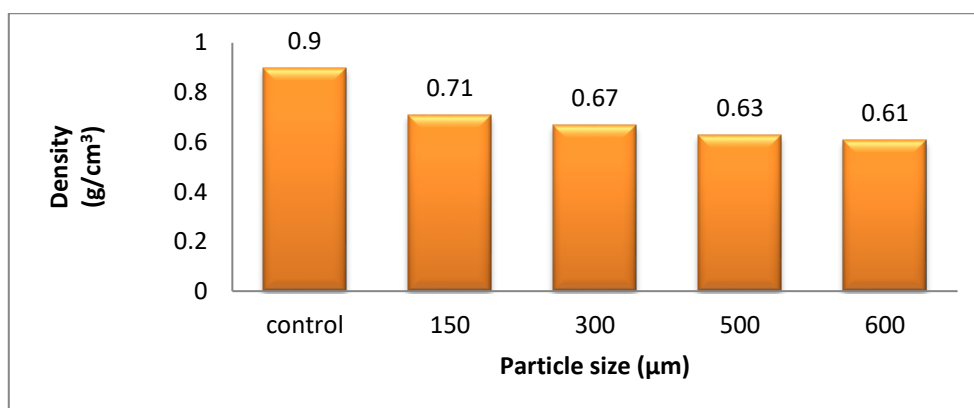


Fig. 12. Density Variation in wLDPE/*D.regia* Seed Composites as a Function of Filler Particle Size

3.7 Water Absorption

Fig. 13 presents the water absorption percentages of composites with varying filler particle sizes after 30 days of immersion. The composite containing 600 μm filler particles exhibited the highest water absorption, while the composite with 150 μm particles showed the lowest absorption. The increased water uptake observed with larger filler sizes is likely due to weaker interfacial bonding between the filler and polymer matrix, which creates voids that facilitate moisture penetration into the composite's interior. Additionally, natural fillers are inherently hydrophilic and tend to absorb water; this effect is amplified when larger filler particles concentrate near the composite surface, enhancing moisture ingress. These findings agree with previous reports by Government et al., Eze et al. [5,12], who also observed a rise in water absorption corresponding with increased filler particle size.

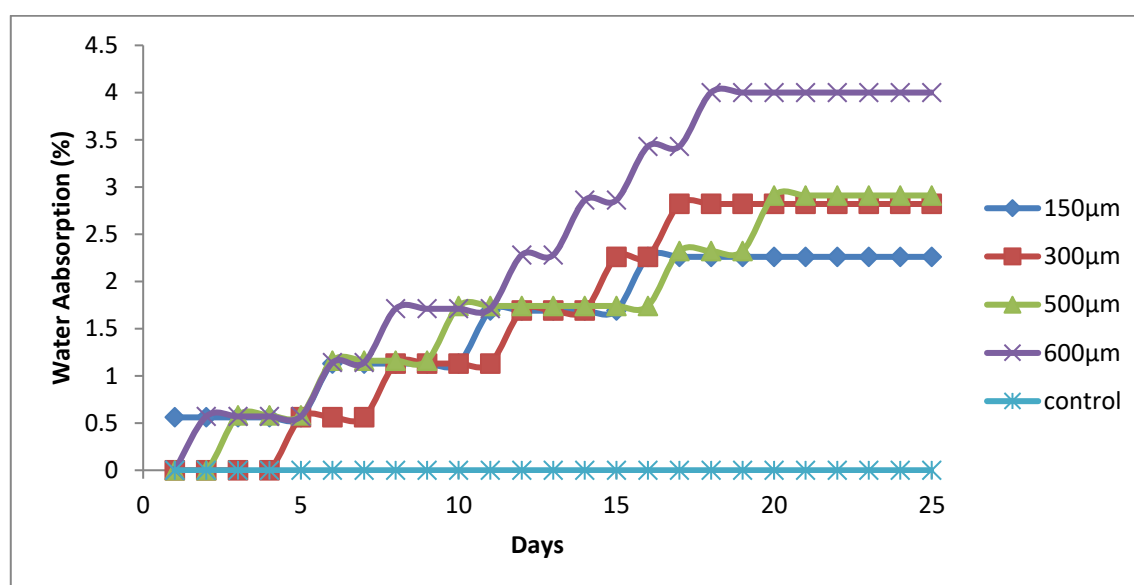


Fig. 13. Effect of particle size on water absorption of WLDPE/*D.regia* seed particulate composite

4. Conclusions

This study successfully demonstrated the potential of combining wLDPE with *D.regia* seed particles to produce composite materials. The findings establish that the particle size of the filler plays a significant role in influencing the physico-mechanical properties of the resulting composites. Among the tested samples, composites reinforced with 150 μm *D.regia* seed particles exhibited superior performance in terms of tensile strength, flexural strength, elongation at break, density, and water resistance. Conversely, composites containing 600 μm filler particles recorded the highest values in hardness and impact strength tests. The materials developed in these study exhibit properties that make them suitable for applications such as partition panels, boards, door components, and floor tiles. Overall, this research underscores the viability of converting plastic waste and agricultural residues into value-added products, offering both economic and environmental benefits through sustainable material development.

Declaration of Competing Interest

No Competing Interest.

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