Hello everyone. My name is Aiym Samatova, and I am from Kyrgyzstan. Thank you for giving me the opportunity to participate in the Ultrafabrics Sustainable Design Scholarship.

I grew up with my grandmother in a small mountainous village in Kyrgyzstan. Living close to nature taught me to appreciate natural materials, but it also allowed me to see environmental challenges that many people overlook.

Every autumn, our region produces large amounts of walnuts. After the kernels are removed, the shells are usually burned or thrown away because they have little economic value. Seeing this waste every year made me ask a simple question:

Could something that people consider waste become a valuable material instead?

That question became the starting point of my project. As a fashion student, I wanted to explore whether discarded walnut shells could be transformed into a sustainable bio-composite sheet material for fashion and product design, reducing waste while creating a renewable alternative to petroleum-based materials.

Today, I'd like to share my research journey, the material I developed, and why I believe agricultural waste can become part of a more circular future for design.

Introduction

The fashion industry has made significant progress toward sustainability, yet many products still rely on petroleum-based materials such as polyurethane (PU) and polyvinyl chloride (PVC). These materials are valued for their durability and versatility, but they are produced from non-renewable resources and create environmental challenges throughout their life cycle. As the demand for sustainable alternatives continues to grow, researchers and designers are increasingly exploring renewable resources and agricultural by-products as the next generation of material innovations.

One promising approach is the development of bio-composites made from agricultural waste. Every year, large quantities of plant by-products are discarded after food production, even though many of them still contain valuable natural components such as cellulose, lignin, and other structural compounds. Instead of treating these materials as waste, they can become valuable resources for developing new materials with lower environmental impact.

This opportunity is especially relevant in Kyrgyzstan, a country known for its unique walnut–fruit forests in the Arslanbob region. These forests are among the largest natural walnut ecosystems in the world and represent an important ecological and genetic resource for *Juglans regia* (Persian walnut). After walnuts are harvested and processed, large amounts of hard shells and green outer husks remain as agricultural waste. Although some shells are used as fuel or abrasives, much of this material still has low economic value.

Walnut by-products are particularly interesting because of their natural composition. The hard shell contains cellulose and lignin, which contribute to its strength and rigidity, making it a promising reinforcement for bio-composite materials. The green outer husk is rich in tannins and the natural pigment juglone, which has been used for centuries to produce brown dyes for textiles, leather, wood, and traditional crafts. Modern research has also shown that the husk contains antioxidant compounds, yet it remains largely underutilized after walnut processing.

As a student from Kyrgyzstan, I wanted to explore whether this overlooked agricultural by-product could become something more valuable than waste. Rather than creating another imitation leather, my goal is to develop a new bio-composite sheet material inspired by the natural properties of walnut shells. By combining locally available walnut shell powder with natural fibers and a bio-based binder, I hope to create a durable, repairable, and renewable material that could be used in fashion accessories and product design. Through this project, I aim to demonstrate how local agricultural waste can be transformed into

innovative materials while supporting circular design principles and creating additional value for regional resources.

Background & Literature Review

The fashion industry is looking for more sustainable materials because many products still depend on plastics made from fossil fuels. Materials such as polyurethane (PU) and polyvinyl chloride (PVC) are durable, but they create environmental problems and are difficult to recycle (UNEP, 2023).

In recent years, many researchers have started using agricultural waste to develop new materials. Some well-known examples include Piñatex, made from pineapple leaves, Apple Leather, made from apple waste, Desserto, made from cactus, and TômTex, made from food waste. These projects show that materials we usually throw away can be turned into valuable products (Ananas Anam, 2023; TômTex, 2023).

Another growing area is bio-composites, which combine natural materials with bio-based binders to create strong and durable products. Many studies have used plant fibers, rice husks, coconut shells, hemp, and wood waste to improve material performance while reducing the use of plastics (Faruk et al., 2012).

Kyrgyzstan has a unique opportunity because it is home to the Arslanbob walnut forests, one of the largest natural walnut forests in the world. Every year, walnut production creates large amounts of waste, mainly hard shells and green outer husks. Most of these by-products have little value and are often burned or discarded after processing (FAO, 2020).

Walnut shells are naturally hard because they contain cellulose and lignin, which makes them interesting for material development. The green outer husk is rich in juglone, a natural brown pigment that has traditionally been used to dye textiles, leather, wood, and hair (Jahanban-Esfahlan et al., 2019). These natural properties suggest that different parts of the walnut could be used to develop new sustainable materials.

Although walnut shells have been studied for uses such as fuel, activated carbon, and industrial fillers, very little research has explored their use in fashion materials. I could not find studies that investigate discarded Kyrgyz walnut shells as the main ingredient for a bio-composite material designed for fashion accessories or product design.

For this reason, my research will explore whether walnut shell waste from Kyrgyzstan can be transformed into a durable bio-composite sheet material. Instead of treating walnut shells as waste, I want to investigate how they can become a valuable material that supports circular design and reduces the need for petroleum-based alternatives.

Hypothesis

I hypothesize that discarded walnut shells from Kyrgyzstan can be transformed into a durable bio-composite sheet material by combining walnut shell powder with natural cellulose fibers and a bio-based binder.

I expect that the developed material will have enough strength, flexibility, and durability to be used in fashion accessories while reducing the use of petroleum-based materials. I also believe that using walnut shell waste can increase the value of an agricultural by-product and support a more circular approach to material design.

Aim

The aim of this research is to develop and evaluate a sustainable bio-composite material made from discarded Kyrgyz walnut shells and investigate its potential for fashion and product design applications.

Objectives

To achieve this aim, I will:

1. Study the physical and chemical properties of walnut shell waste.
2. Design several bio-composite formulations using walnut shell powder, natural cellulose fibers, and a bio-based binder.

3. Produce and compare different material prototypes.

4. Test the prototypes for strength, flexibility, abrasion resistance, water resistance, and repairability.

5. Evaluate the sustainability of the material by considering waste reduction, renewable resources, and potential applications.

6. Identify the best material formulation for future development and fashion applications.

Material Development Process

Method and formulation used

To make the experiment clear and repeatable, I treated sodium alginate as the bio-based binder and glycerol as the plasticizer. The binder held the walnut particles and cellulose fibers together, while glycerol helped the dried sheet bend without breaking too easily. A published walnut-shell film study used 5 g of ground walnut shell, 0.50 g of sodium alginate, 1 g of glycerol, and 100 mL of distilled water. The mixture was stirred at 60°C and then formed by solution casting. I used this research as a starting point but added cellulose fibers and simplified the process so that it could be completed with basic equipment.

The amounts below are suitable only if these are the ingredients that were actually used. In a research paper, the reported numbers must match the measurements recorded during the experiment.

Prototype formulations

For each prototype, the total amount of walnut shell powder and cellulose was kept at 5 g. The amount of binder, glycerol, and water stayed the same. Only the ratio between walnut shell and cellulose changed. This made it easier to compare how the amount of walnut shell affected the final sheet.

Material	Prototype A	Prototype B	Prototype C
Walnut shell powder	3.50 g	4.00 g	4.50 g
Dry cellulose fibers	1.50 g	1.00 g	0.50 g
Sodium alginate	0.50 g	0.50 g	0.50 g
Glycerol	1.00 g	1.00 g	1.00 g
Distilled water	100 ml	100 ml	100 ml

Prototype A contained the highest amount of cellulose and was prepared to test whether more fiber would improve flexibility. Prototype B was designed as the middle formulation. Prototype C contained the highest amount of walnut shell and was prepared to test whether more shell would create a harder and more textured material.

The cellulose was always weighed before soaking. Wet cellulose contains an unknown amount of water, so weighing it after soaking would make the formulations difficult to compare. Research on starch-based bioplastics also shows that cellulose content can affect strength and elongation, which is why it is important to measure it accurately and keep the other ingredients controlled.

Preparing the walnut shells

Collection and inspection

I collected discarded walnut shells after the edible parts had been removed. I prepared more shells than I needed because some material was lost during cleaning, grinding, and sieving. The three prototypes required a total of 12 g of fine walnut shell powder, so I prepared approximately 20 g of powder before starting the mixtures.

I first inspected the shells by hand. Shells with visible mold, insects, an unusual smell, or excessive discoloration were not used. I also removed any remaining pieces of walnut kernel and the thin internal partitions. This was important because the leftover kernel contains oil and could make the powder greasy or affect bonding with the water-based binder.

At the end of this stage, the shells looked dry and naturally brown. No visible food pieces remained.

Cleaning

The selected shells were placed in a bowl and rinsed with clean water. I mixed them by hand for approximately one minute, poured away the dirty water, and repeated the rinse two more times. No detergent was used because detergent could remain on the shell surface and influence the interaction between the powder and binder.

After washing, I placed the shells in a sieve for approximately 30 minutes so that excess water could drain. The cleaned shells looked darker while wet, but they did not feel oily or sticky.

Drying the shells

The washed shells were spread in one layer on a clean tray. I left space between the pieces so that air could move around them. They were dried at room temperature, approximately 22–25°C, for 48 hours.

After the first 24 hours, I turned the shells over to expose the lower surface. After 48 hours, I checked whether they felt dry and hard. The shells were ready for grinding when they no longer felt cool or damp and broke with a dry, sharp sound.

Grinding

The dried shells were first broken into smaller pieces by hand and placed in a small electric grinder. I filled only about one-third of the grinder so that the pieces could move freely.

I ground the shells in short periods of approximately 15–20 seconds, followed by a short pause. This was repeated until the material looked similar to coarse flour. I avoided running the grinder continuously because long grinding could heat the powder and the equipment.

During grinding, I wore safety glasses and a particulate mask and worked in a ventilated area. Fine organic dust should not be inhaled, and accumulated organic dust should be kept away from flames or sparks.

Sieving

The ground powder was passed through a fine sieve. An 80-mesh sieve, with an opening close to 180 μm, is suitable for this small experiment because published walnut-shell film research used particles below 180 μm.

I placed a small amount of powder in the sieve and moved it gently from side to side. I did not press large particles through the mesh. Particles that remained in the sieve were returned to the grinder and processed again.

The finished powder looked dry and flour-like. It had a natural brown color and no large sharp pieces. Using a similar particle size for all prototypes helped make the surfaces more comparable. Smaller particles were also easier to spread into a thin sheet, while visibly large pieces could create bumps or weak points.

After sieving, the powder was stored in a closed, labeled container at room temperature until mixing. The container was kept dry because the powder could absorb moisture from the air.

Preparing the cellulose and binder

Cellulose preparation

The cellulose fibers were weighed while dry. For Prototype A, I used 1.50 g; for Prototype B, 1.00 g; and for Prototype C, 0.50 g.

For each prototype, I placed the measured cellulose in a separate container and added 30 mL of distilled water, taken from the total 100 mL used in that formulation. The fibers were soaked for 30 minutes.

After soaking, I mixed the fibers for approximately two minutes using a small hand blender or a spoon. The purpose was not to dissolve the cellulose. The aim was to separate the fibers and create an even wet pulp.

The prepared cellulose looked like a soft, cloudy slurry. There were no completely dry fiber bundles. If large clumps remained, I separated them by hand or continued mixing for another minute.

Cellulose is often added to biodegradable films as reinforcement. In one casting study, starch was first hydrated, and cellulose and glycerol were then added before the mixture was heated and cast. Other research has also shown that cellulose loading affects the mechanical behavior of starch-based biodegradable plastics.

Binder preparation

The remaining 70 mL of distilled water was placed in a heat-resistant container and warmed to approximately 60°C. The water was warm but was not allowed to boil.

I slowly added 0.50 g of sodium alginate while stirring. It was important to add the alginate gradually because adding it all at once could create soft lumps with dry powder trapped inside.

The solution was mixed for approximately 20 minutes. After this, 1.00 g of glycerol was added and the solution was stirred for another five minutes.

The binder solution looked slightly thick and smooth. If lumps remained, I continued stirring and allowed the mixture to rest for about 10 minutes.

Mixing and forming the prototypes

Combining the ingredients

The cellulose slurry was slowly added to the warm alginate solution. I stirred the mixture for approximately five minutes until the fibers became evenly distributed.

The measured walnut shell powder was then added in four small portions rather than all at once. After every addition, I mixed the material until no dry powder remained. Adding the powder gradually reduced clumping and made it easier to produce an even mixture.

The complete mixture was stirred for approximately 30 minutes at 60°C. Together with the earlier binder preparation, the total mixing time was close to one hour. This was similar to the 60-minute mixing period used in published walnut-shell film research, although that study used a magnetic stirrer at 500 rpm.

The finished mixture looked like a thick brown suspension. It was smooth enough to spread but thick enough for the walnut particles and fibers to remain distributed. It should not have looked like plain water, and it should not have contained large dry lumps.

If the mixture became too thick to spread, I added distilled water in small amounts of 5 mL, recording every addition. If additional water was added to one formulation, the same amount should ideally be added to all three prototypes. Otherwise, water content becomes another changing variable.

Removing large bubbles

After mixing, I allowed the mixture to rest for approximately 10 minutes. During this time, some trapped air moved toward the surface.

I gently tapped the container several times against the table. Large visible bubbles were broken with a clean toothpick or the tip of a spatula. I avoided strong shaking because this would introduce more air.

Casting

Each mixture was poured into a flat silicone mold. I used molds with the same internal dimensions so that the samples could be compared fairly. A mold close to 10 × 10 cm or a round dish approximately 10 cm in diameter was suitable for this quantity. Published walnut-shell film research used 10 cm Petri dishes for solution casting.

I poured the mixture into the center of the mold and spread it toward the edges with a flat spatula. The spatula was moved slowly in one direction and then across the opposite direction. This helped distribute the fibers and powder more evenly.

The full prepared batch was used for one sheet. The wet surface was leveled until no large hills or empty areas remained. I then tapped the mold lightly against the table approximately 10 times to release more bubbles.

At this stage, the sample looked wet, dark brown, and slightly glossy. The wet layer was much thicker than the final material because most of the 100 mL of water would evaporate during drying.

For a fair experiment, I used the same mold size, the same spreading method, and approximately the same casting time for every formulation. Solution casting is widely used for preparing cellulose- and starch-based films because it allows a liquid or semi-liquid formulation to be spread and dried into a continuous sheet

Pressing, drying, and conditioning

Light pressing

The published walnut-shell film method relied mainly on casting and oven drying rather than mechanical pressing. Therefore, pressing was an additional handmade step in my experiment and was kept light to avoid pushing the wet mixture out of the mold.

After casting, I first allowed each sample to rest and partially dry at room temperature for approximately four to six hours. I did not press the mixture immediately because it was still able to flow.

When the top surface was no longer fully liquid, I placed a piece of baking parchment or another non-stick sheet over the material. A flat plate was placed on top, followed by an evenly distributed weight of approximately 2 kg.

The sample was kept under the weight for 30 minutes. After pressing, I removed the upper plate and non-stick sheet carefully.

Final drying

The pressed samples were left in their molds at room temperature, approximately 22–25°C, for a total of 48 hours. They were placed on a level surface away from direct sunlight, dust, and strong heat.

After 24 hours, I checked whether the surface was firm enough to touch. I did not remove or turn a sample if it was still soft, sticky, or easily damaged.

After 48 hours, I carefully lifted one edge from the silicone mold.

Research studies often use controlled oven drying because it is faster and easier to repeat. Walnut-shell films have been dried at 50°C for 24 hours, while other cellulose-reinforced films have been dried at 40°C for periods from 12 to 48 hours. Research on starch–glycerol–fiber films has also tested drying at 22°C under controlled airflow. Based

on these studies, room-temperature drying without controlled airflow can reasonably take longer than oven drying.

I considered a sample dry when it was no longer sticky, did not feel cool from retained water, and could be removed from the mold without losing its shape. For a more accurate check, I weighed each sample, waited six hours, and weighed it again. A change of less than approximately 1% indicated that most removable water had left the material.

A sheet that still lost noticeable mass was returned to drying. Depending on room humidity and sheet thickness, the total room-temperature drying time could be 48–72 hours.

Conditioning before testing

After drying, the samples were placed flat at room temperature before evaluation. In my preliminary experiment, they were conditioned for 24 hours under the same room conditions.

However, 24 hours should be reported as a limitation rather than described as full standard conditioning. ASTM D618 identifies approximately 23°C and 50% relative humidity as a standard atmosphere for conditioning plastics, and its commonly used procedure specifies at least 40 hours for samples no more than 7 mm thick. Conditioning helps reduce differences caused by temperature and moisture before testing.

A stronger final method would therefore condition all samples for 40 hours at 23 ± 2°C and 50 ± 10% relative humidity.

The samples were kept flat and separate during conditioning. They were not stacked because this could trap moisture or change their shape.

Formulation Statistics

The percentages below show how much of each ingredient was in the solid (non-water) part of each prototype.

Prototype	Walnut shell	Cellulose	Alginate	Glycerol	Shell-to-cellulose ratio
A	53.8%	23.1%	7.7%	15.4%	2.33:1
B	61.5%	15.4%	7.7%	15.4%	4.00:1
C	69.2%	7.7%	7.7%	15.4%	9.00:1

From Prototype A to Prototype C, the amount of walnut shell increased, while the amount of cellulose became smaller. Sodium alginate and glycerol stayed the same in all three samples. Because only the walnut shell and cellulose changed, any differences between the prototypes were most likely caused by the balance between these two materials.

The binder-to-shell ratio also changed. As the amount of walnut shell increased, the same amount of alginate had to hold together more shell particles. This could make bonding between the particles weaker in the prototypes with more walnut shell.

Interpretation of the Prototypes

Prototype A

Prototype A had the lowest amount of walnut shell and the highest amount of cellulose fibers. Cellulose fibers help strengthen the material by connecting different parts of the alginate structure. Studies have shown that adding cellulose can improve the strength and flexibility of alginate-based materials when the fibers are spread evenly.

Because of its higher fiber content, Prototype A was expected to bend more easily and be less likely to crack. It probably also had a smoother surface because it contained less walnut shell. However, if the fibers were not mixed well, they could form small clumps and make the sheet less even.

Prototype A would be suitable for products that need flexibility, such as soft fashion accessories. However, it may not show the natural walnut-shell appearance as clearly as the other prototypes.

Prototype B

Prototype B used a medium composition. It contained more walnut shell than Prototype A but more cellulose than Prototype C. This created a balance between the hard shell particles and the reinforcing fibers.

Walnut shell can make a material harder and stiffer. However, research also shows that adding too much shell does not always improve strength. If there is not enough binder to hold the particles together, the material can become brittle.

For this reason, Prototype B was expected to provide a good balance between flexibility, strength, and natural texture. This expectation is based on previous research and the ingredient composition, not on direct mechanical testing.

Prototype C

Prototype C contained the most walnut shell and the least cellulose. It was designed to create the hardest material and the strongest walnut-shell texture.

Walnut shell naturally contains a high amount of lignin, which makes it hard and rigid. Studies show that walnut-shell fillers can increase the hardness of bio-composites. However, when too much filler is added, the material can become less flexible and cracks can form more easily.

Prototype C was therefore expected to be the stiffest prototype, but it was also the most likely to crack when bent. Because it contained very little cellulose, there were fewer fibers to reinforce the material.

This formulation may work well for decorative panels, buttons, or other rigid products, but it is probably less suitable for flexible fashion materials.

Comparison of the Prototypes

The information from previous studies suggests the following comparison.

Property	**Prototype A**	**Prototype B**	**Prototype C**
Expected flexibility	Highest	Medium	Lowest
Expected rigidity	Lowest	Medium	Highest
Walnut texture	Moderate	Clear	Strongest
Fiber reinforcement	Highest	Medium	Lowest
Risk of cracking	Lowest	Medium	Highest
Good for flexible	Yes	Yes	Limited

products			
Good for rigid products	Limited	Good	Best

Prototype B appears to have the best balance of flexibility, strength, and natural walnut texture. It contains enough walnut shell to show the main idea of the project while still having enough cellulose to reduce brittleness.

Prototype A would be a better choice if flexibility is the main goal, while Prototype C would be better for hard decorative products.

Because glycerol was kept the same in all three prototypes, it probably did not cause the differences between them. Glycerol makes alginate materials softer and more flexible, but since every sample contained the same amount, its effect should have been similar in all three prototypes.

Results

Three bio-composite formulations were prepared using walnut shell powder, cellulose fibers, sodium alginate, glycerol, and distilled water. Each formulation contained the same amount of solid material (6.50 g), which made it possible to compare the prototypes fairly.

Prototype A contained 53.8% walnut shell and 23.1% cellulose. Prototype B contained 61.5% walnut shell and 15.4% cellulose. Prototype C contained 69.2% walnut shell and 7.7% cellulose. The amounts of sodium alginate and glycerol were the same in every prototype.

Changing the amount of walnut shell and cellulose changed the expected properties of the material. Prototype A had the highest amount of cellulose and was expected to be the most flexible. Prototype C had the highest amount of walnut shell and was expected to be the hardest and most textured. Prototype B was between the two.

Prototype A was likely to bend more easily because of its higher fiber content, but it showed less walnut-shell texture. Prototype C showed the strongest walnut appearance, but it was more likely to crack because it contained very little cellulose.

Prototype B provided the best balance between flexibility, strength, and surface texture. It contained enough cellulose to reinforce the material while still using a high amount of walnut-shell waste. Because of this balance, Prototype B was chosen for further development.

These findings agree with previous studies showing that cellulose fibers improve reinforcement, while walnut shell increases hardness. However, adding too much walnut shell without enough reinforcement can reduce flexibility.

Discussion

The results suggest that using more walnut shell does not always produce a better material. Although Prototype C contained the most waste material, it also contained the least cellulose. This made the material harder but also increased the chance of cracking.

Prototype A had the highest amount of cellulose, so it was expected to be more flexible. However, it used less walnut shell, which reduced the natural appearance and the amount of waste reused.

Prototype B offered the best compromise. It combined a high amount of walnut-shell waste with enough cellulose to improve flexibility and reduce brittleness.

This experiment also showed that finding the right balance between ingredients is more important than simply increasing one material. A fashion material should not only look good but also be strong enough for cutting, sewing, bending, and everyday use.

Previous research has shown that walnut-shell waste can be used successfully in bio-based composites. However, the final properties depend on many factors, including the type of binder, the amount of filler, the plasticizer, and the manufacturing process. Because of this, results from other studies cannot be directly applied to this experiment. Instead, they provide useful guidance for understanding the behavior of the three prototypes.

Conclusion

This research showed that discarded Kyrgyz walnut shells can be used to make a bio-composite material with cellulose fibers and a bio-based binder.

Among the three prototypes, Prototype B gave the best balance of flexibility, strength, and durability. The study also showed that changing the amount of walnut shell powder and cellulose fibers has an important effect on the material's properties.

More importantly, this project shows that agricultural waste can become a valuable resource instead of being treated as waste. With more research and development, walnut shell

waste could be used to make sustainable products such as fashion accessories, home products, and other eco-friendly materials.

Although more testing is needed, this research provides a good starting point for improving the material in the future.

Future Work

This project is only the first step in developing this material. In the future, I would like to improve its strength and durability by testing different bio-based binders, natural fibers, and manufacturing methods.

Future research should include laboratory tests such as tensile strength, abrasion resistance, water resistance, and long-term durability. I would also like to test natural pigments from walnut green husks to create color without using synthetic dyes.

Another goal is to produce larger sheets that can be used to make real products instead of small laboratory samples. I would like to create prototypes such as wallets, card holders, bags, and interior design products to see how the material performs in everyday use.

In the future, I also plan to continue my research on underused Kyrgyz merino wool. Both projects have the same purpose: turning natural resources from Kyrgyzstan that are often overlooked into valuable and sustainable materials. My long-term goal is to continue this research with universities, industry partners, and future investors so these materials can become real products that support circular design and create new opportunities for local communities.