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# Biocrest: A Novel, Organic and Sustainable Alternative to Traditional Thermoplastic-Based Packaging

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## ABSTRACT

Plastic is highly useful as an industrial packaging material due to its properties of being mouldable, rigid yet flexible, durable, reusable, and cheaper than most of their alternatives, making it profitable to use. Although it has many advantages, it comes with its fair share of drawbacks, with the most concerning being the amount of pollution it causes. Although plastics have been in use only since 1907, they have accumulated over time in astronomical quantities, destroying our environment.

There are already some great sustainable packaging materials out on the market, but it still isn't as mainstream as it needs to be, to put a real dent into plastic pollution. Unless we can find ways to modify plastic to lessen its environmental impact, we need to find sustainable packaging alternatives. Our project presents a novel solution to the pervasive problem of plastic, and looks into the issue in a sustainable manner. Our review showcases how materials such as seed extracts and natural binder extracts can be used to develop material that can serve as a potential replacement for the thermoplastic used presently.

Biocrest offer quite a few novel benefits compared to petroleum-based plastics packaging material

- It is 100% plant based and are hence completely degradable.
- It is recyclable and can aid in the growth of more plants through composting.
- It can be injection moulded and can be shaped to take the same form as traditional thermoplastics, offering an alternative and safer approach.
- Suitable to the wider market, only for very niche applications.
- Releases no harmful material and can be used for food packaging, as they don't taint food with any unsuitable tastes, nor leach chemicals into the soil like traditional oil-based plastics

## Background Information & Problem Assessment

### Use of Plastic Use by Humans

Plastic is a word that originally meant "pliable and easily shaped." Plastic also refers to a category of materials called polymers. The word *polymer* means "of many parts," Polymers are made of long chains of molecules and are abound in nature. Cellulose, the material that makes up the cell walls of plants, is a very common natural polymer. One hundred and fifty years back, humans learned how to make synthetic polymers, sometimes using natural substances like cellulose, but more often using the plentiful carbon atoms provided by petroleum and other fossil fuels. Synthetic polymers are made up of long chains of atoms, arranged in repeating units, often much longer than those found in nature. It is the length of these chains, and the patterns in which they are arrayed, that make polymers strong, lightweight, and flexible. In other words, it's what makes them so *plastic.*

Plastics are a crucial component of our daily life; they are used commercially, domestically, and in various lines of industries. They help facilitate the mass production of goods and services. Plastics are primarily used in packaging, building, construction, textiles, consumer products, vehicular transportation, electronics, industrial machinery, energy generation, medical healthcare, and aerospace engineering. Some domestic uses of plastics include signage, furniture, clothing, sewage treatment and piping, and flooring.

The current usage of plastics is substantial and rapidly escalating. In 1950, 2 million metric tonnes of plastic were created. Over the years, plastic production has increased by a significant amount. From 2004 onwards, the world encountered a considerable spike in production; by 2015, it had increased by a factor of 200, reaching 381 million metric tonnes [1]. This number is expected to continually rise with an growth in human population, globalisation, country development and consumer demand.

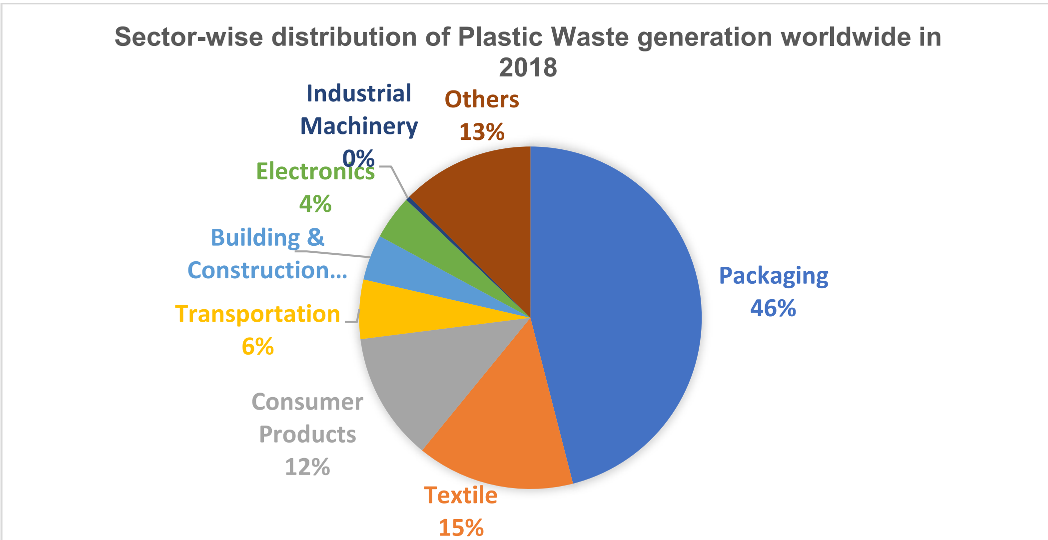


**Figure 1.** Share of Plastic use in various industries [2]

## Plastic in Packaging

Plastic packaging allows us to protect, preserve, store and transport products in a variety of ways. Without plastic packaging, a great deal of products that consumers purchase would not make the journey to the home or store or survive in good condition long enough to be consumed or used.

Plastics have various properties which make them versatile at promoting a diverse range of tasks. Some of these material properties include a great strength to weight ratio, water and shock resistance, as well as thermal and electrical insulation. However, they can be separated into numerous categories based on certain inherent characteristics. In general, there are 6 different types of plastic used in plastic packaging.

1. *High Density Polyethylene* has a high chemical and solvent resistance, high strength and durability. It is used in almost every industry, such as cosmetics and cleaning.
2. *Low Density Polyethylene* is tough, highly flexible, transparent and durable. These properties make it suitable for industries such as food packaging and electronics.
3. *Polystyrene* is rigid (which allows for it to act as a moisture barrier), durable, tough, and has a high melting point. These characteristics make this plastic suitable in making goods such as containers.
4. *Polyvinyl Chloride* is resistant to chemicals and solvents, stable, durable and has flow characteristics. It is mainly used in the electronics industry.
5. *Polyethylene Terephthalate* provides a strong moisture and gas barrier. It is also durable, and has high impact resistance, as well as good mechanical and thermal properties. It is primarily used in the geotextile and carbonated drink industry.

6. *Polypropylene,* which has a high melting point, clarity, moisture barrier properties and chemical resistance. It is used predominantly in the food and automotive industry.

Before the Industrial Revolution, packaging as a means of transport of goods was nowhere as advanced as it is today. In the late 1800s, the material of mainstream mass packaging was paper. In the early 1900s, the material cellophane was accidentally discovered. This was substituted as the main material for packaging based on its transparency and liquid impermeability. The mid 1900s involved the discovery of polyvinylidene chloride and polyethylene terephthalate bottles, which are currently still in use[3]. Recently, however, scientists have identified that the amount of plastic used in packaging is excessive. For instance, in Europe's food and drink industry alone in 2018, 8.2 million metric tonnes of plastic were produced for packaging food and drink, out of the total 20 million metric tonnes produced for packaging. The amount of plastic packaging waste is also increasing by approximately 2% a year and represented 59% of the total mass of plastic wasted in Europe in 2015 [4].

## What is the Problem with Plastics?

All plastics are made up of polymers made up of long chains of hydrogen and carbon atoms that originate from petroleum or natural gases. Since polymers are organic, they are not environmentally harmful in their natural forms. However, when arranged in certain ways to form plastics, they form non-biodegradable materials, which means that it can take anywhere from 20 - 1000 years [5].

When plastic is not recycled correctly, it can take almost centuries to degrade naturally. According to National Geographic, a mere 9% of the produced plastic is recycled every year, with the remaining 91% ending up in landfills and oceans causing severe environmental damage. This leads to nearly 300 million tonnes of plastic waste produced every year, which is equivalent to the weight of the human population. When disposed of, plastic breaks down into micro plastics - also called mermaid tears - which spread across the ocean through currents further polluting the environment.

However, the problem does not lie in plastic itself; rather, it stems from how we do not reuse and recycle enough of it. The major portion of non-reusable plastics come from single use plastics (SUP's), which include any items that are used once and then thrown away, like plastic utensils, food and beverage containers, plastic bags, packaging materials, etc. Most SUP's often end up in landfills or our oceans quickly after they are thrown away. The impact of this kind of plastic waste on our health and environment can be far more drastic than if reused or recycled effectively.

### *Effects of Plastic Usage On Environment*

Primary cause of land pollution: The chemically and thermally resistant plastic can leach harmful chemicals such as phthalates and Bisphenol A (commonly known as BPA) into the soil and groundwater systems. These additives affect a variety of *species* living both in the soil or using it, and the species that consume the ground water under the soil with the presence of these toxins. They can be linked to a wide variety of chemical alterations in the body, ranging from: hormonal imbalances, increased blood pressure, cardiovascular disease, neurodevelopmental issues, male fertility issues, attention-deficit hyperactivity disorder (ADHD), and autism spectrum disorders.

Over 400 million tons of plastic are produced globally each year. It is estimated that one third of all plastic waste ends up in soils or freshwaters. Most of this plastic disintegrates into particles smaller than five millimetres, referred to as Microplastics [6].

A first of its kind study[7] published in the Proceedings of the Royal Society explored the effects microplastics present in soil had on soil fauna. The paper records that terrestrial micro pollution has led to the decrease of the species that live below the surface, such as mites, larvae, worms and other creatures that aid in maintaining the fertility of the land.

There are various ways in which plastic can bring about considerable environmental damage. Firstly, plastic causes immense destruction to natural landscapes, which get replaced with piles of plastic stored in massive anthropogenic landfills. However, plastic packaging can severely affect complex ecosystems, specifically the marine environment.

In 1992, a shipping crate containing 28,000 plastic rubber ducks [8] fell overboard. To this day, there have been sightings of ducks on the shores of Hawaii, Alaska, South America and Australia. Some of these ducks are even situated in the currents of the North Pacific Gyre.

This ocean current is also responsible for what is known as the Great Pacific Garbage patch: a massive island of floating debris which became extremely popular among oceanographers after the duck incident. Most of this garbage patch consists of discarded plastics and chemical sludge. As of today there are about 11 of these ocean currents which can act as potential whirlpools that suck in plastic debris from different parts of the ocean. Although this may already seem like a problem, the real issue arises while considering the impact of these kinds of garbage patches in the future.

As previously mentioned, microplastics that spread across ocean currents can also give rise to significant environmental concerns. A study conducted by Lebreton et al in 2019 [9] proposes that microplastics actually remain in the ocean for longer periods of time as opposed to the common hypothesis that they degrade quickly. Their study suggests that microplastics can remain in the ocean for several decades, be buried along shorelines and also resurface in offshore regions several years after it has been disposed of. The study also modelled how plastics (including microplastics) may affect our water bodies in the near future. The models considered 3 scenarios: *If we stop emitting plastics to our oceans by 2020; If the emissions of plastics continue to increase until 2020; emissions continue to grow until 2050 according to past growth rates.* Using these 3 scenarios, separate models were constructed. It was concluded that, apart from the 1$^{st}$ scenario (which has already been rendered impossible since plastic emissions have skyrocketed these last two years due to the COVID-19 pandemic), both models showed that plastics would continue to exist in our oceans for several decades. Any additional plastics would contribute even further to this growth and allow microplastics to persist in our oceans for even longer periods.

### *Effects on Human and Animal Wellbeing*

Microplastics have been found all around the world from the Antarctic to the Arctic. Several chemicals used in the production of plastic materials are known to be harmful to the body (in certain cases, even carcinogenic). Microplastics enter the human body through direct exposure such as inhalation and ingestion. They can also accumulate on the surface of oceans and other water bodies. As a result of prolonged contact with the water, the toxic chemicals present in plastics can leach into the water, which are then ingested aquatic marine species. These chemicals can also indirectly harm humans and other land animals through ingestion of affected marine animals as seafood. In fact, a study conducted by Smith et. al [10] suggests that seafood represents a major pathway for human exposure to microplastics since global per capita consumption of seafood is almost 20kg which represents about 1/5th of human protein consumption. Health effects of ingestion of microplastics include cytotoxicity, oxidative stress and translocation to other tissues . However, due to gaps in microplastic research and insufficient information, it is not possible to precisely conclude how microplastics affect humans through food.

What is known to us though is its impact on animal life. The most common effects of plastic debris on aquatic life are the ingestion, suffocation and entanglement of animals that mistake plastic for prey. They also suffer from lacerations, internal injuries and reduced ability to swim which consequently leads to their death. This not only impacts particular species, but also affects marine biodiversity as a whole and has drastic side effects. In fact a study conducted by the RSPCA [11] shows that roughly 700 species are at risk of going extinct with special emphasis on water birds and marine animals such as seals. The extinction of such major species can have cascading effects on the food chain, wiping out several other dependent species in the process.

However aquatic animals aren't the only ones to suffer the consequences of irresponsible plastic disposal by humans. In terrestrial animals too the main concern is the mistaking of plastic waste for food. Animals often become hungry and mistake plastic litter for food. Animals may suffer from overheating, suffocation, dehydration, starvation and eventually death. Animals may often suffer from lethargy and weakness after consuming plastic, said Marine biologist, Matthew Savoca [12]. Moreover, the issue has become extremely widespread with littering occurring even in protected national forests and reserves which are often home to several protected and endangered species of animals making

### Why is Plastic Not a Simple Problem to Solve?

To understand why plastic is not a simple problem to solve, we need to understand the problem itself. Plastic is produced on an extremely large scale around the world as a cheap medium for applications such as packaging, construction, engineering raw materials etc. Plastic is a material that takes millions of years to decompose completely into the environment. The overproduction of the material, coupled with our inability to dispose of it efficiently, has had several real-world implications, the most important of these being plastic pollution as we have already discussed above.

In layman's terms, the problem of plastic pollution is not an easy problem to solve mainly because plastic takes extremely long to decompose naturally. Man-made efforts to recycle or decompose plastic have been complicated and pose numerous environmental threats if not done safely or in a controlled, regulated manner. Due to the surge in plastic usage in the 21st century, it has become ubiquitous. This surge in its usage has caused more plastic pollution to occur, and it now poses a serious threat to the Earth's ecosystem.

## Existing Sustainable Alternates to Plastic

### Natural Fibres

Natural fibres are those that are created from the naturally occurring fibres in plants[13]. They are made from biodegradable materials and have the potential to replace a wide variety of plastic products. They occur in many forms, some being vegetable fibres, cotton fibres, flax, jute and hemp.
Natural fibres have risen in popularity in recent times, and for good reason. People have become more aware of the problems that plastic poses to environment and have consciously made the effort to switch to natural fibre-based products.

### Molded Pulp

Moulded pulp or moulded fibre is a packaging material, that is typically made from recycled paperboard and/or newsprint. It is used for protective packaging or for food service trays and beverage carriers. Other typical uses are end caps, trays, plates, bowls and clamshell containers [14]. Molded pulp is often considered a sustainable packaging material, since it is produced from recycled materials, and can be recycled again after its useful life-cycle. Molded pulp products can be made waterproof with a spray or dip coating of wax.

### Bioplastics

Bioplastics are plant-based products, made from natural resources occurring on the Earth. While most conventional plastics are made from fossil fuels, bioplastics are made from renewable biomass sources- materials that include vegetable fats and oils, corn starch, straw, woodchips, sawdust, recycled food waste, etc. They are commonly used as a safer alternative for plastic in food packaging, used to package vegetables, fruit, eggs, meat, drinks, and dairy products. They are materials that can be degraded to their simplest constituent components with the help of microorganisms and enzymes and are made of primarily renewable products.

The bioplastics most used in packaging today are [15]:

- Starch-based blends
- Polylactic acid-based blends (PLA blends)
- Bioplastics made from thermo-plastically modified starch (TPS)
- Bioplastics made from PLA
- Cellulose-based plastics
- Biobased bioplastics (bioPE, bioPET)

## Proposal for Sustainable Packaging

Our studies show that the highest amount of plastic is used in the packaging industry (46%), our project is centred around the development of a type of Biomaterial that can be used as an alternative to traditional thermoplastic for packaging material. After studying the benefits and drawbacks of the various bio-raw material that can be used as bioplastics, like Starch-based plastics, Bacteria-based plastics, Soy-based plastics, Cellulose-based plastics, Lignin-based plastics, Natural fibers reinforcement plastic, we concluded that these Biomaterials still need to be incorporated with various petroleum-based polymers or biopolymers to create unique composite materials. These composite materials are then injection molded or extruded using standard processing machinery. Though bioplastics reduced the degradable time period of these materials, yet it does not completely solve the issue as they still take considerable amount of time to decompose due to plastic contents in them. Our aim is to make packaging material with 100% bio-based raw materials, that meets the Sustainable Packaging Coalition [16] and that it can simply be discarded as an organic waste or used in home compost after its useful life packaging material are over.

One of the highest uses of plastic material is Expanded polystyrene (EPS) foam which is also known as “Thermocol”. EPS is ideal for the packaging and construction industries due to its light weight, strong and excellent thermal insulation properties. It is the largest commodity polymer produced in the world. But as with all plastics, it is a problematic material, in that it's cheap and lightweight but also non-biodegradable and difficult to recycle. Our idea is to devise a method of using natural plant-based material that can be “expanded” like polystyrene when heated and then converted into mouldable parts using Shape moulding – a process which produces parts that are made as per custom design and used for the packaging of many products including consumer appliances, electronic, etc, products.

### Alternative to Bioplastic - Biocrest

Since the alternate material to plastic must have most, if not all the properties of a plastic used for packaging, like good strength to weight ratio, water and shock resistance, thermal and electrical insulation, but most importantly to be bio-degradable, our focus was on a plant-based material that are abundantly available or cultivated and can be “puffed-up” when heated similar to EPS. Some of these crops like Rice, Maize, Lotus seeds, Amaranth, Sorghum, etc are grown widely in the country and show this particular property and are source of our initial investigation.

We took at various crops seeds and tested if they can be puffed and the below table list the outcome.

| Seeds | Rice | Wheat | Corn | Millet | Lotus seeds | Amaranth | Sorghum |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Can Puff | Yes | No | Yes | Yes | Yes | Yes | Yes |

## Binding Agent

Along with the alternate for plastic, a natural binder is also required to make these grit particles to "glue" them called Binding agent. Binding agent or binders are employed to convey the cohesiveness to the granules. Binders are added to the main raw material to impart plasticity as well as increases inter-particulate bonding strength in the grit particles that ensure the final shape remains intact after compression. To hold puffed grits together to form a packaging part, binder can be added either in dry mix or mix in granulating liquid and form matrix with fillers. On drying solid binder forms glue which holds the particles together, the wet binder is the most important ingredient in the wet granulation process, most binders are hydrophilic & most times soluble in water.

Our studies shows that different starches like rice, potato, maize, corn, wheat, tapioca starch and gums and plant fruit like date palm fruit and orange peel pectin shows good potency as a natural binder. Since rice is available abundantly, rice starch can be made into sustainable, biodegradable polymers that can act as a "natural-binder"[17]. Rice husk can also used as an additive filler to give strength to the part without increasing the weight drastically.

## Process

The process consist of 5 major processes as illustrated below;

1. Selection of right seed that can be "puffed" on heating
2. Washing & drying of the seeds
3. Expansion process to "puff" the seeds
4. Addition of natural binder to create binder seed complex "Biocrest"
5. Compressed shape moulding of Biocrest material
6. Final shaped packing product

The components are formed in aluminium mould tools. with male and female form, with the shape between the two halves of the mould being the shape, being produced.

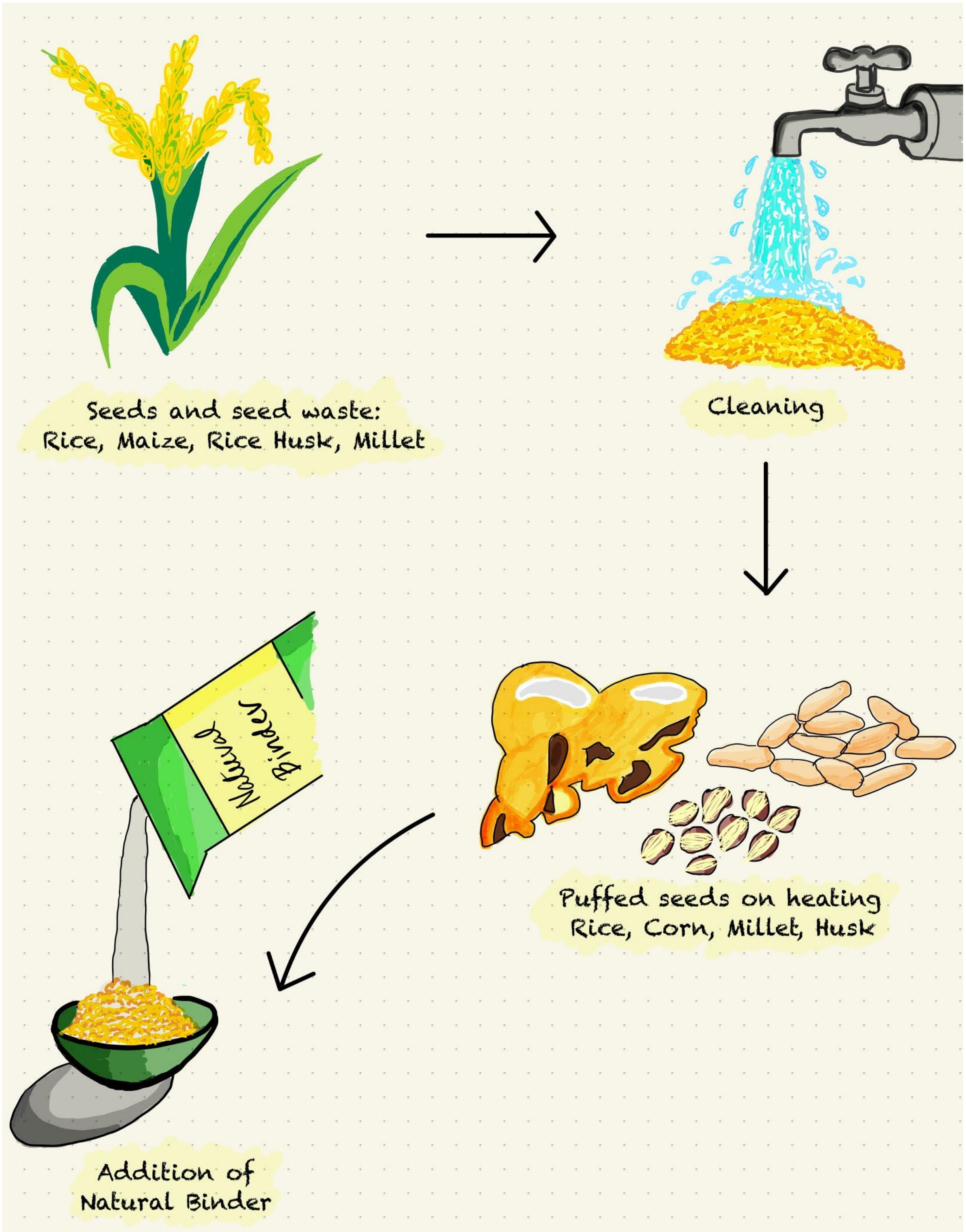
Seeds and seed waste:
Rice, Maize, Rice Husk, Millet
Cleaning
Puffed seeds on heating
Rice, Corn, Millet, Husk
Natural Binder
Addition of
Natural Binder

**Figure 2**

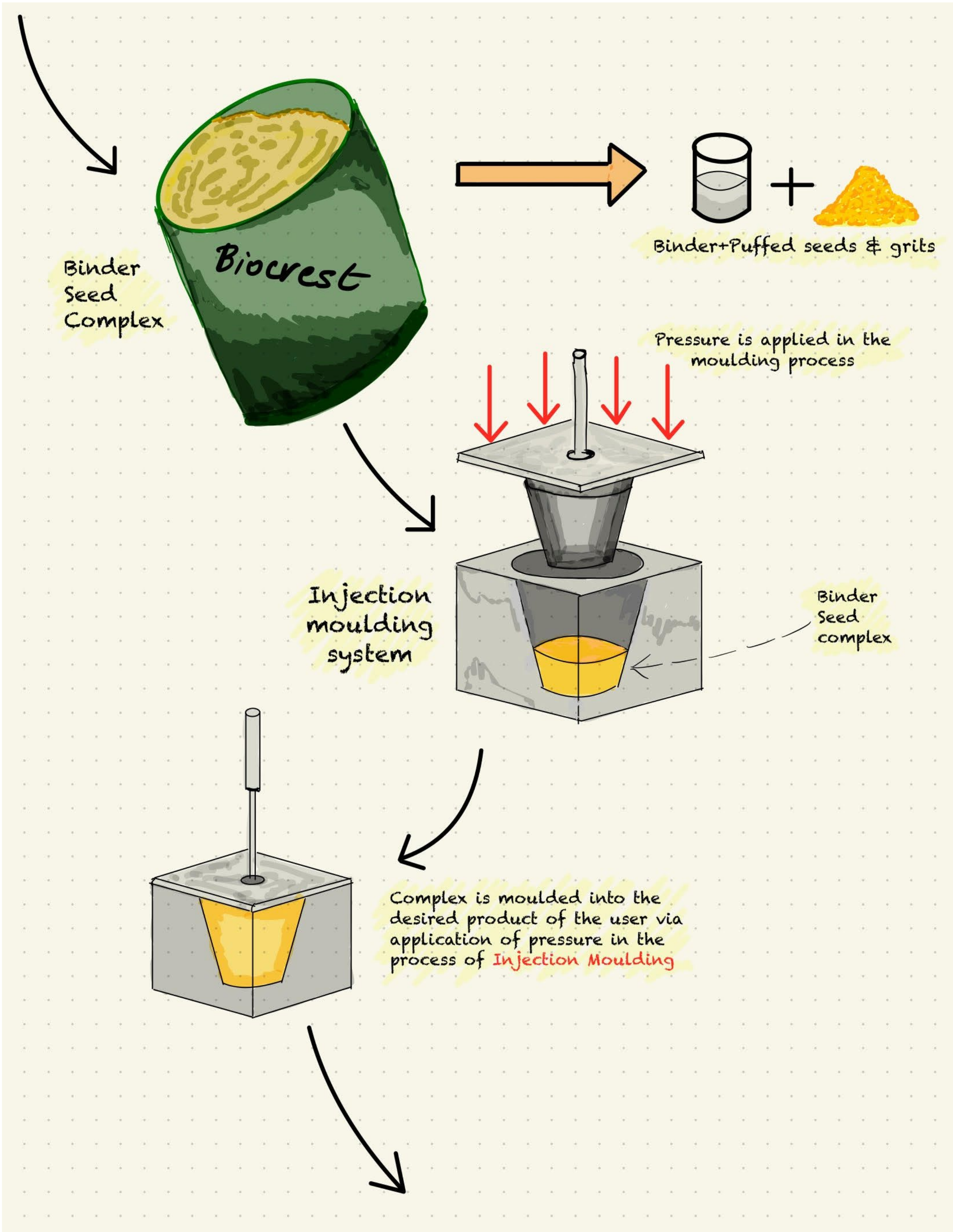
Binder
Seed
Complex
Biocrest
Binder+Puffed seeds & grits
Pressure is applied in the moulding process
Injection moulding system
Binder
Seed
complex
Complex is moulded into the desired product of the user via application of pressure in the process of Injection Moulding

**Figure 3**

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**Figure 4**

## Conclusion

Our background research and initial tests show promising results that the idea of making a 100% bio-degradable material is feasible with the available natural resources. The material is completely de-compostable and can be cost effective. The effects of plastic on our daily lives and its role in industry has been carefully studied, and a potential solution to the problem has been proposed. The binder material will be investigated and reviewed further experimentally in the future, to assure its applicability and effectiveness in the product. Although primary experimentation for the research has not begun, background secondary research conducted on the basis of the materials in terms of heat resistance, malleability, and strength show propitious results.

The purpose of my study and of writing this research paper was to propose novel scientific concept, that is sustainable and renewable, and most importantly, achievable. I wanted to propose a solution to the unwavering problem that current day society faces in terms of plastic. After arduous hours of research regarding the current problem we face with it, the idea of developing a packaging material built ground up solely from plant based products struck me, and this paper has been written in order to review present day research and build up on its concept for a novel concept with potential applications as a replacement of thermos-based plastics.

## Acknowledgments

I would like to thank my advisor for the valuable insight provided to me on this topic.

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