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Cellular agriculture: The way ahead for food, textile, and cosmetic industries

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ABSTRACT

Cellular agriculture, an alternative to animal-based proteins, is an emerging field of biotechnology that aims at developing sustainable products. Harvesting of animal products from cell cultures rather than animals is a promising technology that draws together different disciplines ranging from industrial biotechnology, synthetic biology, materials science, and tissue engineering to social sciences, history, philosophy, and design. Tissue engineering and fermentation are the two major approaches to cellular agriculture. This review extensively discusses some prominent applications of cellular agriculture, namely in the meat, fish, bioleather, silk and cosmetic industries. It incorporates the procedures, drawbacks, challenges and the current market progress of these environment-friendly alternatives. Further research in technological advancements, bioreactor designs, cell scaffolding, bioprinting, and other modern methods will pave a path to large-scale production. Cellular agriculture is the future of diverse industries. With growing research, it will overcome various challenges and limitations of convectional animal farming. The products formed are advantageous and will be valued for their environmental, ethical, health and safety benefits over the animal-derived versions.

Keywords: *Cellular agriculture, sustainable, fish, meat, leather, artificial silk, cosmetics.*

1. INTRODUCTION

A multitude of food products, fabrics and cosmetics utilized by humans is derived from animals. With the ever-increasing human population, which stands at 7.9 billion as of July 2021 [1], the demand for these products also keeps increasing. A study of global biomass has indicated that total biomass on earth has decreased twofold as compared to the value before human civilization [2], implying that human activities like livestock rearing results in the decrease of the total biomass. Therefore, rearing animals alone is not going to be enough to help animal-based industries cope with the future demands. This is precisely where cellular agriculture comes into picture. It is defined as "a field including tissue engineering, stem cell biology, synthetic biology, and genetic engineering, dedicated to produce animal products without using living animals" [3]. Therefore, cell cultures are used to produce animal-derived products as opposed to farmed animals.

The goal of cellular agriculture is to create products that are molecularly identical to those produced by conventional practices. Microorganism cultures (e.g., bacteria, yeasts, fungus, and algae) as well as plant and animal cell and tissue cultures are utilized for this purpose [4]. The resulting products can be either cellular or acellular in nature. Cellular products include living or formerly living plant or animal cells used for food, cosmetics, materials, etc. that are not genetically modified. They are generally produced using a bioreactor [5]. Organic molecules like milk proteins, silk proteins, egg proteins, and fats which are typically produced using genetically modified microorganisms come under acellular products [5, 6]. This review article discusses the method of production and current scenarios of different products of cellular agriculture.

2. CELL BASED FISH

20% of the global demand for animal protein is supported by fish and seafood which includes crustaceans, mollusks, and other aquatic animals [7]. With the rise in demand, pressure on fisheries continues to increase. It remains unclear as to if conventional fishery methods can satisfy the current needs. On

the other hand, genetic modifications, closed system aquaculture, and the development of biomedical engineering have paved the way for innovations in cell-based seafood production [8].

Methods such as aquaculture majorly rely on ingredients obtained from wild fishes and its protein retention lies in the range of 14%-18%. Around 81% of proteins and 90% of calories are lost during fed aquaculture production [9]. Intensification of aquaculture comes with several challenges like greater production of nitrogen, phosphorus, and metabolic waste materials [10], risk of pathogen spread from farmed fish to native species [11], damage of waterways, promotion of algal blooms, and negative impact on the environment [12]. To reduce the pressure on wild fisheries, alternatives like plant-based ingredients and cell-based fish researches are widely explored [9,13]. Production of cell cultures is a preferred method as it has the potential to alter various parameters, enhances food cultivation, and require less time [8].

Cell-based seafood production comprises a closed tissue culture system (refer Fig.1) that requires the desired selected cell type, growth media, and bioreactors which eventually leads to the formation of biocompatible scaffolds [8]. Cell-based lean fish are grown by first creating identical cells and then structuring them into skeletal muscles [14]. A mixture of cellular and nutritional inputs is added to the Bioreactors. Starter cells act as Cellular inputs which could be naturally occurring stem or progenitor or engineered cells. Nutritional inputs include the different growth media, signaling molecules, or nutrients required for the proliferation and differentiation of cells. Air, oxygen, and nitrogen are major essential elements for fish cell growth [8,14].

Cells after introducing into the bioreactor, undergo two processes, namely doubling and structuring. Doubling step results in multiplication and generation of large-scale cell production. The structuring step involves a transformation of cells into full tissued meat. Such cells are then seeded on scaffolding, which is a set of surfaces that help in the development of structural mimic of extracellular matrix (ECM). The process of scaffolding provides mechanical strength, nutrient inputs, exposure to various parameters and subsequently leads to the development of skeletal muscle tissue [14].

For cell culture of fish, the conditions are usually similar to those of their habitats, with culture temperatures varying from 15 to 30°C. The rate of metabolism varies within the 5°C temperature range and depends on the cell lines. Cells metabolize more quickly at higher temperatures. Since fish cells can be cultured at cooler temperatures, the cost, and energy required to maintain a constant temperature culture system gradually reduce [15]. The physiological characteristics of muscles depend on the ability of a cell to maintain a neutral pH in the presence of metabolic end products like lactic acid [16]. In case of invitro culturing, more research will be required to determine if buffering capacity of native muscle tissue correlates to the buffering capacity of the tissues. Fishes are usually subjected to low oxygen levels that result in Hypoxic conditions. Thus, bioreactors are expected to provide oxygen-limited environments as most of the species are genetically adapted to the same [8].

Bioprocessing is majorly required for high protein retention and conversion of a large percentage of amino acid mass input into full-tissued lean fish meat. Here, the system is a closed system due to which waste products are minimized and at least partially reutilized to regenerate some of the inputs. This approach highlights that the cell-based meat bioprocessing can possibly be less resource-intensive than the current animal protein production systems. However, more research, development, and design work will be required to overcome key limitations [14].

To form three-dimensional tissues, numerous scaffolding materials such as cellulose, alginate, and chitosan are employed in medical tissue engineering to form biofabricated food. Chitosan is majorly more preferred as it is edible, inexpensive, accessible, provides mechanical strength, and is well-referenced in the tissue engineering literature [8].

In the case of Zebrafish, starter cells have been isolated from muscle stem/progenitor cells, embryos, and live fish [17]. According to the protocols mentioned in [18], toolkits can also be used to genetically modify cells to obtain better results. The major drawback is the high cost of designing signaling molecules, bioreactors, and maintaining conditions. Scaffolding designs need to be customized and tissue-specific. Computer modeling and prototyping can be possible solutions for enhanced results [14,19].

Cell culture from tissues of Grass Prawn (*Penaeus monodon*) was the first reported successful attempt to subculture tissue cells from a crustacean. Since then, similar systems have been practiced for in vitro culture of tissue cells [20]. The skeletal muscle mass of *Carassius* (Gold Fish) was cultivated using ATCC fish fibroblast cell line which was experimentally proven to be a nutritious, healthy, and safe source of food for Space Voyagers [21].

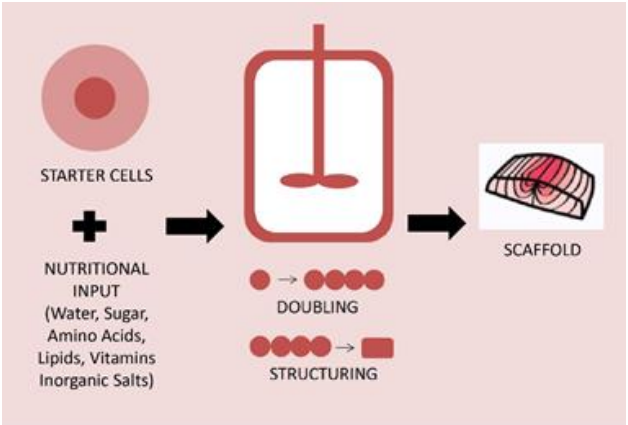

Figure 1: Outline of cell-based Fish Production [8,14]

3. CULTURED MEAT

Meat consumption is increasing in both developed and developing countries around the world. Worldwide meat consumption increased fivefold during the second half of the twentieth century, rising from 45 million tonnes in 1950 to 300 million tonnes as of July 2020. As a result of projected population growth and welfare development, meat demand is anticipated to rise by 75 per cent around 2050, while livestock production may remain slow. More food would be needed to meet the growing population's demand, which will be a significant challenge due to limited resources and agricultural land [52].

"Cultured meat" a term not so commonly heard in society these days is set to have a long-term solution to the problem of animal abuse, insufficient meat, rising prices etc. Cultured

meat, also known as clean meat is an alternative to generic meat which is made in labs under a microscope. Moreover, this ground-breaking technology aims to reduce the harmful effects of current meat processing and consumption on humans, the climate, and animals [22]. It would significantly reduce animal abuse or even eliminate it while simultaneously ensuring the long-term supply of designer goods. Another important advantage of in vitro meat is that it can reduce food shortages by delivering a more effective solution to the conventional meat processing process. Cultured meat will also be chemically stable and free of disease, with a favorable price and a similar or even better nutritional profile. The manufacturing system can also be regulated and manipulated as per need [22, 23].

First, a biopsy from an animal is taken. This tissue is then filtered and isolated to look for cells that can be grown on the media. Usually, satellite cells and adipose tissue-derived stem cells are extracted. In a cell culture, it will be given the correct temperature and oxygen, as well as salt, sugar, and protein and cultured in a way to produce a cell line. Essentially, the scientists trick the cell into believing it is still inside the animal [24, 26]. Therefore, these satellite cells divide and then combine to create primitive myotubes. They bulk up by generating more protein when grown in a donut around a central core of gel. It will then naturally replicate inside of a scaffold which provides a 3D microenvironment for the tissues to grow and is then put in a bioreactor for orderly replication [26]. Naturally, meat includes 90% fat and 10% connective tissues plus fat and approximately 0.3-0.5% blood.

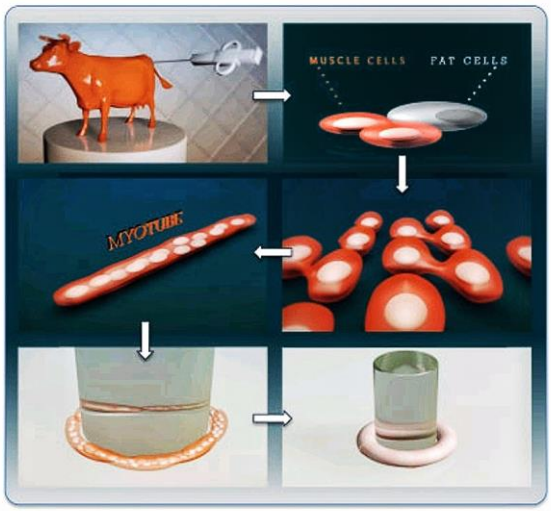

Figure 2: The formation of a donut around a central core of gel [25]

As shown in the figure, obtaining a cell line is the first process of cellular agriculture. Usually, stem cells are used for this process as they are undifferentiated cells and can therefore potentially transform into almost all cell types. However, different cells can be used as well. These cells include Satellite cells, Fibroblasts, ECM and Adipocytes.

After establishing these cell lines, the next step is to immerse them in a growth medium where they are allowed to proliferate. They are provided with all the necessary nutrients like carbohydrates, fats, proteins, salts etc. which they need to grow. After consuming enough, the cell population will increase exponentially. Other additives (growth factors) are added to the culture through the integration of Fetal Bovine Serum [53]. The culture medium must be frequently replaced as differentiation occurs; muscle fibers begin to develop lactic acid, which ultimately releases into the media making it acidic and therefore changing the overall environment of the media from optimum to acidic.

After this is taken care of, scaffolds are used for the next step. Essentially, scaffolds are sponge-like microporous 3D molds that provide mechanical support to the tissue. And in order to endorse tissue development, these scaffolds mimic their natural environment. Hydrogel, macro-porous, sponge-like biomaterial or their combination is used for the composition of the scaffold [23, 24, 53]. Technically, scaffolds should replicate the different layers of the skeletal muscle and connective tissue. These scaffolds are placed inside a bioreactor where the cell growth and proliferation can occur as the temperature of the bioreactor will exactly replicate in vivo condition i.e., 37°C [24]. Stirred tank bioreactors are the most widely used reactors as they homogenize the culture media and consecutively facilitates the exchange of oxygen through the diffuser. Whereas fixed-bed bioreactors are used for suspended culture [53].

The major problem with lab-grown meat is the fat content. Generic meat has fat, muscle and other connective tissues so when cooked, it ultimately contributes to the flavor and taste of the final product. And any slight variance in the taste results in an uncanny valley effect which eventually drifts everything apart [54]. Perhaps, there can be a possible solution to this issue. By using tissue-derived stem cells, fat tissue can be cultured. This can also be achieved from satellite cells if the conditions are favorable. The same biopsy which is used to harvest satellite cells can be used here and the fat tissue can therefore be grown separately from the satellite cells and mixed later in the process of preparing meat [25]. The absence of a bone and cardiovascular system may be a disadvantage in meals where these components play a significant culinary role but it may also be created in the future to give a more palatable experience to the consumers [55].

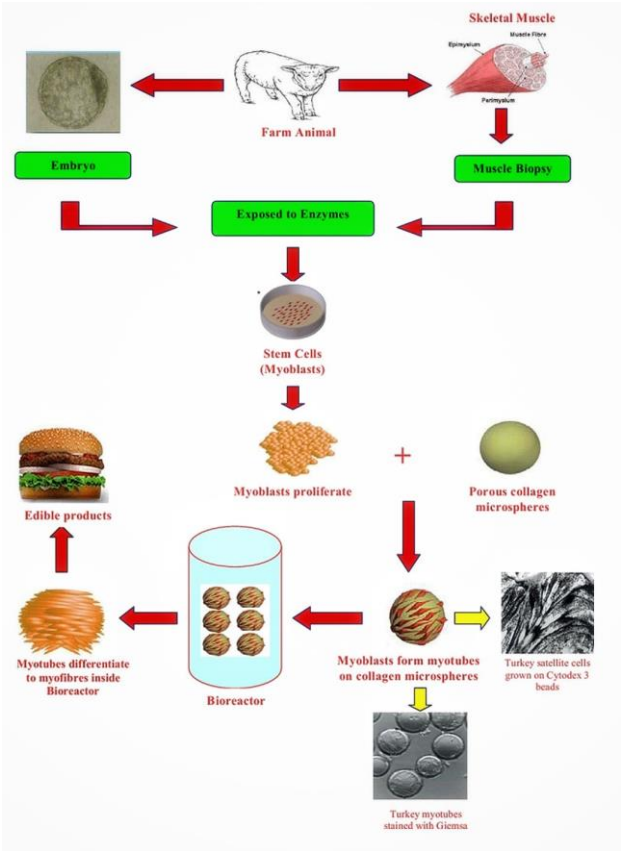

Figure 3: Scaffold based cultured meat production [24]

Application of this also extends to acellular agriculture wherein animal based products are derived from non-living material such as milk, honey, cheese etc. Products like these are made up of proteins therefore they are fermented in a recombinant protein production fashion [56].

4. BIOLEATHER

Leather is a natural product obtained by tanning animal skin and hide. Cattle, sheep, pigs and goats, common sources of skin and hide, are confined to small containments, deprived of food and water, castrated, and slaughtered for their skin [27]. After procuring the skin, it is made to undergo the process of tanning, which involves stabilizing the collagen content so that the skin becomes non-biodegradable and does not rot. This releases a multitude of harmful effluents namely, salt, lime sludge and sulphides into the atmosphere [28]. These effluents, in addition to the requirement of large amounts of energy, land and water, make the leather industry highly unsustainable and damaging to the environment. However, owing to the fact that the international trade value of leather and its products surpasses 80 billion US dollars per annum [29], this industry proves to be of great economic importance.

In order to keep the industry thriving, attempts towards creating more sustainable and eco-friendly alternatives to leather were made, until the creation of bioleather. This is an interesting combination of natural and synthetic leather; in that it is derived from natural sources but manufactured using engineering processes. Fungal mycelium and bacterial cellulose are two of the natural sources that help in obtaining leather-like materials. Both of these are considered to be more economic and less taxing on the environment, when compared to natural or synthetic leather [30, 31].

Collagen is the structural protein that forms the major component of bovine leather, and it provides leather the strength required for its industrial applications [32]. It is a matrix polymer that occurs naturally, and is highly conserved across many multicellular organisms where it plays a structural role [33]. Interestingly, it is possible to produce bioleather containing collagen, without the use of any animals. This has been done by using yeast cells genetically engineered to produce collagen similar to what animal skin is made of [34]. Cellulose and chitin are some other polymers that have similar structural roles to play in the cells of bacteria and fungi respectively. Thus, it was concluded that bacterial and fungal components rich in cellulose and chitin respectively, can be used as the raw material for preparing leather-like materials. A deeper dive into this led to the development of bioleather.

The production of fungal bioleather makes use of the hyphae or mycelium of the mushroom species *Ganoderma lucidum*, commonly known as the lingzhi mushroom in China. *G. lucidum* is an annual fungus that typically grows in subtropical and temperate regions like Asia, Europe, Africa etc., and has wide applications in traditional Chinese medicines [35]. Apart from therapeutic applications, its hyphae and mycelia are extensively being used by some biotechnological companies for producing bioengineered products like bioleather. The reason behind hyphae being the selected source is that its cell wall is rich in chitin, which can serve as the structural protein in bioleather. Hyphae are long tubular structures that branch and grow to form a mycelium [31].

The required hyphae or mycelia can be cultivated by either liquid- or solid-state fermentation. The former requires a nutritious medium, which can either be a generic laboratory medium containing all nutrients essential for fungal growth or a medium containing cheap agricultural by-products like molasses. The fungal biomass obtained after fermentation is separated into fibres, which are then suspended, filtered, pressed and dried [31].

On the other hand, solid-state fermentation uses a bed of sawdust or other forestry and agricultural by-products. The bed also contains proteins, carbohydrates, lignin and fat. This is inoculated with spores of the desired fungal species, and incubated at high carbon dioxide concentrations. The temperature and moisture conditions are strictly controlled such that the hyphae are forced to grow outwards in pursuit of oxygen. This ensures that there is no formation of spores, stipe or cap. Post incubation, a continuous foam-like mat of mycelium, referred to as precursor tissue, is obtained. The tissue is treated with lipids and hydrating agents, like sorbitol or glycerol, to increase the water content. This is followed by chemical treatment to create crosslinking sites, increase resistance to shear stress and microbial decay, odour elimination etc. Hot or cold pressing using rollers reduces the thickness of biomass, which is then dried. In order to increase flexibility, the moisture is returned back to the material, followed by a final drying step [31].

Bioleather synthesized by utilizing bacterial cellulose (BC) makes use of *Komagataeibacter xylinus*, a type of acetic acid bacteria, which is capable of naturally producing BC [36]. Upon aerobic fermentation, the bacteria extracellularly produce thin films of cellulose, which when dried forms material that closely resembles leather used in the footwear industry [37].

With the growing environment consciousness, many companies are starting to develop fungal bioleather as an alternative for bovine leather. This is closely followed by lab-grown leather developed using yeast cells. Bacterial cellulose-based leather is still in the developmental phase.

Out of the three variants of bioleather discussed above, fungal bioleather has the highest potential of becoming an environment-friendly fabric. This can be attributed to the biodegradable nature of the final product. Additionally, solid-state fermentation upcycles waste produced by forestry [31]. As for lab-grown leather, it does not reuse waste and it is also not biodegradable [34]. Industrial production of bacterial cellulose is not economical, making it an unrealistic alternative. This is mainly because of the expensive synthetic media needed for culturing the bacteria [37].

5. ARTIFICIAL SILK

Natural silks, obtained from silkworms or spiders, are ideal biomaterials for a wide range of applications not only in the silk industry, but also in the military and medical industries. Spider silk is considered to be one of the best silk fibers with remarkable strength and extensibility. However, mass production of silk by cultivating spiders is not possible due to their territorial and cannibalistic behaviour. Collecting silk from their webs is also a time-consuming task. Therefore, the biotechnological production of recombinant spider silk is the only viable solution to obtain silk on a larger scale and to meet the growing needs of medicine and biotechnology [38].

As platforms for generating spider silk proteins, a variety of heterologous host systems, including bacteria, yeast,

mammalian cell lines, transgenic plants, animals, and insects, have been explored.

Because of the relative simplicity of gene modification and metabolic engineering, as well as the cost effectiveness of fermentative production, unicellular organisms, particularly bacteria and yeasts, have been intensively explored as host systems for manufacturing spider silk proteins. The most common host for the product has been *Escherichia coli*, a workhorse for recombinant protein synthesis. However, due to the poor production rate and instability of the spider silk gene, synthesis of recombinant spider silk proteins in E. coli proved ineffective. Because of the spider silk gene's exceedingly repetitive amino acid sequence, DNA deletion in the spider silk gene, as well as transcription and translation mistakes, were often seen during the growth of recombinant *E. coli* harbouring the gene [39].

As mammalian cell lines bear a potential of appropriately producing a larger protein than bacteria or yeasts, they are being examined as a platform for generating recombinant spider silk proteins. Spider dragline silk genes, including ADF-3, MaSp1, and MaSp2, were expressed in bovine mammary epithelial alveolar cells (MAC-T) and baby hamster kidney cells (BHK), and it was seen possible to create soluble recombinant dragline silk proteins ranging in size from 60 to 140 kDa [39].

Recombinant spider silk protein has also been produced in transgenic mice in such a way that it was released into the milk via the mammary gland. Nine of the 58 transgenic mice examined demonstrated positive expression of recombinant spider dragline silk protein, with a maximal output of 11.7 mg/L. Similarly, transgenic goats secreting recombinant spider silk proteins have been developed [39].

The silkworm is another host organism that has been studied as a platform for generating recombinant spider silk protein. Considering the silkworm is capable of not only manufacturing huge numbers of silkworm silk proteins but also of spinning the silk fibres smoothly, it is reasonable to consider replacing the silkworm silk gene with the spider silk gene for the effective synthesis of spider silk. In silkworm and other insects, a baculovirus-based gene expression system has been well developed for the generation of recombinant proteins. The expression of spidroins in the silkworm *Bombyx mori* has been investigated using this expression method. Approximately 6 mg of the 70 kDa fusion spider silk protein could be generated in silkworm larvae. Furthermore, proteins with enhanced mechanical characteristics were expressed in the *B. mori* silk gland epithelium. However, there were difficulties to achieving significant yields of recombinant spider silk protein due to the protein's high insolubility and the silkworm's inability to assemble spider silk protein into threads [38, 39].

To address these issues, the piggyBac vector was used to generate transgenic silkworms that encoded a chimeric silkworm and spider silk protein. Under the control of the *B. mori* Ser1 promoter, the expression vector included the gene encoding the native *N. clavipes* MaSp1 protein. The Fhc promoter in the vector was used to further control spatial and temporal expression of the chimeric silkworm and spider silk protein, resulting in stably generated chimeric silk protein. The transgenic silkworm could spin composite silk fibres with better mechanical characteristics; the fibre was harder than parental silkworm silk fibres and as tough as native dragline silk fibres [39, 40].

6. COSMETICS

Plant cell cultures are able to synthesize a wide variety of phytochemicals that are used as cosmetic ingredients. Nowadays, while choosing cosmetics, most people prefer natural products. Consistent with this trend, an exponential increase in plant cell culture extracts in recent years has been highly desirable because it is a unique blend of secondary and primary metabolites that occur naturally in nature. Final cosmetic formulations often contain active ingredients in lower concentrations, which enables plant cell extracts to be made in small quantities at reasonable prices that cover production costs. The various steps of the extraction process include the selection of the appropriate plant material and its sterilization, callus induction and subculture in a commercially available plant tissue culture medium. The selection of the appropriate cell line can be based on the highest biomass production and the shortest doubling time. The established suspension culture can be processed with high pressure homogenization to completely break the suspended cells and completely release active ingredients. Plant stem cells can be encapsulated in various transport systems for better topical delivery as a cosmetic product [43, 44].

Techniques of production of Plant cell culture are as follows: In undifferentiated plant in vitro systems, at present, most of the cosmetic ingredients obtained by commercially available plant cell culture technology are based on the cultivation of dedifferentiated callus cultures or dedifferentiated plant cell suspension cultures.

In differentiated plant in vitro systems, various plant tissues and organs can be isolated and cultured under a controlled aseptic environment that encourages their rapid growth and maintains a high level of cell differentiation and tissue organization. Differentiated cultures have better biosynthetic stabilities and ability to produce and accumulate higher concentrations of certain specific metabolites. The biosynthesis of it occurs in specific plant tissues but, mass propagation of differentiated plant cultures in vitro is an expensive and laborious process that requires special and expensive equipment.

In bioreactor systems, in order to be profitable, the commercial production of plant cells or tissue biomass requires the process to be scaled to the required quantities in order to ensure a continuous supply. So, various modified bioreactor systems can be used to cultivate undifferentiated or differentiated in vitro plant cultures. The culture can be carried out in small or medium volume bioreactors, or even in a solid medium (in multiple containers) or in a stirred liquid medium of small volume [44, 50].

The plant cell cultured products used in cosmetics are coffee beans, tomato, olives, pineapple, citrus fruits and grapevine. The gelatin extract in coffee beans is observed to promote the natural cell renewal of the skin, promote an even skin tone for a glowing complexion and strengthen the epidermal barrier. In addition, it has helped prevent water loss, skin lightening by inhibiting melanin synthesis and speeding up the repair of damaged skin by reducing the inflammatory process [42, 46].

Stem cells of the *Lycopersiconesculentum* plant cultivated in tomatoes have shown significant potential for protecting the skin against heavy metal toxicity. Tomato stem cell extract was high in antioxidants and metal chelators such as phytochelatins which trap metals and prevents damage to cell structure

[43, 47]. Lycopene, a compound known for its role in preventing skin disease is present in tomato [42].

Olives contain monounsaturated fatty acids and phenolic compounds, they are a good source of antioxidants, anti-inflammatory,

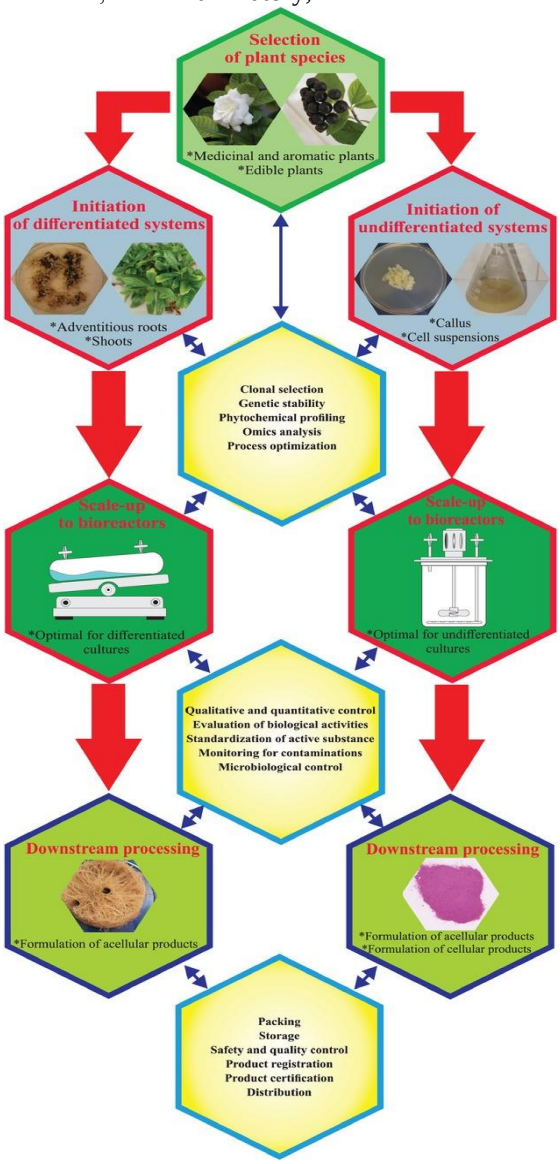

Figure 4: Production methods of cosmetics products

antimicrobial, antiviral, hypolipidemic and play a vital role in the cosmetics industry [42].

The peel and core of the pineapple are rich in antioxidants, which gives them enormous potential in terms of their valorisation in the cosmetics industry [42].

Melanin, the end product of melanogenesis, determines the colour of human skin, hair, and eyes. Its role is absorbing free radicals in cells and protecting skin against UV light. Melanin production is determined by the activity of an enzyme, tyrosinase, and its transcription factor MITF (microphthalmia-associated transcription factor). It is found that treatment with citrus press cake extracts significantly reduced the cellular melanin content by inhibiting tyrosinase activity and the transcription factors TRP-1 and TRP-2 in a dose-dependent manner. The specific transcription factor MITF was also downregulated in a dose-dependent manner. The by-product was a promising candidate for the treatment of skin pigmentation disorders [42, 48, 51].

Grapevine contains various types of lipophilic compounds such as resveratrol, lycopene, ellagic acid and especially carotenoids, which at the time of pressing do not dissolve in the water-soluble juice, but can be extracted with oil-soluble solvent (fat-soluble) and the extract obtained can be used as an active ingredient for skin care cosmetics be used [42, 49].

Calendula (*Calendula officinalis L.*), has been used extensively in traditional herbal medicine and skin care cosmeceuticals for topical application. This plant has shown to be rich in phenolic acids, flavonoids, triterpenes, carotenoids, aromatics and a unique blend of polyunsaturated fatty acids. Due to their high therapeutic value and proven cosmetic effect, the Bulgarian company "Innova BM" has developed two high-quality cosmetic active ingredients and brought them to the market. The steps included in the formation of the cosmetic product are

1. screening of calendula plant which exhibit superior phytochemical profiles
2. selection
3. sterilization
4. cultivation of plant explants in induction medium of callus
5. selection of friable cell lines with suitable phytochemical profiles
6. initiation of the culture in liquid cell suspension
7. optimization of the culture conditions and the composition of the nutrient medium

In this technology, a significant increase in the biosynthetic potential and the accumulated biomass of the selected cell line can be achieved. After optimization, the selected line was scaled up to a large-scale culture in a stirred tank bioreactor. Cells and culture fluid were then processed with high pressure homogenizer to produce glycerol extract (50% by weight) or marigold emulsion (75% by weight cell suspension). The active ingredient produced has superior moisturizing, anti-wrinkle and regenerating effects when applied to the skin. These effects are due to the high levels of exopolysaccharides secreted by marigold cells during cultivation [50].

A few advantages of using plant cell cultures as sources of active ingredients are that there is continuous supply of fresh material regardless of the reproductive cycle of the plant, growing conditions can easily be standardized to always achieve a high level of batch-to-batch consistency, there is no risk of pathogens or environmental pollution, the production system is very sustainable, no agricultural land is required, which means less water and less waste material and the extraction process is simpler and less time consuming. As we see the advantages of using plant cell cultures as sources of active ingredients, we should use it more often [41, 45]. Recently, fresh and lyophilized cell cultures of three types of berries (*Rubus chamaemorus, Rubus saxatilis L. and Vaccinium vitis-idaea L.*) were examined for their nutritional values and their possible use as cosmetic ingredients. It has been shown that all cultures analyzed have compounds, colours, optical appearance and sensory properties similar to strawberries. Red dye shikonin (a naphthoquinone compound that is used as a component of the popular cosmetic product "Biolipstick") was manufactured by Mitsui Petrochemical Industries Ltd. commercially produced, with a two-stage cell suspension culture process developed by Lithospermumerythrorhizon Siebold & Zucc. in 200 litre (growth medium) and

750 litre (production medium) agitated air lift bioreactors. More research needs to be conducted in this field for optimum utilisation [4, 5].

7. CONCLUSION

Cellular agriculture is still in its preliminary stages, as a concept and as an area of study. Refinement is still needed in specific areas for further optimization of acellular and acellular products. It is, however, revolutionary since it allows humans to produce animal-derived products without utilizing any living animals. Growing awareness about the environmental harm caused by large-scale rearing of livestock has amplified the interest in using sustainable products, among the masses. Hence, genetically modified goods offer a safer, purer product, and a more constant supply than traditional counterparts since they are produced in a safe, sterile, and regulated setting. Therefore, by using cellular agriculture as the backbone for each of the industries mentioned above show a great potential to grow in the upcoming years as it gives us the opportunity to design, fine-tune and possibly alter the genes of a given product which may lead us to having lactose free milk one day!

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