Chapter 2

Review of literature

2.1. Oilseeds, nutritional values and functional properties

Over 60% of people worldwide receive their main healthcare from traditional medicine, according to the World Health Organization. Additionally, the WHO has helped poor nations create innovative healthcare programmes by utilizing locally accessible and natural medicines (Zaky et al., 2021). India comes fourth in the production rate of oilseeds across the world after USA, China and Brazil, with average yield of 25 million tons annually (Reddy and Immanuelraj, 2017). Oilseeds are known for their fat providing dense food along with high amount of minerals, vitamins, fatty acids and specially fibres. Due to different geographical divisions and agro-ecological conditions in India, a large number of oilseeds are produced annually including edible, non-edible, agroforestry and horticulture varieties and even for non-conventional sources. Groundnut, mustard-rapeseed, sunflower, nigar, sesame, soybean and safflower come under edible oilseeds. The popular linseed and caster oils are grouped under non-edible oilseeds. Coconut and palm oils are of forest cum horticultural origin crop whereas, rice bran, cotton seed and tobacco seeds as vegetable oils. The most common oilseed cakes used as animal feeds are soybean, groundnut, cotton seed, rapeseed, sunflower, coconut, palm kernel, linseed and sesame seeds (Jha et al., 2012). In addition to providing oil for our daily diet, oilseeds like caster, rapeseed, neem, and benniseed, among others, are important for industry because they are used to make soaps, perfumed hair oils, pharmaceuticals, textiles, lubricants, paints, raw materials for the plastics industry, floor coverings, coatings, inks, linoleum, and varnishes, among other products, all of which contain oil as a primary ingredient (Aramwit et al., 2022; Egbekun and Ehieze, 1997; Garg, 2017; Gupta et al., 2018; Shukla et al., 1992)

Oilseed meals of defatted, roasted and enzyme treated capia pepper seeds were found to have amounts of minerals and proteins enough to enhance the functional properties of food products. Nutritional and functional characterization of defatted groundnut seed cake, defatted cakes of cold oil pressed capia pepper seeds, whole and defatted meals from pumpkin seeds are studied by many researchers (Fekria et al., 2012; Rodríguez-Miranda et al., 2012; Yılmaz et al., 2017). Teh et al., (2014) studied the effect of the defatting process, acid and alkali extraction on the physicochemical and functional properties of flax and canola seed cake protein isolates. The effects of oil extraction methods on recovery yield and emulsifying properties of proteins from rapeseed meal and press cake have been studied by Östbring et al., (2020).

The functional attributes are among the physicochemical features that would affect the behaviour of raw materials and final products throughout processing, storage, and usage (Zaky et al., 2021). Many studies are carried out on physicochemical and functional properties of protein isolates from different oilseeds. However, very fewer studies were reported on functional properties of oilseed cakes and meals. Sehwag and Das, (2015) explains that mustard seed proteins from cakes can be a promising alternative with soy protein in highly populated developing countries to minimize malnutrition in terms of FAO. The oilseed rich in oleochemicals and phytochemicals such as phenolic compounds, tocopherols, tocotrienols and polar antioxidants such as phenolic acids, lignans or flavonoids. These antioxidants can be obtained as concentrated form and can behave as primary antioxidants, synergists and chelators and can be further incorporated into special foods and helps to release oxidative stress in the body and reduces the risk of developing certain types of cancers (Gupta et al., 2018). Table 2.1. represents various oilseed cakes and their health-promoting functional properties gained from the studies literatures.

Black cumin, or Nigella sativa, seeds and cakes are incredibly nutritious since they are high in proteins, phenolics, vital amino acids, and bioactive substances (Zaky et al., 2021). The low-fat groundnut concentrate, composite flour, morning cereal flakes, snack foods, newborn and weaning meals, extruded foods, manufactured foods, and multifunctional supplements are only a few uses for soybean and groundnut cakes (Behera et al., 2013). Therefore, there is a great possibility that these functional compounds remain in oilseed meals even after oil extraction from oilseeds. Fig. 2.1. shows different types of oilseeds consumed all over the world and Fig. 2.2. represents oilseed as a functional food ingredient in the varietal food preparation.

Fig. 2.1. Different types of oilseeds (adapted from Gupta et al., 2018)

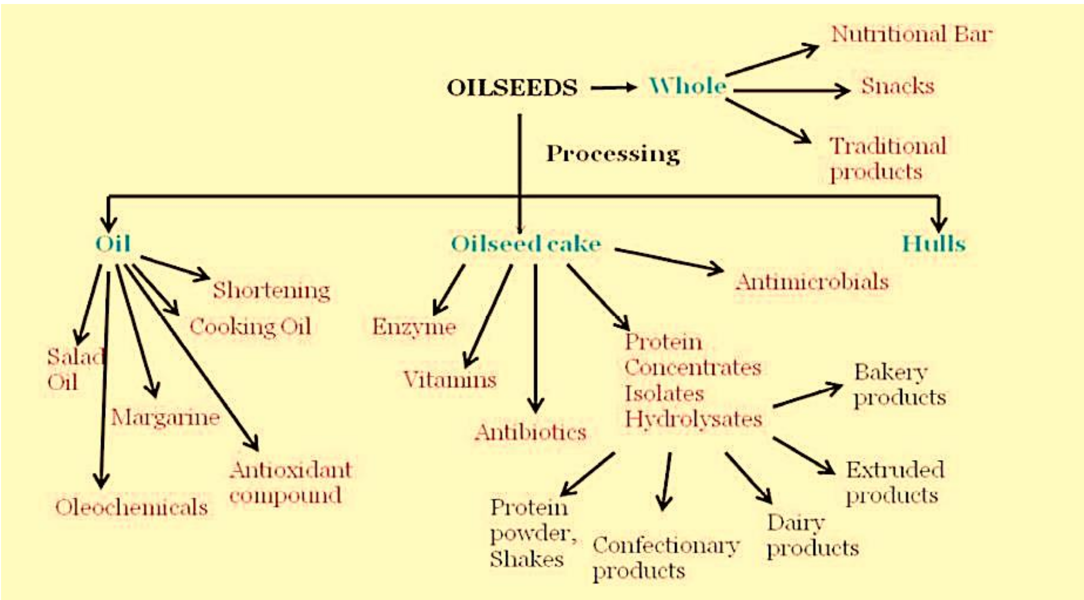

Fig. 2.2. Oilseed as a functional food ingredient in the varietal food preparation (adapted from Gupta et al., 2018).

Table 2.1. Oilseed cakes for health-promoting functional properties

Oilseeds	Nutritional values	References
Sesame (Sesamum indicum L.) meal	Protein	(Sharma and Singh, 2016)
Nigella sativa (black cumin) cakes	Essential amino acids, proteins, phenolics, and bioactive substances	(Zaky et al., 2021)
Canola Meal	Protein, essential minerals, crude fibre etc.	(Khattab and Arntfield, 2009)
Neem seed meal	Protein, carbohydrates	(Aramwit et al., 2022)
Safflower seed meal	Protein, fibre, minerals	(Mansouri et al., 2018)
Peanut cake meal	Protein	(Chavan et al., 1991)
Capia Pepper Seed Cakes	Protein and some minerals	(Yılmaz et al., 2017)
Sunflower seed flour	Fibre, minerals, B group vitamins, vital amino acids (including lysine, methionine, cysteine, and tryptophan) and fibre	(Grasso et al., 2020)
Hazelnut meal	Protein, carbohydrate, energy value, NDF and ADF	(Xu and Hanna, 2011)
Groundnut and soybean cake	Cholorogenic acid, syringic acid, and p-coumaric acid minerals and vitamins, fatty Bioactive substances, fibre, and acids minerals, crude fibre, carbs, and protein	(Behera et al., 2013)
Flaxseed cake	Protein, polysaccharides, polyphenols, lignans etc.	(Hakeem et al., 2015)
Olive cake	Polyphenols	(Hakeem et al., 2015)
Pumpkin cake	Protein	(Hakeem et al., 2015)
Grape seed	Antioxidants (catechin, epicatechin, gallic acid and resveratrol)	(Hakeem et al., 2015)
Coconut cake	α-amylase	(Hakeem et al., 2015)

2.2. Plant fibres, properties and extraction procedures

A plant fibre is one of the unit botanical cells that allows for the differentiation of leaf and bast fibres also described as a unit of matter that possesses qualities such as flexibility, fineness, and a high length-to-thickness ratio (Mwaikambo, 2006). Plant fibres are strong because of fibrillar, intramolecular and intermolecular hydrogen bonding, the stiffness and high molecular weight of cellulose chains, and the crystalline structure of the fibres (Mwaikambo and Ansell, 2006). Based on their morphological structure, the fibres have been divided into three main class groups: (a) bast fibres, which are made from plant stems e.g. Banana pseudostems and sugarcane bagass; (b) leaf fibres, which are made from plant leaves e.g. pineapple leaf; and (c) seed hair fibres, which, for convenience's sake, will include fruit fibres e.g. coconut coir. The traditional process of extraction of fibres from plant includes ratting process. The duration and process of extraction process depends on the sources of fibres such as for fruit fibres- retting of the husk is done by submerging in water for three to nine months and the fibre bundles may also be separated through a process called decorticating whereas for leaf fibres - they are extracted from the strands by boiling them in an alkali solution and usually has are smooth and uniformly sized pattern with fibre lumen is enormous. The bast stem fibres have high water content and are manually separated by cutting pieces combing and drying at ambient temperature (Mwaikambo, 2006). Compared to synthetic fibres, natural occurring plant fibres are readily available, sustainable, biodegradable, renewable, affordable, and environmentally benign. Although natural fibres often have incredible mechanical and physical qualities, this might vary according on the type of plant, where it comes from, the climate, the breed, and other factors (Padzil et al., 2020).

There are different concentrations of every component in the multilayer cell wall. They fall into three general categories: non-lignocelluloses, which have no lignin, hemicellulose, and lignocelluloses, which include 85% or more cellulose. Every component adds something unique to the fibres' characteristics. Although plant fibres are sometimes thought of as trash from the agricultural industry, research into these sectors reveals that they represent a plentiful supply of raw materials that may be processed into useful, lucrative goods (Jústiz-Smith et al., 2008). The high molecular weight and stiffness of cellulose chains, hydrogen bonds between and among molecules, fibrillar, and the crystalline structure of the fibre are all thought to contribute to the strength of plant fibres. The primary wall, or outer layer, and the cuticle make up the fibre cell wall. The secondary wall, which connects the secondary wall to the lumen, is made up of three layers: S1- similar to the main wall, resistant to expanding media like water and acetic acid, S2- readily splits into helical fibrils & has a dominant property while under tension, and S3- generally oppose the hydrostatic pressure within the lumen (Mwaikambo, 2006). Not to be overlooked are the usual deformations that fibrous materials experience, which include tension, compression, bending, torsion, shear, abrasion, wear, and flexing. To forecast the behaviour of a fibre material throughout transformation processes, specific knowledge about the material is helpful. Density and porosity, two physical attributes that are associated with heat and mass transmission, are crucial for design, other property estimates, material characterization, and the forecasting of heat transfer processes during handling and processing (Ramirez and Lagunas, 2010).

Three naturally occurring fibres from the agricultural sector were chosen based on these investigations: sugarcane bagasse, banana pseudostems, and coconut coir. The performance of plant fibres in final use applications, including composites for industrial usage, is our primary interest.

2.2.1. Sugarcane Bagasse fibres

Bagasse, a fibrous substance made from sugarcane, is a dry pulp that is obtained in large amounts from the global sugar and alcohol industries. Approximately 280 kg of bagasse are generated for every tonne of sugarcane, with a global production of 1869.71 million metric tonnes in 2020 (Singha et al., 2023b). Cellulose, hemicellulose, lignin, ash, and wax are the main components of sugarcane bagasse. Sugarcane bagasse's chemical makeup makes it a great component to employ as a reinforcing fibre in composite materials to produce biomaterials with distinct chemical and physical features (Fauziyah et al., 2020). Although a wide range of biopolymers, including cellulose, starch, chitin, and chitosan, are accessible and may be utilised to create biodegradable films, their hydrophilic nature results in poor barrier qualities for these films. By bolstering the strength of these composite materials, the cellulose derived from sugarcane bagasse can enhance their barrier qualities and biocompatibility. When compared to fibres made of other materials, sugarcane bagasse fibres provide a substantial commercial economic advantage due to their cheap manufacturing and pre-treatment costs. Unlike other sources of fibre, sugarcane bagasse does not need the significant cost of collection and transportation. Sugar mills have an economic point over other fibres due to their massive reserves of sugarcane bagasse fibre, which is a byproduct of the sugar extraction process (Boontima et al., 2015; Deshwal et al., 2021; Nonato et al., 2001). Fig. 2.3. and Fig. 2.4. represents the structural diagram of sugarcane plant and remains of bagasse obtained after sugarcane juice extraction respectively.

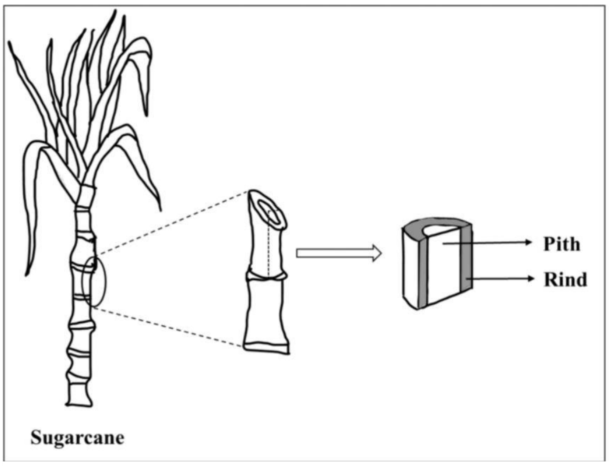

Fig. 2.3. Structural diagram of sugarcane plant (adapted from Agarwal et al., 2023)

Fig. 2.4. Sugarcane bagasse after extraction of juice (source: www.google.com)

2.2.2. Banana Pseudo-stem fibres

Fibrous plants are widely accessible in tropical countries, and some of them, like bananas, are used as agricultural crops. Banana bast fibre is a byproduct of growing banana plants. Better mechanical qualities may be obtained from the pseudo-stem of the banana plant by extracting a lingo-cellulosic fibre. Good specific strength qualities found in banana fibre are equivalent to those seen in traditional materials like glass fibre (Muralikrishna et al., 2020). The outer sheath of these pseudostems may be used to make around 1.5 million tonnes of dry banana fibres per year, indicating that they are useful for producing banana fibres (Vigneswaran et al., 2015). Every banana plant bears fruit just once, hence banana stalks are a waste biomass generated in enormous quantities when the fruit is harvested. The plant's inedible components, which include pseudo-stems and leaves and account for over 88% of its total weight, are thrown away as trash. It is estimated that China alone will produce 29.0 million tonnes of banana stalk residue annually. High levels of cellulose fibre are present in the pseudo-stem of bananas. It follows that banana pseudostems are a valuable but underutilised source of cellulose that may be used to create a wide range of goods with additional value (Guimaraes et al., 2009; Li et al., 2016; Reddy et al., 2015). In addition to being utilised as a raw material for a variety of items including paper, cardboard, tea bags, and currency notes, banana fibre may also be reinforced with polymer composite to create high-quality garment fabrics (Mukhopadhyay et al., 2008). Fig. 2.5. represents the structural diagram of banana plant and Fig. 2.6. and the cross-sectional image of banana pseudo-stem respectively.

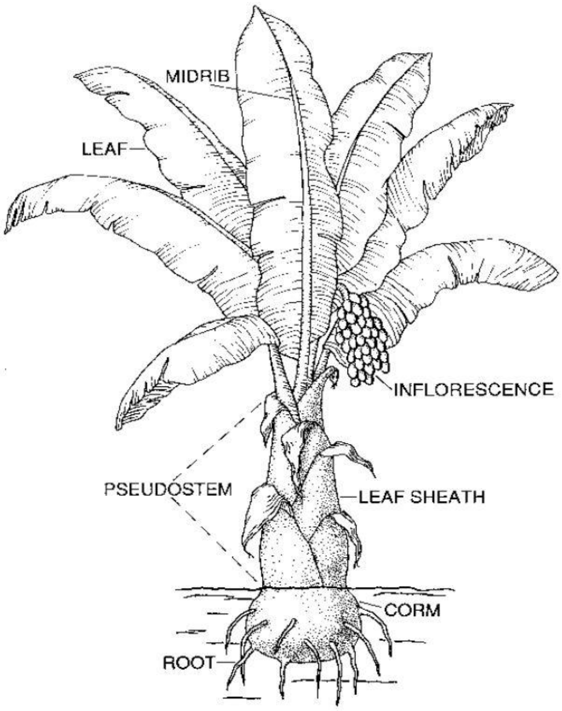

Fig. 2.5. Structural diagram of banana plant (adapted from Ma, J. (2015))

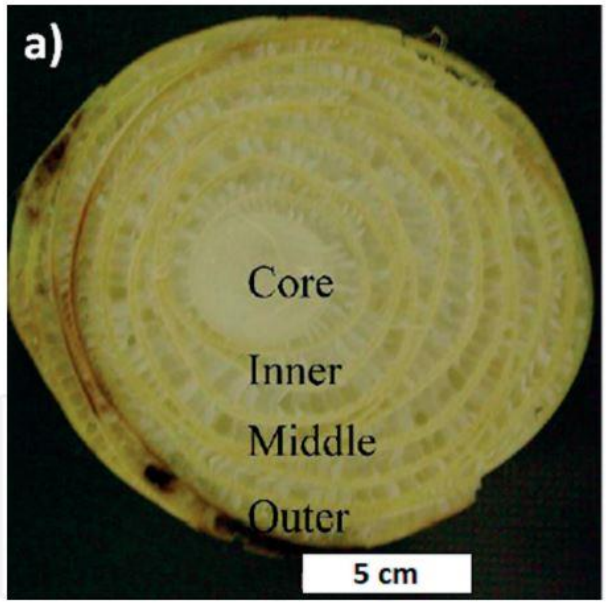

Fig. 2.6. Cross-sectional image of banana pseudo-stem (adapted from Subagyo and Chafidz, 2018)

2.2.3. Coconut Coir

Coir fibre, a robust and resilient natural fibre found in coconut husk, is considered one of the toughest fibres in nature with a strength of 21.5 MPa. Its chemical makeup has been previously studied and found to consist of 44% (cellulose), 33% (lignin), 12%

(hemicellulose), 6% (extractives), and 2% (ash) (Khalil et al., 2006). Even while some coir fibre might be used to make mattresses, sackings, carpets, brushes, and other items, a significant amount is still left over or even dumped. Furthermore, the bulk of coir fibre-based products on the market today technically fall under the category of low-value goods, and because coir fibre has a high cellulose content, it's a perfect starting point for the creation of potentially high-value cellulose-based biomaterials (Rencoret et al., 2013). As per data released by the Food and Agriculture Organisation of the United Nations, 11,864,344 hectares of land are covered by coconut trees, yielding 61,708,358 tonnes of coconuts at a yield of 5.20 tonnes per hectare. In terms of coconut output, India comes in at number three out of the top 90 nations, accounting for 16.4% of global coconut production. In India, coconut trees cover around 1.93 million hectares of land and yield 21 million nuts annually, or 10,122 nuts per hectare (Divyashree et al., 2016). Fig. 2.7. represents different parts that compose the coconut fruit.

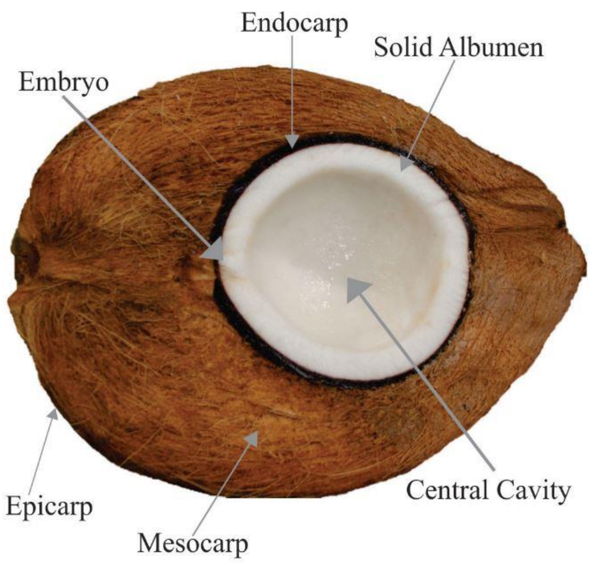

Fig. 2.7. Different parts that compose the coconut fruit (adapted from Lédo et al., 2019)

2.3. Natural gums

Polysaccharides such as natural gums considered useful element in food industry due to its various structural composition, easy accessibility and eco-friendly and noble behaviour (Mateescu et al., 2012; Otoni et al., 2014). The nature of compounds of hydrocolloids depends on its chemical structure. The hydrocolloid with highly branched structure tends to form gels more easily and are more stable in nature. In comparison to branched structure, linear structured hydrocolloids has less extension along the chains (Jani et al., 2009). The uses of natural gums in film formation have property to bind, stabilize, and suspend the agents and work excellently as emulsifiers and thickening agents. The most common gums which can be used are Arabic gum and Xanthan gum (Desplanques et al., 2012).

Arabic gum, sometimes called gum acacia, comes from plants that are a derivative of the Acasia Seyal tree's exudate. With a complicated branch-on-branch structure made up of L-arabinose, D-galactose, L-rhamnose, D-glucuronic acid, and a minor amount of nitrogen-containing compounds, this non-toxic polysaccharide has a tetra-heteroglycan monomeric structure (Jani et al., 2009; Nair et al., 2020). Gum Arabic is found highly interactive with proteins (highly charged in nature) to form complexes due to their low linear charge density. The gum acacia is acidic in nature and behaves negatively charged in presence of wide pH range. Electrostatic interaction between gum acacia and different proteins such as canola protein isolate, soy protein isolate, and gelatin have been studied (Naderi et al., 2020).

Xanthan gum being microbially originated, extracellular heteropolysaccharide by the culture of microorganism *Xanthomonas campestris*. Xanthan gum's main structural component is a linear β−1,4 linked D-glucose chain that is replaced every other glucose residue with a charged trisaccharide side chain that has a glucuronic acid residue in between two mannose residues. The helix's outermost point, C(6), is where the inner mannose residue is often acetylated to stop aggregation (Veiga-Santos et al., 2005). Xanthan gums are specified as non-ionic gums with chemically short, branched tri-heteroglycans in structure. Maillard-type reactions, also known as glycation, are carried out by hydrocolloids conjugating proteins between the reducing end carbonyl group in polysaccharides and the ε-amino groups in proteins (Chen et al., 1997). Literature has effectively shown synergistic interactions when combined with other natural products such as starch, gums, CMC etc. to produce a successful packaging. Gum content at its ideal level might enhance mechanical and barrier qualities. A combination of xanthan gum and acacia gum can produce film with advantageous synergy and promising film characteristics (Jain et al., 2015; Veiga-Santos et al., 2005).

2.4. Crosslinkers

Crosslinkers such as aldehydes are considered a suitable auxiliary and have the strong ability to replace synthetic polymers in the food industry as packaging films. Crosslinkers also have high thermal stability and ability to lower the degradation process of packaging films (Fan et al., 2018; Jani et al., 2009). Crosslinking of the biopolymers such as proteins and their interaction with other polymers has been observed as an approach towards improving the mechanical and barrier properties of film (Sharma et al., 2018). Industrial citric acid are called as green crosslinkers, is a natural crosslinker procured from an aerobic organism *Aspergillus niger* and extracted from citrus fruits through different fermentation processes (Salihu et al., 2021). Conversely, glutaraldehyde is an artificial crosslinker made in an industrial setting by hydrogen peroxide-catalyzed cyclopentene oxidation, which is accomplished in the presence of hetero polyacid catalysts based on tungstic acid (Chandler et al., 2021; Hiroshi et al., 1999). Citric acid and glutaraldehyde are both water soluble and economically cheap (Migneault et al., 2004; Reddy and Yang, 2010).

Citric acid structurally tricarboxylic acid and one hydroxyl group compound, when added with isolated proteins in any solution as crosslinkers, act as lysine. During the crosslinking reaction, the hydroxyl groups of polysaccharide and the two groups of citric acid get crosslinked by covalent intermolecular di-easter linkages (Ma et al., 2018). Protein modifications make additional reaction sites available for citric acid crosslinking prior to thermal processing (Newson et al., 2023). Structurally, glutaraldehyde is a linear, 5-carbon dialdehyde. Glutaraldehyde added with proteins in basic or neutral medium, its α,β-unsaturated molecules predominates on protein molecules. The main amines and aldehyde molecules combine to generate imines, or Schiff bases, which are stabilised by resonance. When the concentration of proteins is greater than that of the cross-linking agent, amine attaches itself to the ethylene bond of α,β-unsaturated polymers, resulting in a secondary Michael reaction (Marquie, 2001).

2.5. Biopolymeric films and biocomposites

Biopolymers are organic substances found in natural sources in the form of monomeric units that can be treated and refined to meet specific needs. Polymers with the prefix "bio" referring to living things, are the source of biopolymers. Living organisms, which consist of monomeric components such as nucleic acids, fatty acids, and amino acids with either branching or linear architectures, form biopolymers. Conglomerated materials, known as biocomposites, are reinforced with a suitable natural fibre as fillers and have an exterior layer constructed of biopolymer resin (John and Thomas, 2008). Numerous techniques, including grafting, various moulding processes, extrusion, intercalation, phase separation, filament winding, melt mixing, solvent casting, electrospinning, laser printing, and film stacking, can be used to create these biopolymer composites (Udayakumar et al., 2021).

Comparing natural polymers to their parent polymers, it was discovered that natural composites made from raw polymers have superior tensile and mechanical characteristics (Thakur et al., 2014). There are two types of biodegradable polymer composites: natural fibres and matrix-reinforced fibres. Naturally occurring plant fibre composites have a high cellulose and lignin content, which improves their tensile strength and crystal formation (Tharanathan, 2003). Economical biopolymers may be produced from microorganisms including algae, plants, and animals as well as from agricultural waste (Udayakumar et al., 2021). The commonly known natural components used in the fabrication of biopolymeric films are polysaccharides, protein, lipids or synthetic polymers and natural polymer used in combination with each other (Shit and Shah, 2014).

From the very early days, there has been several studies going on across the world over the development of biodegradable films from waste, however, biodegradable film provides inferior mechanical strength and barrier properties compared to fossil-derived films (Platt, 2006). Considering this, the modification of films or exploring the waste materials to tailor the biopolymeric films is a noteworthy choice (Ortega et al., 2022). The de-oiled meals naturally contains high amount of proteins thus, the use of these proteins for developing biopolymeric films material is an attractive alternative (Arrutia et al., 2020). For the usage of biopolymeric films and natural composite packaging materials with improved mechanical properties are demanded in a wider range of applications. The Soybean and flaxseed meals are found to have higher least gelation concentration and good emulsion stability required for the ability to bind protein, fat or starches in film suspension enhancing good elasticity and plasticity for film formation. Mucilage or extract of flaxseed comprises of polysaccharide which has the capacity to ease in film forming traits (Waghmare et al., 2022). Flaxseed meals are hydrophilic in nature and slightly branched structure. The films formed with flaxseed meals have high solubility thus, can be healthy and eco-friendly giving us good bio-packaging solutions (Bangar et al., 2021).

2.6. Biodegradable containers and its applications

Biodegradability is an eco-friendly concept that benefits from both user- and eco-friendliness. Since the raw materials are primarily derived from waste products from the marine food processing industry or from agricultural feedstocks that can be recycled, it maximises the conservation of natural resources while maintaining a safe and eco-friendly. Moulded pulp products have been widely used in the disposable goods market because of its affordability, biodegradability, and ease of disposal. Moulded pulp products are replacing plastics in the food business as consumer expectations demands for sustainable and eco-friendly products (Zhang et al., 2022). Pie shells and ice cream cones are examples of edible packaging that is sometimes so intimately associated with the product it carries that it is no longer seen as a container. The use of biodegradable materials and their sphere of effect seem to be growing continuously. Oilseed meals are not commonly used in the area of rigid packaging (Mohareb and Mittal, 2007). Usually polymer, glass, and metal-based containers are commonly used for the purpose of rigid packaging in the food industry. Moreover, the use of wood pulp as biodegradable packaging have the primary disadvantage i.e. it consumes a massive amount of energy to create the cardboards (Changmai and Badwaik, 2021).

Hot compression, induction moulding, extrusion, solvent casting and hot mold baking procedure (Kaisangsri et al., 2012) are some of the common technologies used for the purpose of the development of rigid containers such as trays, cutleries, etc. from plant fibres, fruit and vegetable wastes incorporated with polysaccharides. Proteins that can be extracted from oilseed cake and utilised to create films with desirable properties, such as barrier and adhesive qualities and resistance to organic and oily solvents, are available at a reasonable cost (Popović et al., 2020). The by-product of the widely used industrial process of extracting oil from sunflower seeds has intriguing qualities that make it suitable for injection moulding (Rouilly et al., 2006). In order to produce a new polyester-based hybrid composite plates, Jagadeesan et al. (2023) reinforced basalt/banana fibres with a filler made of cellulose produced from sesame oil cake (sesame cake cellulose, or SCC) using a hand layup-cum-compression moulding technique. Fibre hybridization, filler inclusion, and coupling agents had beneficial effects in improving the properties of all-natural composites. Plant fibre based foams for food packaging are approved for direct contact with food products, are high in purity, elasticity and strength (Dey et al., 2020).

Fig. 2.8. Hot compression moulded tray from de-oiled crambe meal (adapted from Newson, 2015)

Many uses of proteins have been investigated, including its usage as a thermoplastic for non-food purposes. A thermoplastic polymer was initially made using oilseed meal. The field of moulded fibre technologies and products is experiencing rapid evolution. To fully realise the potential of moulded fibre products for a range of packaging applications, scientific knowledge and engineering design/practices are essential. The benefits of moulded fibre products include cost-effectiveness and environmental advantages. The food industry apps must fulfill with certain standards because of stringent guidelines (Zhang et al., 2022).

Purpose and selection and of raw materials and fillers used for foam plates plays a crucial role. But in some cases, addition of agro-industrial residues were not been successful in few cases such as in case of addition of peanut skin to the cassava based foams (Machado et al., 2020). Many research literatures are also available on development of edible packaging and tableware from fruit and vegetable wastes such as apple pomace, and the glycerol and fruit sugars helped in strength of such plates (Gustafsson et al., 2019). Agricultural wastes such as potato by-product, xanthan gum, oats fibre wheat bran, resultant atta, soy-protein, wheat flour, ragi flour, sorghum flour and Indian ginseng roots powder, pearl millet, barnyard millet etc. are used for the development of biodegradable/edible plates, packaging trays and these can also be used as an alternative to plastic plates (Hazra and Sontakke, 2023; Mohareb and Mittal, 2007; Rajendran et al., 2020; Rana et al., 2023; Rodrigues et al., 2020).

The biodegradable plates can be used in various purposes. Engel et al., (2019) studied on the development of biodegradable starch-based foams incorporated with grape stalks for food packaging and concluded that they are compactable for low-moisture resistance foods in alternative to the traditional EPS single use containers. Starch foam trays when added with adding lipids (beeswax or shortening) and filler materials as kaolin, montmorillonite or zinc oxide nanoparticles), kaolin, reduces water absorption of the tray and adding wheat fibres makes the foam high melting point extending their uses to hot food packaging also (Aygün et al., 2017; Cheng et al., 2021; Polat et al., 2013).

The recyclability, sustainability, biodegradability, and renewability of moulded fibres and pulp-based products—such as pulp preparation, forming, pressing, and drying in the mould compression moulding to form various three-dimensional fibre products—have drawn increasing attention. These products are used commercially in a variety of packaging markets, including those related to horticultural trays/pots, food (egg and fruit trays), disposable items (bedpans and urine bottles), and other industrial packing (electronics and vehicle parts) (Zhang et al., 2022).