Anal. Methods Environ. Chem. J. 5 (4) (2022) 20-42

AMECJ

Research Article, Issue 4
Analytical Methods in Environmental Chemistry Journal
Journal home page: www.amecj.com/ir

Review Article: Development of biodegradable films using nanocellulose for food packaging application

Asha Valsalan[a,*], and Paramasivan Sivaranjana [a]

[a] *Department of Chemistry, School of Advanced Sciences, Kalasalingam Academy of Research and Education Krishnankoil, Srivilliputhur, Tamil Nadu 626126*

ARTICLE INFO:

Received 16 Aug 2022
Revised form 20 Oct 2022
Accepted 11 Nov 2022
Available online 30 Dec 2022

Keywords:
Nano cellulose,
Biodegradable Films,
Food Packaging,
Extraction methods,
Test methods,
Tensile and physical characteristics

ABSTRACT

Due to the development of nanotechnology and changing customer demands for food safety and hygiene, the food packaging industry is growing significantly. In today's worldwide market, active packaging offers a number of advantages over traditional wrapping because of its capacity to absorb or release substances to improve the shelf life of food. Traditional food packaging materials are difficult to recycle and are made from nonrenewable fossil fuels. The development of biodegradable films using Nano cellulose can be a good replacement for synthetic plastic packaging materials and can be a good solution for this problem. Other than that it has multiple advantages regarding tensile and physical properties, also as reducing health hazards. Tensile and physical characteristics are improved and water vapor permeability is decreased with the addition of cellulose nanoparticles to the biodegradable films/biodegradable composite films. The production of biodegradable materials employing Nano cellulose has been covered in this review study in four different ways, including extracts from agricultural waste, rice husk, various plant extracts, and biopolymer composite material in food packaging. The reason for using Nano cellulose-based biodegradable films in food packaging is also reviewed in this article. The key points for future research in overcoming the problems related to Nano cellulose and biodegradable films are also predicted in the paper.

1. Introduction

The rapid population expansion, high standards of living, and high rates of energy and goods consumption all contribute to significant levels of waste generation that, if not properly disposed or recycled, represent serious risks to the environment [1]. Plastic waste is a non-biodegradable component that can linger in the environment for hundreds of years. Both people and animals should avoid them because of how much land they consume. Additionally, as plastics are petroleum-based materials, the ongoing engineering of plastics, which results in the depletion of petroleum, offers additional issues [2]. Over the past few decades, petroleum-based materials have been widely used in a variety of industries, especially for food wrapping because of their affordability, exciting technological features, as well as mechanical and physical capabilities. The bulk of plastics made from fossil fuels is bad for both public health and the environment [3]. In order to replace petroleum-based goods in food packaging applications, more renewable alternatives are being sought after. A large amount of the numerous tones of

*Corresponding Author: Asha Valsalan
Email: id-bs.ashav@sbcemail.in
https://doi.org/10.24200/amecj.v5.i04.207

inedible plant debris produced each year gets landfilled. Reusing lignocellulose biomass wastes has received attention recently as a healthy and practical substitute for the usage of fossil fuels. Due to the enormous amount of agricultural waste produced annually, this reuse serves two purposes: Reducing landfill overflow and Reducing reliance on fossil fuels, with all the attendant environmental advantages [4]. They might also be referred to as bio-waste. Sludge from wastewater treatment plants, food manufacturing plant waste, and trade trash are all examples of biodegradable wastes [5]. Nowadays, biodegradable wastes are used in an effective manner for the manufacturing of various products, especially in the food packaging industries. The food packing sector is currently looking for lightweight, biodegradable packaging in an effort to utilize fewer resources, produce less waste, save transportation costs, maintain the freshness of food materials, and also to reduce health hazards [6]. Plastic food packaging materials are replaced by producing biodegradable films incorporated with Nano cellulose extracted from various types of biodegradable wastes like agri-waste, plant extracts, biodegradable polymers, etc. Biodegradable films are produced by adding some additives with them during the manufacturing process. Biodegradable films are an alternative to petroleum-based and plastic-based films.

2. Experimental

2.1. Nano Cellulose

Using various extraction methods, native cellulose is converted into the distinctive and natural molecule known as Nano cellulose. The amazing properties of Nano cellulose, such as its distinct surface chemistry, exceptional physiochemical toughness, and abundance of hydrophilic groups for alteration, are increasingly attracting attention. In addition to being environmentally friendly, it has significant biological qualities such as recyclability, bioactivity, and non-toxicity [7]. The term "Nano cellulose" refers to a class of cellulosic nanoparticles with at least one dimension up to 100 nm. Cellulose nanofibers (CNF), cellulose nanocrystals (CNC), and bacterial Nano cellulose (BNC) are the three varieties of "Nano cellulose" that may be identified by their diameters [8]. The picture of Nano cellulose is depicted in Figure 1.

2.2. Basic Extraction method of Nano cellulose

Many techniques have been developed to extract Nano cellulose from cellulose fiber. The diverse extraction methods led to a variety in the kinds and quality of the Nano cellulose that was produced. The three fundamental extraction techniques are acid degradation, enzymatic hydrolysis, and mechanical procedure. Acid hydrolysis is one of the main techniques for eliminating Nano cellulose

Fig. 1. The picture of Nano cellulose [8]

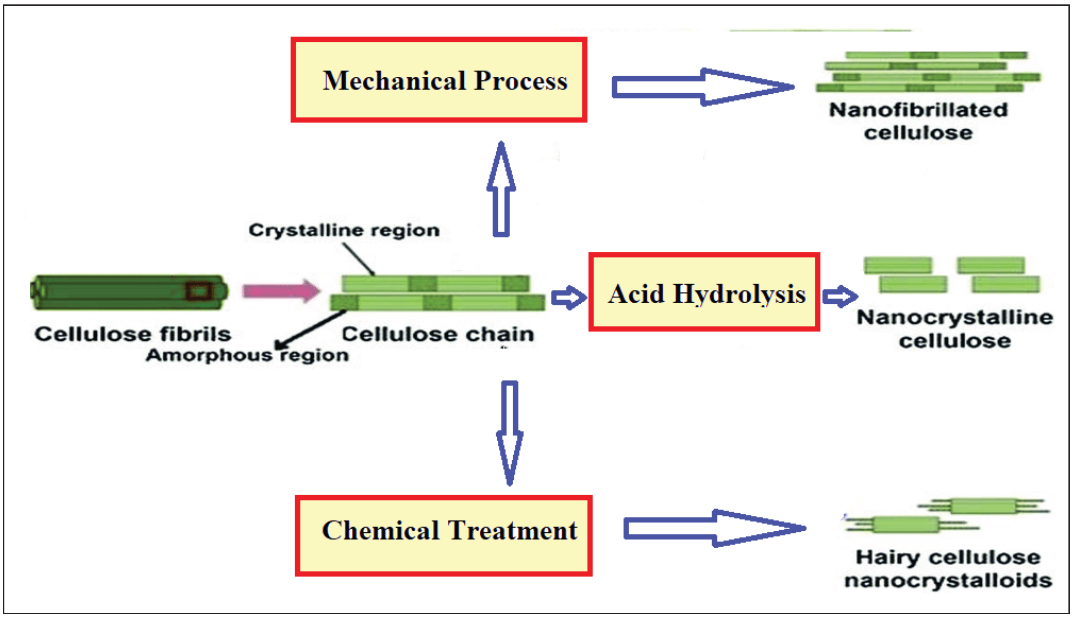

Fig. 2. The illustration of Nano cellulose extraction from lignocellulose biomass [9]

from cellulosic products. Because cellulose chains include equally arranged and unstructured regions, the organized regions survive acid degradation while the disorganized regions break down quickly. The acid most frequently used for acid hydrolysis is sulfuric acid. Enzymes are used in the biological process known as enzymatic hydrolysis to degrade or modify fibrous material. The biological treatment with enzymes may typically be carried out under modest conditions, although a lengthy procedure is needed. To solve this problem, enzymatic hydrolysis is always used in conjunction with other methods. A mechanical process isolates cellulose fibrils, resulting in Micro reinforcing materials cellulose, by using a powerful shear force to split the cellulose fibres along their longitudinal axis. The three mechanical processes that are most frequently used are ball milling, high-pressure homogeneity, and ultrasonication [9]. The separation of Micro cellulose from biomass including lignocellulose is depicted in Figure 2.

2.3. Types of Nano cellulose

Below is an explanation of the three different types of Nano cellulose: cellulose nanofibers (CNF), cellulose nanocrystals (CNC), and bacterial Nano cellulose (BNC).

2.3.1. Cellulose Nanofibers (CNF)

Length, elastic, and intertwined nanoscale fibers known as "cellulose nanofibers" (CNF) can be recovered from lignocellulose-containing crops. Due to their superior hardness, rigidity, lightweight, environmental friendliness, and recyclability, CNFs are being researched for usage in a variety of applications, including electronics, packaging, and nanocomposites [10]. CNF have crystalline and amorphous regions, and they resemble ropes. When dried, CNF form a highly connected network as a result of strong intermolecular hydrogen bonding [11]. The SEM picture of CNF is displayed in the following Figure 3.

2.3.2. Cellulose Nanocrystals (CNC)

The particles known as cellulose nanocrystals (CNC) are small, stiff, and rod-shaped. It is also known as Cellulose Nano whiskers. They are typically created through the process of strong acid hydrolysis, which separates the stiff crystalline sections from the amorphous phases of cellulose strands [11]. Researchers in both research and industrial applications have shown a great deal of interest in cellulose nanocrystals (CNCs) because of their intriguing structural features and distinctive physicochemical properties, like amazing structural

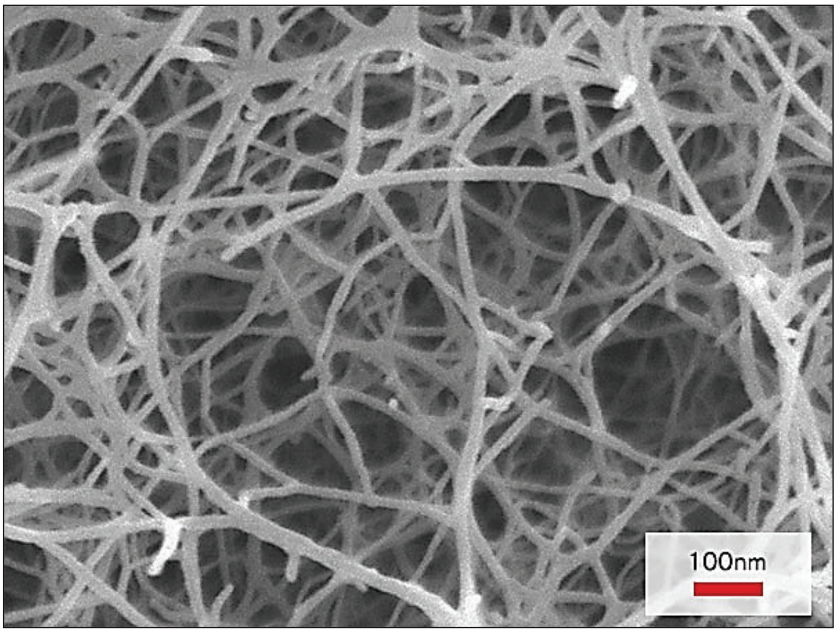

Fig. 3. SEM of Cellulose Nanofibers (CNF) [11]

rigidity, large surface region, numerous hydroxyl groups for chemical treatment, lightweight, and biodegradability. CNCs are a strong candidate for use in a variety of industries. In addition, cellulose nanocrystal extraction and surface modification continue to advance in response to producers' growing demand for cellulose nanocrystal-based goods [12]. Figure 4, presents the image of CNC.

2.3.3. Bacterial Nano cellulose (BNC)

Bacterial Nano cellulose (BNC), a naturally occurring biopolymer of enormous significance in many technical domains, has exceptional physicochemical and biological features. Specific species of bacteria generate bacterial Nano cellulose (BNC), a promising natural biopolymer, as an exopolysaccharide of D glucopyranose. BNC

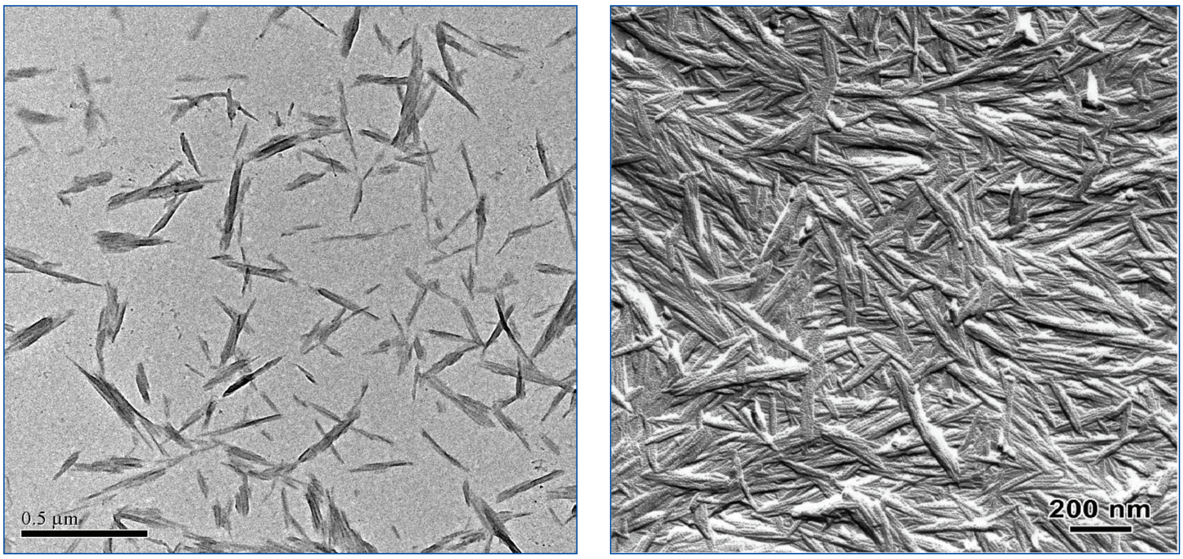

Fig. 4. Cellulose Nanocrystals (CNC) [12]

is 99 percent water but has excellent mechanical properties. Due to its ability to store water and its Nanostructured form, which is similar to the extracellular matrix protein collagen, BNC is particularly suitable for cellular immobilization and adhesion. Bacterial Nano cellulose is suited for a variety of uses since it has a number of unique characteristics and is a product that is generally regarded as safe (GRAS) [13]. The picture of BNC [14] is displayed in the Figure 5.

2.4. Reason for using Nano cellulose based biodegradable films in food packaging

The main objective of food packaging is to preserve the production of agricultural products through storage and delivery. As a result, it's critical to grow the shelf life of food goods by avoiding issues such as microbial deterioration and chemical pollutants, carbon dioxide, water vapor permeation, flammable substances, dampness, and light exposure as well as outside physical influences. The materials used for packaging must ensure physical safety and establish suitable physicochemical conditions to ensure food quality [15]. Hence Nano cellulose incorporated biodegradable films thus produced plays a vital role as a food packaging material by overcoming all these defects due to their beneficial amount of physical, chemical, water solubility, and water absorption properties. These properties are discussed briefly in the upcoming sections. In this paper, a review based on development of biodegradable films using Nano cellulose from various extracts and useful analyzing in food packaging applications was presented. This review paper's structure is followed as: the experimental section evaluates the existing research on biodegradable films using Nano cellulose in four different directions, the results section gives the summary of this paper, another section comes out with the key points to be researched in the future and conclusion.

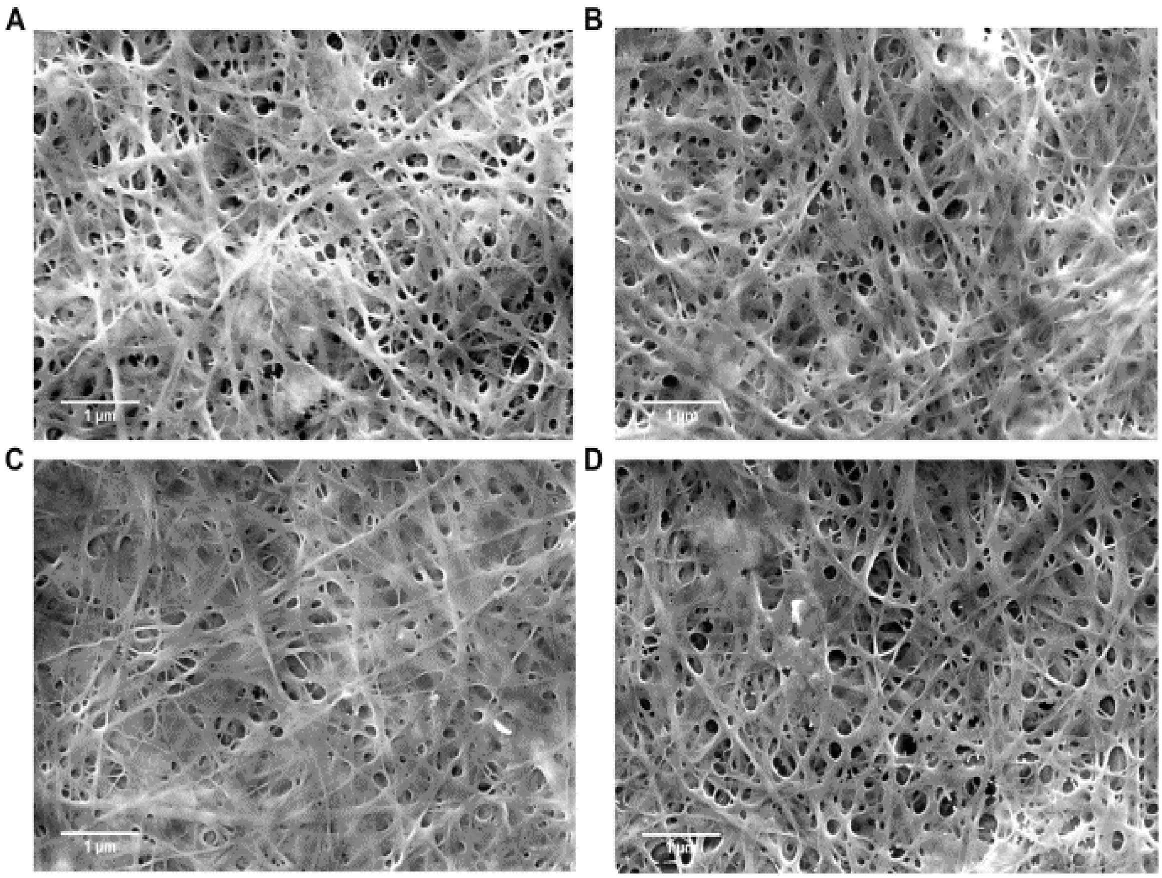

Fig. 5. Bacterial Nano cellulose (BNC: A-D) [14]

3. Results of literature review

This section reviews the development of biodegradable films using Nano cellulose from – agricultural waste, rice Husk, various plant extracts, and biopolymer composite material in food packaging. Agricultural Waste: Agro-wastes come from a variety of materials, including rice husks, wheat straw, palm oil fibers, pineapple, orange, and tomato pomace, grape pomace, lemon peels, and sugarcane bagasse [16]. Agro-industrial waste is a byproduct of agricultural-based businesses that is frequently rich in lignocellulose resources and bioactive compounds. The industries where these pollutants are frequently disposed of in uncontrolled procedures have weak regulations for their management. These actions have had a negative impact on the ecology and the economy as a whole. Due to this, extensive research has been done to extract useful materials from these wastes [17]. Rice husk is a lignocellulose biomass, that comes under non-woody biomass sources. Non-woody plants are ones that have frail stems and are susceptible to yearly regrowth to the ground. They go by the name herbaceous plants as well [18]. Some of the Plant extracts used for Nano cellulose production, that we have discussed in the upcoming section are as follows: sugarcane bagasse, olive tree pruning scraps, yam beam, sunflower oil cake (SOC), Natural essential oil from the clove bud, buffered with fermented black tea and cellulose nanocrystals fiber. Biopolymer composites are reinforced polymer materials in which the polymer functions as a matrix resin that reaches the bundles of reinforcement and forms bonds with it [19]. The upcoming sections deeply describe the related works of the above-mentioned directions.

3.1. Biodegradable films using Nano cellulose from agricultural waste

Ilya et al examined the effects of different sugar palm nano fibrillated cellulose (SPNFCs) reinforced sugar palm starch (SPS) concentrations on the morphological, structural, and physical characteristics of the bio nanocomposite film [20]. Starch granules and filaments from sugarcane plants are regarded as agricultural waste. A suspended sentence of sugar palm Nano fibrillated cellulose (SPNFCs) with a mean duration of many µm in diameter and diameters of 5.5 and 0.99 nm was made from sugar palm fibres using a high-pressure homogenization technique. SPNFCs were then used to strengthen the sugarcane bagasse carbohydrate sequence for the creation of bio nanocomposites using a remedy technique. The miscibility of SPS and SPNFCs was shown to be good using FESEM analysis of the casting solution. The FTIR analysis proved that intramolecular hydrogen bonds existed between the SPS and SPNFCs and that they were compatible. SPS/SPNFC bio nanocomposite films outperform control carbohydrate bio nanocomposite films in terms of physical and mechanical properties. The segmental molecular chains of the carbohydrate bio composite became less mobile and flexible as a result of the addition of Nano-reinforcements, which decreased the elongation at break. The ductility strength and modulus of the nanocomposite films were dramatically increased from 6.80 to 10.68 MPa and 59.07 to 121.26 MPa, respectively, by the increase in SPNFC reinforcement from 0 to 1.0 wt. percent. Adriana Nicoletta Frone et al used plum shells' agricultural residues to Nano cellulose as a biopolymer reinforcement [21]. Cellulose nanocrystals (CN) and cellulose nanofibers (CF) are the two types of Nano cellulose derived from plum seed shells. For the first time, CN and CF of cherry fruit skins were used as reinforcing agents in a polylactic acid/poly(3-hydroxybutyrate) (PLA/PHB) matrix using a solution-casting technique. A cost-effective and successful strategy to utilize agricultural waste as a source of production for elevated goods is to adopt this technique. Some of the CF type's limitations in terms of morphological characterization and thermal performance include that type CN cellulose nanocrystals are more similar in shape, have a smooth texture, and have a larger image size. The melting temperature of CN was somewhat less than that of CF due to the sulfate groups added to the cellulose's external side during the hydrolysis process, which led to the dewatering of the cellulose fiber and a decrease in thermal properties. Thermal and XRD tests showed that adding CN improved the PLA/PHB bio-composite film's thermostability and crystalline nature.

According to report of Reshmy et al, jackfruit (Artocarpus heterophyllus) skin was used as the hydrolysis source for pure Nano cellulose [22]. Using liquid water evaporation, the thin films were created using BS as the filling, activator, and NC as the substrate. Solvent casting Nano cellulose and various plasticizers were used to make various thin films. FT-IR and XRD were used to describe thin films, and FESEM was used to explore surface changes. The advantages of this strategy are as follows: (i) To avoid chlorine bleaching solutions for natural fibers, the raw material was bleached with a 4 percent soapnut solution. (i) A unique filling named Boswellia serrata (BS) was used to enhance the properties of NC thin films for future applications. The breakage of bonds between NC and plasticizers caused commodities to decay during food storage due to the large price of WHC for NC alone and NC/Gly/BS. This resulted in less moisture absorption and swelling compared to other thin films.

Sheng Xu et al stated that Artemisia selengensis stalks were used as a source of hemicelluloses (ASH) and cellulose nanocrystals to create biodegradable films (ASCNC) [23]. Acid hydrolysis was used to separate the ASCNC from the ASC. SEM, TEM and FTIR methods are used for the test results, and OT and WVP are also checked. The composite membranes enhanced by ASCNC exhibited increased durability and performed much better as a water vapor shield when contrasted to the reference ASH/PVA film. Additionally, compared with the control screen, the ASCNC-enhanced ASH/PVA composite material decreased light transmission considerably. In the morphology of composite films, the ASH/PVA film's cross-section had many voids, and the structure was loose. With ASCNC loading reaching 9%, the composite film's tensile strength improved by 80.1 percent to 36.21 MPa, while the water vapor transfer rate fell by 15.45 percent when 12 percent ASCNC was added.

Banana pseudo-stems were proposed as a potential source of environmentally friendly Nano cellulose-based recyclable plastic as an agricultural waste by R. H. Fitri Faradilla et al [24]. This study looked closely at the impact of nanoclay (NC) and graphene oxide (GO) as nanofillers and glycerol as a lubricant on the mechanical, morphological, chemical, thermal, and impact resistance of banana pseudo-stem Nano cellulose films. TEM, SEM, FEI NOVA 230, AFM, Bruker, X-ray diffraction (XRD), panalytical Xpert multipurpose X-ray diffraction, thermos gravimetric analysis, and differential scanning calorimetry, ATR-FTIR, Bruker IFS 66/S, and Mocon-OX-TRAN are the testing methods used to find the results. Synergistic effects were seen when nanoparticles and glycerin were combined. Tensile modulus and flexibility were both risen, and the contact area of the motion pictures was considerably higher than that of films containing only nanoparticles. The thermoplastic had a massive effect on the barrier properties of the composites, while the glycerol concentration was positively correlated with the water vapour permeability. Oxygen permeability, however, was reduced when glycerol content increased. Also, the films' tensile strength was found to be improved by NC and GO, but not their elasticity. These results strongly imply that the characteristics of the banana pseudo-stem Nano cellulose film may be altered by modifying the nature and amount of additional chemicals.

It was suggested to separate bulgur bran into cellulose and hemicellulose-rich components, opening the way for exploiting this under-utilized agro-industrial biomass by Didem Sutay Kocabas et al [25]. Commercial cellulose nanocrystal (CNC) and cellulose nanofiber (CNF) were added to the hemicellulose substrate to remove bottlenecks. The characteristics of plain and Nano cellulose-reinforced films were compared using the thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), and Fourier transform infrared spectroscopy (FTIR) techniques. A dense architecture was discovered by SEM analysis of films reinforced with CNC and CNF. The hemicellulose channel's tensile properties were significantly improved by adding CNC and CNF as fills. After adding Nano cellulose, the films' water vapour permeability (WVP), light transmittance, overall mismatching, and biocompatible all fell. Additionally, the hemicellulose precipitate contains lignin (6.70 percent), starch, potassium acetate, and other impurities. The proposed full-quadratic model was shown to have excellent accuracy within the 95 percent confidence interval (R^2 = 0.9877). According to the findings, films with 10% (w/w) CNC and 10% (w/w) CNF incorporation had a 21.3 percent lower FWS when compared to neat pictures.

Krishnavani Pavalaydon et al extracted Micro cellulose from cassava peel and coco fiber using chemical processes such as mercerization, bleaching, and acid hydrolysis [26]. Taguchi design is the technique used in the process of Fourier-Transform(FT). The test techniques employed in the procedure include DLS, transmission electron microscopy, and infrared spectroscopic. Bio-nanocomposite films were created using the solvent casting method using polyvinyl alcohol (PVA) as the matrix. Excellent sources of Micro cellulosic include sugarcane bagasse and coir, which can be used to create bio-composites having good strength properties. Nanocellulose, which is made from bagasse, first appeared as crooked and minute circular particles. The highest tensile strength (38.2 MPa) was achieved for CNCs derived from coir at a CNC/PVA loading of 0.5 wt%, which is a 96.9 percent improvement in strength properties over the unstrengthened PVA substrate.

According to Vu Nang An et al, the goal of the study is to separate high-crystallinity Cellulose Nano Crystals (CNCs) from Vietnamese agricultural residues (Nypa Fruticans trunk, coconut husk fiber, and rice husk) [27]. Using a three-step process that involved pre-treatment with formic/peroxyformic acids, processing with hydrogen peroxide/sodium hydroxide, and disintegration by hydrolysis, so, CNCs were extracted from the aforementioned natural origin. After every phase of behavior, the thermophysical characteristics of the obtained resources were examined using XRD, TGA, TEM, and FT-IR studies. Nano cellulose fibres were found to have improved thermal stability through thermogravimetric analysis, making them suitable for the creation of bio nanocomposites for a variety of uses, including the production of functional paper, flexible assistance for the synthesis of metal/oxide metallic nanoparticles, and cell wall filters. The amorphous portions of the cellulose structure have been utterly destroyed by the corrosive ions, remaining the crystalline structure unharmed. Because of this, CNCs are both shorter and have a higher CrI than cellulose. The CNCs nanofibers have a high crystalline index (almost 80%), increased heat stability, and indicating an extensive variety of applications. Hui Li et al aimed to isolate cellulose nanocrystals (CNC) from pea hull and test their capacity to strengthen carboxymethyl cellulose (CMC) film [28]. To better utilize and get rid of cheap and plentiful farmed pea husk trash, the needle-like CNC was finally recovered from the trash by alkalization, washing, and sulfuric acid degradation. The solvent casting process produced CNC, which was then used as a reinforcing component in the creation of compound products which was depended on CMC. The tests included scanning electron microscopy, ATR-FTIR and X-ray diffraction analysis, hand-held digital microscopy, gravimetric technique, and DSC. The CMC/CNC nanocomposites saw improvements in their thermal properties, ultraviolet layer, mechanical properties, and water vapor barrier. The lower the endothermic peak, the larger the additional concentration of CNC. This was due to a lower hygroscopic affinity caused by the addition of additional sulfate groups to the CMC/CNC nanocomposite. In comparison to pure CMC film, the 5-weight percent CNC reinforced composite film had a 53.4 percent lower water vapour absorption and a 50.8 percent better durability.

According to research of Jayachandra S. Yaradoddi et al, the objective is to transform carboxymethyl cellulose (CMC), which is generated from agricultural residues, into a workable, biodegradable plastic that often includes a packaging material [29].

Mixtures were created using CMC (trash generated), gelatin, agar, and varied levels of glycerol; 1.5 percent (sample A), 2 percent (sample B), and 2.5 percent (sample C) were added. CMC was recovered from agricultural residues, primarily cane sugar waste. Thermogravimetric analysis(TGA), Fourier Transform Infrared (FTIR) spectroscopy, and Differential Scanning Calorimetry (DSC) were used to describe the physiochemical parameters of each created biodegradable plastic (samples A, B, and C). Sample C, which was made with gelatin, CMC, agar, and 2.0 percent glycerol, was discovered to be the best combination and ideal for possible future use in food applications because it had identified the strengths like the smallest water vapour permeability and the greatest recyclability rate when compared to other samples. As commercially available CMS is currently too expensive, farm waste-derived carboxymethyl cellulose (CMC) is used largely to reduce the cost of film development. As a consequence, sample C's (gelatin+CMC+agar) film functioned better than samples A and B related to the addition of glycerol at a softener concentration of 2.0 percent.

Table 1 shows the overall review of the techniques such as Nano cellulose produced, the material, testing method, advantages, limitations, and performance parameters. Table 1 explained the direction - Biodegradable films using Nano cellulose from agricultural waste.

Table 1. Review on Biodegradable films using Nano cellulose from agricultural waste

Technique	Nano cellulose Produced	Material	Testing Method	Advantages	Limitation	PP	Ref.
HPHM & SCM	SPNFCs	AW-SPF	FESEM and FTIR	MP> CSBNF	Reduced the elongation at break Affecting mobility and ductility of the biopolymer's segmental	TS=6.8 - 10.7 MPa Modulus= 59.1 - 121.3 MPa	[20]
Solution-casting method	CF and CN	Agri waste-PSS	Thermal and XRD analyses	Cost-effective and well-organized	Compared to the CF type, type CN's morphology is much more regular, its surface is finer, and its aspect ratio is higher.	The thermal stability was improved by the calculation of CN and crystallinity of the PLA/PHB biocomposite film	[21]
Acid hydrolysis, BS filler and NC	Solvent casting Nano cellulose	(i)Agri waste - Jackfruit peel (ii)Bleaching Agent - Soapnut solution	FT-IR, XRD and FESEM	(i)Chlorine bleaching solutions (i)Boswellia serrata (BS) improve the characteristics of NC thin films	Because of the tall value of WHC for NC alone and NC/Gly/BS, commodities spoiled during food storage due to breakdown of bonds between NC and plasticizers	When compared to other thin films, this resulted in less moisture absorption and swelling	[22]
Acid hydrolysis	Hemicelluloses (ASH) and cellulose nanocrystals (ASCNC)	Agri waste - Artemisia selengensis straw	SEM, TEM and FTIR methods, OT and WVP is also checked.	water vapour shield effectiveness, and light transmission reduction.	ASH/PVA film's cross section had a lot of voids and the structure was loose	With ASCNC loading reaching 9%, the composite film's tensile strength improved 80.1 percent to 36.21 MPa	[23]
Modified Nano cellulose film	Banana pseudo-stem Nano cellulose films	Agri waste - banana pseudo-stem	TEM, SEM, FEI NOVA 230, AFM, Bruker, XRD, ATR-FTIR,	(i) Enhanced tensile power and flexibility, (ii) The greate materials' contact angle (iii) The film resistance affected by the plasticiser.	(i)Oxygen permeability, reduced when glycerol content increased (ii)Film's tensile strength was found to be improved by NC and GO, but not their elasticity	By varying the type and concentration of added additives, the properties of the banana pseudo-stem Nano cellulose film might be modified.	[24]

Bulgur bran hemicellulose	Cellulose nanocrystal (CNC) and Cellulose nanofiber (CNF)	Agri waste - Bulgur bran	TGA, DSC, FTIR	(i)Revealed a compact structure (ii)Increased the tensile strength	(i)Water vapor permeability (WVP), light transmittance, overall colour difference, and biodegradability all are decreased (ii)Contains lignin (6.70%), starch, potassium acetate	(i) Have great accuracy ($R2 = 0.9877$) (ii)10% (w/w) CNC- and 10% (w/w) CNF incorporated films had a 21.3 percent decrease in FWS	[25]
Bleaching, Acid hydrolysis and Solvent casting process	Bio-nanocomposite films with polyvinyl alcohol (PVA)	Agri waste - Sugarcane bagasse and coir	FTIR, SEM, DLS	(i)Good bases of Nano cellulose (ii) employed to create bio-composites with good strength properties.	Bagasse-derived Nano cellulose emerged as irregular and tiny circular particles	The ultimate compressive strength (38.2 MPa) for CNCs of coir,	[26]
(i)Pre-treatment with HCOOH (ii)treatment with H_2O_2/ NaOH (iii)disintegration	Cellulose Nano Crystals (CNC)	Vietnamese agricultural waste (Nypa Fruticans trunk, coconut husk fiber, and rice husk)	XRD, TGA, TEM, and FT-IR analyses	(i)Nano cellulose fibers have improved thermal stability (ii)The cellulose material's unstructured regions have been attacked and destroyed by the acidity ions	CNCs have a greater CrI than cellulose and have a shorter length than cellulose	CNCs nanofibers have a high crystalline index (almost 80%) and increased heat stability	[27]
(i)Alkali treatment, Bleaching, For CNC (ii)Solution casting For CMC	Cellulose nanocrystals (CNC)	Agri waste - Pea hull waste	SEM, ATR-FTIR analysis, Gravimetric Method, DSC	CMC/CNC hybrid sheets' UV barrier, mechanical properties, and heat resistance were enhanced.	The presence of more sulphate groups in the CMC/CNC composite film resulted in a decreased hygroscopic affinity	(i)50.8 percent improvement in tensile strength (ii)53.4 percent decrease in water vapor permeability	[28]
Bleaching	Carboxymethyl cellulose (CMC)	Agri waste - Sugar cane bagasse	TGA, FTIR, DSC	Sample C:(i)best formulation (ii) food packaging (iii) lowest water vapor permeability	Expensive	The film generated from sample C outperformed the other samples A and B	[29]

PP: Performance Parameters
TS: Tensile strength
HPHM & SCM: High-pressure homogenization method and Solution-casting method
SPNFCs: Starch reinforced with sugar palm Nano fibrillated cellulose
AW-SPF: Agriculture waste- Sugar palm fibers
MP: Mechanical properties
CSBNF: Control starch bio nanocomposite films
CF: Cellulose nanofibers **CN**: Cellulose nanocrystals
PSS: Plum seed shells

3.2. Biodegradable films using Nano cellulose from rice Husk

Rice Husks were cleaned, chemically hydrolyzed, and ultrasonically processed at a low temperature by Pedro Nascimento et al to produce Nano cellulose [30]. An agricultural sector byproduct called rice husk can be utilized to make Nano cellulose. SEM, TEM, XRD, FTIR, TGA, and DSC are the tests undergone to find the characterization of Nano cellulose-reinforced starch-glycerol films. When added as reinforcement to the starch films, the Nano cellulose created webs of connected, tiny fibers (about 100 nm in diameter) that reduced opacity, increased mechanical characteristics, and were less permeable to water vapor. The inclusion of 2.5 percent (w/w) of the nanostructures to starch-glycerol films increased the mechanical characteristics, water vapor permeability, and opacity of starch films (made by extrusion). After the alkaline pre-treatment, the fibre surface has been less tiny as well as its actual construction has been altered. This outcome showed that the exterior non-cellulosic layer, which is made up of hemicelluloses and lignin, had been partially removed. The produced Nano cellulose displayed lower lignin levels than 0.35 percent, greater thermal strength than the raw substantial, and higher crystallinity (up 70%). Sumira Rashid et al used rice grains with short, medium, and long husks to extract Nano cellulose [31]. During the steps of delignification and acid hydrolysis, the noncellulose amorphous and noncrystalline cellulose fractions were successfully removed because of increased crystallinity and altered infrared diffraction. Nanocelluloses are more heat resistant than cellulose. The results are obtained using the tests methods: SEM, TEM, AFM, NT-MDT, SOLVER NANO, ZP, ATR-FTIR, XRD, TGA, DSC, and HA. Delignification in conjunction with bleaching led to gradual depigmentation and turned the material's hue to white. The size, crystallinity, strength, and thermal stability of long husks built at the nanoscale were better than those of medium and short husks. Cellulose nanomaterials are totally consistent with fortifying biopolymers, according to J. F. Delgado et al [32]. The effects of rice husk cellulose nanofibers (RHCNF) and bacterial nanocellulose (BNC) on water vapour transport and mechanical behavior were examined in yeast biomass films made from dispersions (processed by greater homogenized and subsequently thermal treatment) at pH 6 and 11. BNC was created using a culture of the NRRL B-42 strain of Gluconacetobacter xylinus. The tests used to analyze the results are NMR, XRD, AFM, SEM, and WVP. Nano fibers could be successfully added to yeast matrices and both increased tensile strengths, while BNC was more effective than RHCNF at improving the mechanical properties of yeast films. Despite having identical diameters and costing more to produce than RHNCF, only BNC improved Young's modulus, elastic modulus, modulus of rupture, and mechanical hardness of the yeast matrix simultaneously. Although they had little effect at pH 6, both supplements had a 5-weight percent reduction in water vapor permeability in films made at pH 11. The impact of Nano cellulose on the film properties of edible coatings was studied by Jeya Jeevahan Jayaraj et al [33]. To produce Nano cellulose from rice husk, a three-stage biochemical process involving alkaline solution, whitening, and acid hydrolysis was applied. Using native potato starch, glycerin, and varying amounts of Nano cellulose, the edible coatings (potato starch films) were produced using the solution casting method (0 percent, 5 percent, 10 percent & 15 percent). AStM E96, Digital colorimetric method, and AStM D882 are the test analysis methods conducted to determine the WVTR, Film color, and Powered strength of the comestible films. It was discovered that the addition of Small amounts of cellulosic had created films with a lower Water Vapor Transmission Rate (WVTR), more mechanical strength, and greater transparency compared to the control films. Mechanical strength did not increase as the Nano cellulose content was raised above 10%. With the rise in Nano cellulose percentage from 5 % to 15 %, the WVTR of bio nanocomposite edible films reduced. Starch granules only have between 40 and 60 percent visibility compared to Nano cellulose's greater than 95 percent visibility. According to A. Ganesh Babu et al, bio-films were produced utilizing the solution casting process employing liquid polyvinyl alcohol (PVA) and variable amounts (5-25wt percent) of rice husk flour as reinforcing filler [34]. FTIR, XRD, TGA, DSC, Tensile test, Surface morphology investigations, WVP, and Antibacterial tests were used to examine the impact of RHP on the PVA matrix. Some of the advantages are (i) Bio-films could tolerate temperatures of up to 350 °C (ii) The stronger interaction of polymer chains is present with lower WVP levels (iii) Exhibit strong antibacterial activity (iv) Bio-films were clearly homogenous, free of fractures and phase separation (v) Enhance the biofilm's thermo-mechanical properties. The presence of hydrogen bonding makes films less flexible. Tensile modulus and tensile properties steadily rise as RHP is infused into the matrix, reaching their maximum values at a concentration of 25 percent RHP in PVA and 23.32 MPa and 684 MPa, respectively. Himanshu Gupta et al focused on using leftover lignocellulose biomass (such as sugarcane bagasse and rice hulls) to make carboxymethyl cellulose (CMC), which is then transformed into a biodegradable film [35]. The methods of Mercerization and Etherification are used to create CMC from SCB Cellulose and Rice Hulls. The characterization is done by the FTIR, XRD, MC, and TS test methods. The biopolymer film made from sugarcane bagasse CMC had the highest strength and elongation when compared to films manufactured from conventional CMC and CMC made from rice

Table 2. Review on biodegradable films using Nano cellulose from rice husk

Technique	Nano cellulose Produced	Material	Analysis	Advantages	Limitation	PP	Ref.
(i)NC - Bleaching, Acid hydrolysis, and Ultrasonic (ii)SGF -Extrusion	(i)NC from rice hulls (ii)SGF	Rice hull	SEM, TEM, XRD, FTIR, TGA, DSC	(i)Reduced opacity (ii)Increased mechanical characteristics (iii)Less permeable to water vapor	Less dense fibre layer with lessral shape and the exterior non-cellulosic layer removed	(i)Displayed lower lignin levels than 0.35% (ii)Higher thermal stability than the raw material (iii) Higher crystallinity (up 70%)	[30]
Delignification and Acid hydrolysis	Nano cellulose	Rice grains with short, medium, and long husks	SEM, TEM, AFM, NT-MDT, SOLVER NANO, ZP, ATR-FTIR, XRD, TGA, DSC, HA	(i)Noncellulosic and noncrystalline cellulose removed (ii)Increased crystallinity (iii)Nanocelluloses are more heat resistant than cellulose and husks	Delignification led to gradual depigmentation and turned the material's hue to white	The size, crystallinity, strength, and thermal stability of long husks were better than medium and short husks	[31]
(i)Yeast biomass films - Dispersions at pH 6 and 11 (ii)RHCNF and BNC	Rice husk cellulose nanofibers (RHCNF) and Bacterial Nano cellulose (BNC)	(i)For RHCNF (ii)For BNC (iii)For Yeast Biomass Films	NMR, XRD, AFM, SEM, WVP	(i) BNC was more successful than RHCNF in enhancing the mechanical properties of yeast films (ii)BNC and RHCNF, both boosted tensile strengths	(i)Only BNC enhanced the yeast matrix's Young's modulus, tensile strength, (ii) BNC is more expensive than producing RHNCF	Water vapor permeability was reduced by 5 weight percent in both reinforcements in films created at pH 11.	[32]
(i)Nano cellulose - Alkaline treatment, Bleaching, and Acid hydrolysis (ii)Potato starch films - Solution casting method	Nano cellulose	(i)For NC – Rice Husk (ii)For Potato Starch Film - glycerol with varied NC (0 - 15 %)	AStM E96, Digital colorimetry method, AStM D882	(i)Lower Water Vapour Transmission Rate (WVTR) (ii)Greater mechanical strength (iii)Greater transparency	Mechanical strength did not increase as the Nano cellulose content was raised above 10%	(i)Rise in Nano cellulose percentage from 5 % to 15 % - WVTR of bio nanocomposite edible films reduced. (ii)The transparency of Nano cellulose is greater than 95%	[33]
Solution casting method	Polyvinyl alcohol (PVA)	Rice Hull powder as filler	FTIR, XRD, TGA, DSC, Tensile test, Surface morphology studies, WVP and Antibacterial testing	(i)Tolerate up to 350 °C (ii)High interaction of polymer chains (iii)Exhibit strong antibacterial activity (iv)Bio-films were clearly homogenous, electrical and thermal qualities.	Lower flexibility of films is caused by the existence of hydrogen bonds	Tensile strength and tensile modulus - 23.32 MPa and 684 MPa, at a concentration of 25 percent RHP in PVA.	[34]
Mercerization and Etherification	CMC from SCB Cellulose and Rice Hulls	Rice husk and Sugarcane bagasse	FTIR, XRD, MC, TS	(i)Had the highest tensile strength and elongation (ii)Improved machine-driven possessions (TS and Elongation)	(i) negatively affect the strength of the material (ii) the DS and TS of the rice hull CMC were lower than those of the SCB	With an increase in DS of CMC and as the degree of CMC substituition grew the film's opacity, moisture content, and solubility also increases	[35]

NC: Nano cellulose
SGF: Starch glycerol films

hull. The bio-composite material formed from mixed carbohydrate manufactured CMC solution has exhibited superior mechanical properties in comparison to the film made from blended Starch-Commercial CMC solution (TS and Elongation). Because rice husk contains a lot of sodium chloride and sodium glycolate, (i) it has an adverse effect on the material's strength properties and (ii)it has lower DS and TS than the SCB. The degree of CMC substitution and the DS of CMC both grow as do the film's transparency, water levels, and solubility. Table 2, describes an overall review of the techniques such as Nano cellulose produced, the material, testing method, advantages, limitations, and performance parameters which was explained under the biodegradable films using Nano cellulose from the rice husk..

3.3. Biodegradable films using Nano cellulose

from Various Plant Extracts

Using a more effective, economical enzymatic hydrolysis pathway, R. Reshmy et al proposed a straightforward method for the extraction of Nano cellulose from sugarcane bagasse [36]. It was possible to extract NC fibres from sugarcane bagasse. NC was produced by alkaline treatment, bleaching, and acid hydrolysis. The solvent casting method was used to create thin films. FT-IR, XRD, FESEM, DLS, and AStM D 2216 methods were used to characterize the films. Non-edible sustainable material usefulness, cost efficiency, simple ease of processing, minimal energy usage, non-hazardousness, and simple degradation rate are advantages of this upgraded technology. These thin films might degrade well in situations with soil, salt, acid, and alkaline conditions. Glycerol, a plasticizer, is present in NC, which lessens its tendency to inflate. The acid resistance is increasing due to the use of glycerol as a plasticizer and the reduction in weight loss from 50% to about 40% is a result of the plasticizers included in NC. Nano cellulose was suggested to be added to polyvinyl alcohol by Mónica Sánchez-Gutiérrez et al in order to enhance the technical prowess of the composite coating used for food packaging (PVA) [37]. PVA films reinforced with (L)CNFs derived from olive tree trimming leftovers were manufactured using the solvent casting method. Micro cellulosic was created from pulp that had been both dyed and unbleached using a mechanical and TEMPO preparation. The test methods are as follows: Perkin Elmer UV-Vis Lambda 25 spectrophotometer, FTIR, TGA, SEM, XRD, and AStM E96/E96M-10. From six percent for the pure PVA film to 50 percent and 24 percent, respectively. For unbleached and bleached Nano cellulose, the UV barrier was increased in terms of optical properties. Associated with pure PVA film, the antioxidant capacity of mechanical Nano cellulose films made without bleaching significantly increased (5.3%). The mechanical Nano cellulose films with a 5% unbleached component demonstrated noticeably greater tensile strength as compared to pure PVA film. The 5 percent Nano cellulose films were also improved in terms of their thermal properties and impermeability. They offered an oxygen shield akin to aluminum layers and plastic films while reducing water vapour leakage by 38–59%. Because they are more sensitive to environmental conditions like humidity and temperature. (L) CNF-reinforced films obtained by mechanical pretreatment (MU and MB) needed a lengthier stabilization period than (L)CNF-reinforced films obtained through TEMPO pretreatment (TU and TB). This behavior is displayed by other materials, such as EVOH, which are greatly affected by the surrounding humidity. According to Mochamad Asrofi et al, a Yam Bean (YB) starch substrate and Micro Cellulosic Water Hyacinth Fiber (WHF) reinforcing were employed to develop bio nanocomposites utilizing the casting process [38]. The secret to creating good bio nanocomposites was adding Micro viscose as a solution to the YB starch matrix, allowing it to gel, and then briefly sonicating it. The effect of Nano cellulose suspension loading on the YB starch matrix was examined using mechanical testing, Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), Thermogravimetric Analysis (TGA), Fourier Transform Infrared (FTIR), and wettability. After the addition of Nano cellulose, tensile strength (TS) and tensile modulus (TM) greatly increased. With higher Micro lignocellulosic content, heat resistance and water resistance were also improved. Bio-nanocomposites have a rougher fracture surface than pure YB starch sheets. The greatest amounts of Nano cellulose (1 wt. percent) were used to achieve the maximum values for TS (5.8 MPa) and TM (403 MPa). With just a little more than 1 weight percent of extra Nano cellulose, the bio-nanocomposite's crystallinity index (CrI) increased by more than 200 percent. Zineb Kassab et al proposed that Sunflower oil cake (SOC) was found to be a bio-sourced resource for the manufacture of cellulose nanocrystals (CNC) after chemical processing and sulfuric acid hydrolysis [39]. This study also looked into the newly created CNC's polymer nanoreinforcing capabilities. PVA-based nanocomposite films with CNC30 concentrations of 1, 3, 5, and 8 weight percent were produced using the solvent casting technique. The rheological properties of CNC solutions at different percentages were evaluated using systemic resistance stiffness studies and cyclic dynamic experiments. When the mechanical and transparency properties of CNC-filled PVA nanocomposite films were examined at various CNC contents (1, 3, 5, and 8 wt%), clear nanocomposite products with high hardness properties were produced. The resultant CNC displayed remarkable saturated solution stabilization and gel-like properties at very low CNC concentrations. Nanocomposite materials with significantly better tensile characteristics were produced by incorporating CNC into a PVA polymeric matrix. The addition of CNC causes slight changes in the FTIR spectra of PVA nanocomposites that are filled with CNC. It is possible to see a tiny variation in the OH stretching vibration's intensity. When 8-weight percent CNC was added to PVA-based nanocomposite films, the tensile strength and elastic modulus improved by 107 and 78%, respectively. Swarup Roy and Jong-Whan Rhim showed that an extremely stable nanoscale Pickering emulsion(PE) was made using natural clove bud essential oil stabilized with nanocellulose fibre [40]. The PE was used to produce gelatin and agar functional films. The gelatin/agar-based bidirectional compound film was made using the solution casting technique, and the cellulose nanofiber-based PE was made by preparing a cellulose nanofiber solution. AStM D 882–88, TGA, FESEM, FTIR, and Chroma meter are tests taken to predict the characterization. The inclusion of PE only slightly changed the mechanical properties and vapor impermeability of the gelatin/agar-based film, with no discernible impact on temperature. Without affecting the film's transparency, the inclusion of PE also gave it exceptional UV-barrier qualities. Additionally, the composite film had strong antioxidant properties. The power of the gelatin/agar film was significantly impacted by the addition of PEC. The film has high transmittance to UV and visible light, with corresponding T280 and T660 values of 26.9%, 88.0%, and 1.4 %. The neat gelatin/agar film's minimally changed WVP was 0.59 x 10^{-9} $gm.m^{-2}Pa^{-1}s^{-1}$. The utilization of static intermittent fed-batch (SIFB) equipment and a cheap medium, such as fermentation black tea, according to Chhavi Sharma et al, this study proposes a technique with industrial significance for the creation of inexpensive and environmentally friendly bacterial Nano cellulose (BNC) films [41]. Chitosan, a natural polymer, successfully altered the BNC film (BNC-chitosan film). SCOBY, black tea, and tomatoes were the materials used. The films were characterized using FE-SEM (Field Emission Scanning Electron Microscopy), ATR-FTIR (Attenuated Total Reflectance and Fourier Transform Infrared Spectrometry), X-ray diffraction (XRD), and thermogravimetric analysis (TGA). Because of their high tensile properties, crystallinity, air resistance, and tomato shelf life evaluation, BNC-chitosan coatings have a considerable potential to be used for economical encapsulation, which is unquestionably wanted by the packaging sector. The surface morphology of BNC changed after chitosan treatment. BNC yield was higher in this modified bioprocess (29.2 g L^{-1}) than in the standard static approach (13.3 g L^{-1}) with a BNC yield of 29.2 g L^{-1}. Segal method calculations showed that the CrI of BNC formed via the SIFB technique was 79.2 percent(%), which is nearly identical to the CrI of BNC previously shaped under the traditional fixed technique (79.4 %). The upcoming Table 3, describes an overall review of the techniques such as, Nano cellulose produced, the material, testing method, advantages, limitations, and performance parameters which was explained under the biodegradable films using Nano cellulose from various plant extracts.

3.4. Biodegradable films using Nano cellulose

Table 3. Review on biodegradable films using Nano cellulose from various plant extracts

Technique Used	Nano cellulose Produced	Material	Analysis	Advantages	Limitation	Performance Parameters	Ref.
(i)NC - Alkaline treatment, Bleaching, and Acid hydrolysis (ii)Thin films - Solvent casting method	NC Fibres	Sugarcane bagasse	FT-IR, XRD, FESEM, DLS, AStM D 2216	Non-edible renewable feedstock utility, cost-effectiveness, easy processibility, less energy consumption, non-hazardous and easy degradability	Glycerol, a plasticizer, is present in NC, which lessens its tendency to inflate	(i)Acid resistance is increasing (ii) The reduction in weight loss from 50% to about 40% is a result of the plasticizers included in NC	[36]
(i)Nano cellulose - Mechanical and TEMPO preparation (ii) PVA films with (L)CNF reinforcement - Solvent casting	PVA films reinforced with (L) CNFs	Olive tree pruning scraps	Perkin Elmer UV/VIS FTIR, TGA, SEM, XRD, AStM E96/ E96M-10.	(i)UV barrier was raised (ii)Antioxidant capacity of mechanical Nano cellulose films is increased (iii)Had higher tensile strength (iv)Thermal stability (v) Reduced water vapor permeability by 38–59% (vi) oxygen barrier	(L)CNF-reinforced films required a longer stabilisation period than (L) CNF-reinforced films obtained by TEMPO pretreatment	(i)UV barrier increased – 50% & 24% (ii)Antioxidant capacity increased – 5.3% (iii)Reduced water vapor permeability - 38–59%	[37]
(i)NC- Gelation and a brief Sonication (ii)Bionanocomposite Film - Casting method	(i)Nano cellulose - (WHF) (ii)Film - Yam Bean (YB)	Yam Beam	TT, SEM, XRD, TGA, FTIR, MA	(i)Tensile strength (TS) and Tensile modulus (TM) greatly increased (ii)Thermal stability and moisture resistance were also raised	Bio-nanocomposites have a rougher fracture surface than pure YB starch sheet	(i)TS- 5.8 MPa and TM -403 MPa (ii)CrI-increased by more than 200 percent	[38]
(i)Nano cellulose - Chemical processing and Sulfuric acid hydrolysis (ii)Film - Solvent casting method	(i)Cellulose nanocrystals (CNC) (ii)PVA-based nanocomposite films	Sunflower oil cake (SOC)	observations of constant rheological properties and cyclic dynamic tests	(i)Has transparent nanocomposite materials with potent mechanical properties (ii)Exhibited exceptional aqueous colloidal stability and gel-like behavior (iii)Has better tensile characteristics	(i)Addition of CNC causes slight changes in the FTIR of PVA nanocomposites with CNC. (ii)A tiny variation in the OH stretching vibration's intensity	Elastic mechanical and physical properties improved by 107 and 78%, respectively.	[39]
(i)Nano cellulose (ii) Film - Solution casting method	(i)Nano cellulose - CNFPE (ii)Film - Gelatin/ Agar-based BCF	CBN stabilized with Nano cellulose fiber	AStM D 882–88, TGA, FESEM, FTIR, Chroma meter	(i)Increased the mechanical strength and decreased the vapor barrier qualities of the gelatin/agar-based film (ii)Good UV-barrier qualities (iii)Had strong antioxidant properties	The strength of the gelatin/ agar film was significantly impacted by the addition of PEC	(i)High transparency to UV and visible light - 26.9 1.3 %, 88.0 1.4 % T280 and T660 (ii)Gelatin/agar film's WVP - 0.59 10 9 g.m./ m2. Pa.s	[40]
Static intermittent fed-batch (SIFB) technology	(i)NC - (BNC) (ii)Film - BNC-chitosan film	SCOBY, black tea and tomatoes	FESEM, ATR-FTIR, XRD, TGA	(i)Good mechanical strength (ii)Crystalline nature (iii)Resistance to air (iv)Shelf life evaluation of tomatoes	The surface morphology of BNC changed after chitosan treatment	(i)BNC yield was higher - 29.2 gL-1 (ii)CrI of BNC formed via SIFB method - 79.2 %	[41]

WHF: Water Hyacinth Fiber
CNFPE: Cellulose nanofiber-based PE
CBNO: Clove bud natural essential oil
BCF: Binary composite film
BNC: Bacterial Nano cellulose

Gelatin and carbohydrate substrates were examined by S.M. Noorbakhsh-Soltani et al for the integration of Nano-cellulose [42]. Chitosan enhances the mechanical, anti-fungal, and waterproofing properties of materials. The response surface approach is used in the design and analysis of experiments. Acid hydrolysis is used to create Nano cellulose, which is then wet-processed and added to base matrices. Films are produced by film casting techniques. The strength properties, storage of food, clarity in visible and ultraviolet light, and water contact angle are also conducted on the Nano-composite films. On the ideal films, DSC/TGA, SEM, TEM, XRD, and air permeability tests are also carried out. The advantages are include, (i) High elasticity, strength properties, extension to break, clarity, and possibly foodstuff storage properties of both gelatin and starch bases can be improved (ii) Decrease in UV transmittance (iii) Gelatin films offer greater transparency, elastic modulus, and break length than starch films. According to the results of the stress-strain curves, which measure the mechanical strength of nanocomposite films, some of the samples exhibit thinning, others exhibit thickening, and some exhibit a straightforward linear response. According to the results, increasing the amount of Nano cellulose to 10% raises the mechanical properties at the break to 8121 MN m^{-2}, while decreasing the ductility. Furthermore, chitosan content can be increased from 5% to 30% to enhance food storage for up to 15 days. Using the wire extension method, Yasmim Montero et al suggested making PBAT active films that were packed with nanocellulose and infused with cinnamon essential oil [43]. The connections among NC-EO-PBAT were investigated, and the results demonstrated that the direct closeness between the EO and the PBAT matrix changed the conformations of the polymer molecules. FT-Raman, FTIR, TGA, and WVP are the tests undergone for the process. The modified CNF films displayed a controlled Fickian diffusion, a greater essential oil release, reduced water vapor permeability, and effective filler dispersion. The film at 3085 cm1 lost its form and intensity after 3 wt% CNF was inserted. Fruits loaded in films with 0.5 weight percent modified-CNF have little weight reduction, better quality maintenance, and no fungal attack after 15 storage periods. According to the report of Syafiq et al, liquid casting was used to generate biodegradable nanocomposite films using sugar palm starch (SPS), sugar palm nanocrystalline cellulose (SPNCC), and cinnamon essential oil (EO) [44]. By using an acid hydrolysis technique, sugar palm Nano crystalline celluloses (SPNCC) was created. Solution-cast SPS/SPNCC nanocomposite coatings with added cinnamon essential oil were created. The SEM, AStM D 644, AStM 570, FTIR, disk diffusion method (DDM), and Agar disc method (ADM) are the test methods used to find o ut t he r esults. Mechanical characteristics experiments on films containing cinnamon EO revealed improved tensile strength and tensile stiffness n umbers f rom 4 .8 t o 5.3 MPa and 122.49 to 130.52 MPa, respectively. In addition, the density was lowered from 1.38 to 1.31 g cm^{-3} and the moisture content was reduced from 13.65 to 12.33 percent, respectively. The results unambiguously demonstrate that the introduction of cinnamon essential oil caused a decrease in the films' e longation a t break, from 1 8.14 to 3.35 percent.

The effects o f d extran-coated s ilver nanoparticle loading on the robotic, boundary, and antibacterial activities of skinny movies produced from cellulose nanofibrils b y s olvent e vaporation t echnique were shown by Vesna Lazi'c et al [45]. They showed an environmentally friendly and food-preservative packing material. The film is created using hybrid materials based on CNF and Ag NPs covered with dextran. The test methods employed to ascertain the properties of the film i nclude T EM, S EM, AStM D3985, and a Shimadzu AGS-X electromechanical universal testing machine. The advantages of adding dextran are as follows: (i) Acts as dispersing media (ii) it is an additive that seals out moisture (iii) It has insufficient oxygen penetrability (iv) Keeps the food safe from bacterial growth. These films also exhibit better Young's moduli while maintaining their flexibility and tensile strength. Both artificial substrates like hydroxyapatite and magnetite, as well as Ag NPs attached to macroporous polymer substrates, demonstrate lesser antibacterial activity against S. aureus than E. coli. The 99.9% suppression of Escherichia coli after five repetitive cycles of 24 h exposed to 0.9 percent NaCl aqueous solution was demonstrated, supported by a sustained release of Ag^+ ions (underneath the toxicants dangerous criterion). Lower oxygen transmitting percentages from 2.07 to 1.40-0.78 cm^3 m^{-2} d^{-1}, hydrophilicity from 20.8^0 to 52.4^0 for MilliQ water, and from 35^0-37^0 to 62^0-74^0 for 3 % acetic acid and 0.9 % NaCl simulant solutions were obtained.

Nano-chitosan (NCH), Nano-cellulose (NCL), and cellulose derivatives were employed by Narges Jannatyha et al as biodegradable biopolymers [46]. Various amounts of nano chitosan or nanocellulose were added using casting procedures to the carboxyl methyl cellulose (CMC) film solution (0.1, 0.5, and 1 percent). XRD, DSC, and DC are the test methods conducted to predict the results. Some of the advantages are: (i) When the concentration of the nanocomposite rose, the WVP of the polymer and nanofiller decreased (ii) By increasing concentration, the TS and elongation at the break of a nanocomposite film were improved (iii) CMC/NCH provides more benefits than CMC/NCL biopolymer when used as a biocompatible film (iv) Particularly at concentrations of 1%, physical characteristics like water solubility(WS), moisture content(MC), and moisture absorption(MA) were lowered by both CMC/NCH and NCL and also causes the nanofiller in CMC film to aggregate. The antibacterial properties of CMC and CMC/NCL are absent. The physical and thermal properties in CMC/NCH were lower than CMC/NCL for the concentration $p < 0.05$. The melting points (Tg) of CMC, CMC/NCL 1 %, and CMC/NCH 1 % films were, 206.31 °C, 221.97 °C, and 200.91 °C, respectively. Nanofiller utilized (1%) WS decreased to 18% and 33% for CMC/NCL and CMC/NCH films, respectively. Sapuan et al reported that the mechanical, barrier and thermal characteristics of nanocellulose-reinforced polymer composites were improved [47]. Enhancing the useful qualities of TPS, PLA, and PBS for food packaging through the addition of Nano cellulose is undoubtedly advantageous. Thermoplastic starch (TPS), polylactic acid (PLA), and polybutylene succinate (PBS) were selected as the alternatives because they are easily accessible, biodegradable, and have high food contact properties. FESEM and SEM are the tests conducted. Reinforcing Nano cellulose has many advantages such as, (i) Tensile strength and elastic modulus are improved by PLA biocomposites (ii) Poor water barrier was improved by TPS/Nano cellulose (iii) The mechanical and oxygen barrier characteristics of PLA and PBS were enhanced. In comparison to pure PBSA, CNN decreased the tensile strength and elongation at break. Their usable characteristics did not necessarily increase with increased Nano cellulose loading. If the amount of Nano cellulose in the polymers was too high, agglomeration took place. The hydrophilic Nano cellulose and hydrophilic PLA are unsuitable and result in weak matrix interaction, hence only low Nano cellulose loadings between 0.5 and 2 weight percent are required for the optimum results. On the other hand, the addition of 2% PA increased the strength of PBS/CNN by about 120%. (95:5). Table 4 describes an overall review of the techniques such as, Nano cellulose produced, the material, testing method, advantages, limitations, and performance parameters which was explained under the direction - Biodegradable films using Nano cellulose from polymer composite material in the food packaging.

4. Discussion

Petroleum-based products have already been employed in a variety of industries, but packaged foods have benefited most from their minimal price and strong mechanical and physical properties. But it is non-biodegradable and also produces numerous health hazards. Plastic or petroleum-based food containers need to be replaced in order to do so, various types of research have been going on for producing biodegradable films using Nano cellulose extracted from various biodegradable wastes such as agri-waste, various plant extracts, non-woody biomass, biopolymer composite materials, etc. Nano cellulose is produced by various extraction methods and the basic method is discussed in the paper. The three primary methods utilized to create Nano cellulose from diverse extracts are acid degradation, enzymatic hydrolysis, and electromechanical process. The common method used to make biodegradable composite films is a solvent-casting method. The types of Nano

Table 4. Review on biodegradable films using Nano cellulose from polymer composite material in Food Packaging Reduced

Technique	Nano cellulose Produced	Material	Analysis	Advantages	Limitation	Performance Parameters	Ref.
(i)Nano cellulose - Acid hydrolysis (ii)Film - film casting technique	Nano-composite films	Gelatin, Starch, Chitosan	air permeability, tensile strength, food preservation, transparency in visible and UV light	(i) High elasticity, elastic modulus, extension to break, clarity can be improved. (ii) Decrease in UV transmittance (iii)In comparison to starch films, gelatin films have better transparency	the stress-strain curves , thinning, thickening, linear line response	(i)Nano cellulose content to 10%, tensile strength at break - increase to 8121 MN/m2, lowers the elongation at break (ii)Increasing the chitosan content from 5% to 30% - improve food preservation for up to 15 days	[42]
Wire extension method	NC-EO-PBAT Films	PBAT, Cellulose nanofibers, Cinnamon oil	FT-Raman, FTIR, TGA, WVP	(i)Fickian diffusion, (ii)Greater essential oil release (iii)Reduced water vapor permeability (iv)Effective filler dispersion	After the addition of 3 wt. % CNF, the film at 3085 cm1 lost its form and intensity	The fruits sealed in films with 0.5 weight percent modified-CNF have very little losing weight, better fresh preservation, and no fungal attack after 15 storage periods.	[43]
(i)Nano cellulose - Acid hydrolysis process (ii)Film - Solution casting method	(i)Nano cellulose - (SPNCC) (ii)Film - SPS/SPNCC	Sugar palm starch (SPS)/(SPNCC) and Cinnamon essential oil (EO)	SEM, AStM D 644, AStM 570, FTIR, DDM, ADM	(i) Enhanced tensile strength and tensile modulus values (ii)The moisture content and density were decreased	Addition of cinnamon EO reduced the films' elongation at break to drop from 18.14 - 3.35 % to 13.9 - 5.57 %	(i) Enhanced TS and TM - 4.8 to 5.3 MPa and 122.49 to 130.52 MPa MC and thickness were decreased - 13.65 to 12.33 % and 1.38 to 1.31 g cm^{-3}	[44]
Solvent casting method	Ag NPs with dextran coating and CNF-based composite sheets	Dextran, coated AgNPs and Cellulose nanofibrils	TEM, SEM, AStM D3985, a Shimadzu AGS-X electro-mechanical machine	1. Dextran (i) Act as dispersing (ii)Moisture-resistant sealable additive (iii) Reduced oxygen permeability 2.Films also exhibit better Young's moduli while maintaining their flexibility and tensile strength.	Ag NPs as well as inorganic supports like hydroxyapatite and magnetite both exhibit lower antibacterial efficacy against S. aureus than E. coli	(i)Reduced OTR - from 2.07 to 1.40-0.78 cm^3 (ii)Hydrophilicity - from 20.8◦ to 52.4◦ for MilliQ water, from 35-37◦ to 62-74◦ for 3 % acetic acid, 0.9 % NaCl simulant solutions yielding a 99.9 % inhibition of E-Coli	[45]
Casting technique	CMC/NCH and CMC/NCL	Nano-chitosan (NCH), Nano-cellulose (NCL), Cellulose derivative and (CMC)	XRD, DSC, DC	(i)Concentration of the nanocomposite rose, the VWP decreased (ii) Enhanced TS and elongation at break (iii)CMC/NCH provides more benefits than CMC/NCL (iv)At 1%, physical characteristics lowered by both CMC/NCH and NCL	(i)The antibacterial of CMC and CMC/NCL are absent (ii)The physical and thermal properties in CMC/NCH were lower than CMC/NCL for the concentration $p < 0.05$.	(i)Tg of CMC, CMC/NCL 1 %, and CMC/NCH 1 % films - 206.31 °C, 221.97 °C, and 200.91 °C. (ii)Nanofiller utilized (1%) WS decreased - 18% and 33% for CMC/NCL and CMC/NCH films	[46]
Technique stated as in citation [47]	Nano cellulose reinforced polymer composites	TPS, PLA, and PBS	FESEM and SEM	(i) Tensile strength and elastic modulus are improved by PLA biocomposites (ii) Poor water barrier were improved by TPS/Nano cellulose	(i)In comparison to pure PBSA, CNN decreased the tensile strength and elongation at break	(i)For best outcomes - between 0.5 % and 2 weight % are necessary (ii)Addition of 2 % PA enhanced the tensile strength of PBS/CNN by around 120 % (95:5)	[47]

SPNCC: Sugar palm nanocrystalline celluloses

cellulose are CNF, CNC, and BNC. The XRD, SEM, TEM, DSC, FTIR, and FE-SEM are some of the test methods used to characterize biodegradable composite films. The tensile properties and physical characteristics of biodegradable films and biodegradable composite films are enhanced overall by the use of nanocellulose. Water vapor permeability, Moisture content, etc., are reduced thus enabling the biodegradable films more suitable and efficient for food packaging.

5. Challenges and Future Research

There are more recent advancements have emerged in the development of biodegradable films using Nano cellulose from various biodegradable extracts but there are still some parameters to be enhanced. Some of the key points to be noted for future research are as follows: (i) Due to the large variety of bio-based substrates and essential oils offered, it is difficult to make general recommendations for the creation of proactive packaging products when using them. Greater attention should be paid to sensory evaluation, making additional, and the synergistic effects of numerous essential oils in order to enhance the active packaging on various food products [48] (ii) BNC offers intriguing uses in food packaging, but these uses aren't being fully investigated because to the material's high production costs and difficult commercialization in the packaging industry [49] (iii) Even with new approaches that have enabled controlled delivery of antibacterial agents in the appearance of NC feasible, utilizing bio-polymers as natural resources with appropriate membrane characteristics, strength properties, and satisfying the regulations for packaged foods is still a difficult problem to tackle [49]. (iv) More research is necessary to determine the effectiveness and durability of Nano cellulose-based packaging technologies during the real food warehouse and transportation process [50]. (v) Biopolymer-based nanocomposites begin to replace conventional synthetic plastic products in the near future only if:

I. It would be energy and cost-effective to isolate cellulose and turn it into nanoparticles;
II. Hydrophilic polymers and hydrophobic natural fibers (cellulose) would be able to coexist without conflict;
III. It is advisable to lessen the variability of the extracted fiber's characteristics
IV. It is advisable to produce compatibilizers, coupling agents, and adhesives from renewable sources;
V. Nanocomposites' biodegradability and life cycle assessment should be thoroughly studied;
VI. It is necessary to create new processing technologies [51].

6. Conclusion

In this review paper, we have analyzed Nano cellulose, its types, and the basic extraction methods. The reason for using Nano cellulose-based biodegradable films in food packaging is also discussed. Also, we have explored the recent research on the development of biodegradable films using Nano cellulose from agricultural waste, rice husk, various plant extracts, and biopolymer composite materials on food packaging. The techniques used, other Nano cellulose produced, various test methods adopted to define the characteristics of the films, advantages, limitations, and performance parameters are discussed briefly in the experimental section. The result section summarizes the paper, and other sections give the future research points that should be considered. From this review, we learned that developing biodegradable films using Nano cellulose has various valuable parameters in food packaging. A notable replacement for synthetic products has been highlighted for nanocomposites, particularly those that contain Nano cellulose as reinforcement.

7. Funding and Conflict of Interest

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript. I hereby declare that the disclosed information is correct and that no other situation of real, potential or apparent conflict of interest is known to me.

8. Acknowledgment

We would like to thank Sree Buddha College of Engineering, Pattoor, Kerala, and Chemistry department of Kalasalingam Academy of Research and Education, Krishnakovil, India.

9. References

[1] S. Nanda, F. Berruti, Municipal solid waste management and landfilling technologies: a review, Environ. Chem. Lett., 19 (2021) 1433-1456. https://doi.org/10.1007/s10311-020-01100-y.

[2] S.H. Gebre, M.G. Sendeku, M. Bahri, Recent trends in the pyrolysis of non-degradable waste plastics, Chem. Open, 10 (2021) 1202-1226. https://doi.org/10.1002/open.202100184.

[3] C. Amara, A. El Mahdi, R. Medimagh, K. Khwaldia, Nanocellulose-based composites for packaging applications, Curr. Opin. Green Sustain. Chem., 31 (2021) 100512. https://doi.org/10.1016/j.cogsc.2021.100512.

[4] J.R. Pires, V.G.L.D. Souza, A.L. Fernando, Production of nanocellulose from lignocellulosic biomass wastes: prospects and limitations, In International Conference on Innovation, J. Eng. Entrep., 505 (2018) 719-725. https://doi.org/10.1007/978-3-319-91334-6_98.

[5] V. Katinas, M. Marčiukaitis, E. Perednis, E.F. Dzenajavičienė, Analysis of biodegradable waste use for energy generation in Lithuania, Renew. Sustain. Energ. Rev., 101 (2019) 559-567. https://doi.org/10.1016/j.rser.2018.11.022.

[6] L.K. Ncube, A.U. Ude, E.N. Ogunmuyiwa, R. Zulkifli, I.N. Beas, Environmental impact of food packaging materials: A review of contemporary development from conventional plastics to polylactic acid based materials, Materials, 13 (2020) 4994. https://doi.org/10.3390/ma13214994.

[7] G.K. Gupta, P. Shukla, Lignocellulosic biomass for the synthesis of nanocellulose and its eco-friendly advanced applications, Front. Chem., 8 (2020) 1203. https://doi.org/10.3389/fchem.2020.601256.

[8] S. Mondal, Chapter11, Nanocellulose reinforced polymer nanocomposites for sustainable packaging of foods, cosmetics, and pharmaceuticals, Sustainable nanocellulose and nanohydrogels from natural sources, Elsevier, Micro Nano Technol., (2020) 237-253. https://doi.org/10.1016/b978-0-12-816789-2.00011-0.

[9] P. Phanthong, P. Reubroycharoen, X. Hao, G. Xu, A. Abudula, G. Guan, Nanocellulose: extraction and application, Carbon Resour. Convers., 1 (2018) 32–43. https://doi.org/10.1016/j.crcon.2018.05.004.

[10] M. Hietala, K. Varrio, L. Berglund, J. Soini, K. Oksman, Potential of municipal solid waste paper as raw material for production of cellulose nanofibres, Waste Manage., 80 (2018) 319-326. https://doi.org/10.1016/j.wasman.2018.09.033.

[11] J. Pennells, I.D. Godwin, N. Amiralian, D.J. Martin, Trends in the production of cellulose nanofibers from non-wood sources, Cellulose, 27 (2020) 575-593. https://doi.org/10.1007/s10570-019-02828-9.

[12] A.K. Rana, E. Frollini, V.K. Thakur, Cellulose nanocrystals: Pretreatments, preparation strategies, and surface functionalization, Int. J. Biol. Macromol., 182 (2021) 1554-1581. https://doi.org/10.1016/j.ijbiomac.2021.05.119.

[13] C. Sharma, N.K. Bhardwaj, Bacterial nanocellulose: Present status, biomedical applications and future perspectives, Mater. Sci. Eng. C, 104 (2019) 109963. https://doi.org/10.1016/j.msec.2019.109963.

[14] D. Abol-Fotouh, M.A. Hassan, H. Shokry, A. Roig, M.S. Azab, A.E.H.B. Kashyout, Bacterial nanocellulose from agro-industrial wastes: Low-cost and enhanced production by Komagataeibacter saccharivorans MD1, Sci. reports, 10 (2020) 1-14. https://doi.org/10.1038/s41598-020-60315-9.

[15] E. Souza, L. Gottschalk, O. Freitas-Silva, Overview of nanocellulose in food packaging, Recent Pat. Food Nutr. Agric., 11 (2020) 154-167. https://doi.org/10.2174/2212798410666190715153715.

[16] C. Maraveas, Production of sustainable and biodegradable polymers from agricultural waste, Polymers, 12 (2020) 1127. https://doi.org/10.3390/polym12051127 www.mdpi.com/journal/polymers.

[17] A.N.S. Ahmad Khorairi, N.S. Sofian-Seng, R. Othaman, H. Abdul Rahman, N.S. Mohd

Razali, S.J. Lim, W.A. Wan Mustapha, A review on agro-industrial waste as cellulose and nanocellulose source and their potentials in food applications, Food Rev. Int., (2021) 1-26. https://doi.org/10.1080/87559129.2021.1926478.

[18] S.J. Owonubi, S.C. Agwuncha, N.M. Malima, G.B. Shombe, E.M. Makhatha, N. Revaprasadu, Non-woody biomass as sources of nanocellulose particles: A review of extraction procedures, Front. Energ. Res., 9 (2021) 608825. https://doi.org/10.3389/fenrg.2021.608825.

[19] J.P. Greene, Automotive plastics and composites: Materials and processing, William Andrew, Elsevier, (2021) 191-222. https://doi.org/10.1016/B978-0-12-818008-2.00007-6.

[20] R.A. Ilyas, S.M. Sapuan, R. Ibrahim, H. Abral, M.R. Ishak, E.S. Zainudin, R. Jumaidin, Effect of sugar palm nanofibrillated cellulose concentrations on morphological, mechanical and physical properties of biodegradable films based on agro-waste sugar palm (Arenga pinnata (Wurmb.) Merr) starch, J. Mater. Res. Technol., 8 (2019) 4819-4830. https://doi.org/10.1016/j.jmrt.2019.08.028.

[21] A.N. Frone, D.M. Panaitescu, I. Chiulan, A.R. Gabor, C.A. Nicolae, M. Oprea, A.C. Puitel, Thermal and mechanical behavior of biodegradable polyester films containing cellulose nanofibers, J. Therm. Anal. Calorim., 138 (2019) 2387-2398. https://doi.org/10.1007/s10973-019-08218-4.

[22] R. Reshmy, E. Philip, P.H. Vaisakh, S. Raj, S.A. Paul, A. Madhavan, A. Pandey, Development of an eco-friendly biodegradable plastic from jack fruit peel cellulose with different plasticizers and Boswellia serrata as filler, Sci. Total Environ., 767 (2021) 144285. https://doi.org/10.1016/j.scitotenv.2020.144285.

[23] S. Xu, M. Jiang, Q. Lu, S. Gao, J. Feng, X. Wang, P. Ouyang, Properties of polyvinyl alcohol films composited with hemicellulose and nanocellulose extracted from artemisia selengensis straw, Front. Bioeng. Biotechnol., 8 (2020) 980. https://doi.org/10.3389/fbioe.2020.00980.

[24] R.H. Faradilla, G. Lee, J. Roberts, P. Martens, M. Stenzel, J. Arcot, Effect of glycerol, nanoclay and graphene oxide on physicochemical properties of biodegradable nanocellulose plastic sourced from banana pseudo-stem, Cellulose, 25 (2018) 399-416. https://doi.org/10.1007/s10570-017-1537-x.

[25] D.S. Kocabaş, M.E. Akçelik, E. Bahçegül, H.N. Özbek, Bulgur bran as a biopolymer source: Production and characterization of nanocellulose-reinforced hemicellulose-based biodegradable films with decreased water solubility, Ind. Crop. Prod., 171 (2021) 113847. https://doi.org/10.1016/j.indcrop.2021.113847.

[26] K. Pavalaydon, H. Ramasawmy, D. Surroop, Comparative evaluation of cellulose nanocrystals from bagasse and coir agro-wastes for reinforcing PVA-based composites, Environ. Dev. Sustain., 24 (2022) 9963-9984. https://doi.org/10.1007/s10668-021-01852-9.

[27] V. Nang An, C. Nhan, H. Thuc, T.D. Tap, T.T.T. Van, P. Van Viet, L. Van Hieu, Extraction of high crystalline nanocellulose from biorenewable sources of Vietnamese agricultural wastes, J. Polym. Environ., 28 (2020) 1465-1474. https://doi.org/10.1007/s10924-020-01695-x.

[28] H. Li, H. Shi, Y. He, X. Fei, L. Peng, Preparation and characterization of carboxymethyl cellulose-based composite films reinforced by cellulose nanocrystals derived from pea hull waste for food packaging applications, Int. J. Biol. Macromol., 164 (2020) 4104-4112. https://doi.org/10.1016/j.ijbiomac.2020.09.010.

[29] J.S. Yaradoddi, N.R. Banapurmath, S.V. Ganachari, M.E.M. Soudagar, N.M. Mubarak, S. Hallad, H. Fayaz, Biodegradable carboxymethyl cellulose based material for sustainable packaging application, Sci.

reports, 10 (2020) 1-13. https://doi.org/10.1038/s41598-020-78912-z.

[30] P. Nascimento, R. Marim, G. Carvalho, S. Mali, Nanocellulose produced from rice hulls and its effect on the properties of biodegradable starch films, J. Mater. Res., 19 (2016) 167-174. https://doi.org/10.1590/1980-5373-mr-2015-0423.

[31] S. Rashid, H. Dutta, Characterization of nanocellulose extracted from short, medium and long grain rice husks, Ind. Crop. Prod., 154 (2020) 112627. https://doi.org/10.1016/j.indcrop.2020.112627

[32] J.F. Delgado, O. de la Osa, A.G. Salvay, E. Cavallo, P. Cerrutti, M.L. Foresti, M.A. Peltzer, Reinforcement of yeast biomass films with bacterial cellulose and rice Husk cellulose nanofibres, J. Polym. Environ., 29 (2021) 3242-3251. https://doi.org/10.1007/s10924-021-02109-2.

[33] J.J. Jayaraj, K. Renugadevi, P. Prakash, M. Harish, R.D. Kumar, Effect of nanocellulose extracted from rice husk on the film properties of native starch based edible films, In AIP Conference Proceedings, 2311, AIP Publishing LLC, (2020) 080015. https://doi.org/10.1063/5.0033961.

[34] A. Ganesh Babu, S.S. Saravanakumar, Mechanical and physicochemical properties of green bio-films from poly (Vinyl Alcohol)/nano rice hull fillers, Polym. Bull., 79 (2022) 5365-5387. https://doi.org/10.1007/s00289-021-03757-z.

[35] H. Gupta, H. Kumar, M. Kumar, A.K. Gehlaut, A. Gaur, S. Sachan, J.W. Park, Synthesis of biodegradable films obtained from rice husk and sugarcane bagasse to be used as food packaging material, Environ. Eng. Res., 25 (2020) 506-514. https://doi.org/10.4491/eer.2019.191 eISSN 2005-968X.

[36] R. Reshmy, E. Philip, S.A. Paul, A. Madhavan, R. Sindhu, P. Binod, A. Pandey, A green biorefinery platform for cost-effective nanocellulose production: investigation of hydrodynamic properties and biodegradability of thin films, Biomass convers. Biorefin., 11 (2021) 861-870. https://doi.org/10.1007/s13399-020-00961-1.

[37] M. Sánchez-Gutiérrez, I. Bascón-Villegas, E. Espinosa, E. Carrasco, F. Pérez-Rodríguez, A. Rodríguez, Cellulose nanofibers from olive tree pruning as food packaging additive of a biodegradable film, Foods, 10 (2021) 1584. https://doi.org/10.3390/foods10071584.

[38] M. Asrofi, H. Abral, A. Kasim, A. Pratoto, M. Mahardika, F. Hafizulhaq, Characterization of the sonicated yam bean starch bionanocomposites reinforced by nanocellulose water hyacinth fiber (WHF): the effect of various fiber loading, J. Eng. Sci. Technol., 13 (2018) 2700-2715. https://jestec.taylors.edu.my/

[39] Z. Kassab, M. El Achaby, Y. Tamraoui, H. Sehaqui, R. Bouhfid, Sunflower oil cake-derived cellulose nanocrystals: Extraction, physico-chemical characteristics and potential application, Int. J. Biol. Macromol., 136 (2019) 241-252. https://doi.org/10.1016/j.ijbiomac.2019.06.049.

[40] S. Roy, J.W. Rhim, Gelatin/agar-based functional film integrated with Pickering emulsion of clove essential oil stabilized with nanocellulose for active packaging applications, Colloids and Surf. A: Physicochem. Eng. Asp., 627 (2021) 127220. https://doi.org/10.1016/j.colsurfa.2021.127220.

[41] C. Sharma, N.K. Bhardwaj, P. Pathak, Static intermittent fed-batch production of bacterial nanocellulose from black tea and its modification using chitosan to develop antibacterial green packaging material, J. Clean. Prod., 279 (2021) 123608. https://doi.org/10.1016/j.jclepro.2020.123608.

[42] S.M. Noorbakhsh-Soltani, M.M. Zerafat, S. Sabbaghi, A comparative study of gelatin and starch-based nano-composite films modified by nano-cellulose and chitosan for food packaging applications, Carbohydr.

Polym., 189 (2018) 48-55. https://doi.org/10.1016/j.carbpol.2018.02.012.

[43] Y. Montero, A.G. Souza, E.R. Oliveira, D. dos Santos Rosa, Nanocellulose functionalized with cinnamon essential oil: A potential application in active biodegradable packaging for strawberry, Sustain. Mater. Technol., 29 (2021) e00289. https://doi.org/10.1016/j.susmat.2021.e00289.

[44] R. Syafiq, S.M. Sapuan, M.R.M. Zuhri, Antimicrobial activity, physical, mechanical and barrier properties of sugar palm based nanocellulose/starch biocomposite films incorporated with cinnamon essential oil, J. Mater. Res. Technol., 11 (2021) 144-157. https://doi.org/10.1016/j.jmrt.2020.12.091.

[45] V. Lazić, V. Vivod, Z. Peršin, M. Stoiljković, I.S. Ratnayake, P.S. Ahrenkiel, V. Kokol, Dextran-coated silver nanoparticles for improved barrier and controlled antimicrobial properties of nanocellulose films used in food packaging, Food Packag. Shelf Life, 26 (2020) 100575. https://doi.org/10.1016/j.fpsl.2020.100575.

[46] N. Jannatyha, S. Shojaee-Aliabadi, M. Moslehishad, E. Moradi, Comparing mechanical, barrier and antimicrobial properties of nanocellulose/CMC and nanochitosan/CMC composite films, Int. J. Biol. Macromol., 164 (2020) 2323-2328. https://doi.org/10.1016/j.ijbiomac.2020.07.249

[47] A. Nazrin, S.M. Sapuan, M.Y.M. Zuhri, R.A. Ilyas, R.S.F.K.S. Syafiq, S.F.K. Sherwani, Nanocellulose reinforced thermoplastic starch (TPS), polylactic acid (PLA), and polybutylene succinate (PBS) for food packaging applications, Front. Chem., 8 (2020) 213. https://doi.org/10.3389/fchem.2020.00213.

[48] S. Casalini, M. Giacinti Baschetti, The use of essential oils in chitosan or cellulose-based materials for the production of active food packaging solutions: a review, J. Sci. Food Agric., (2022)1-21. https://doi.org/ 10.1002/jsfa.11918.

[49] S.S. Ahankari, A.R. Subhedar, S.S. Bhadauria, A. Dufresne, nanocellulose in food packaging: A review, Carbohydr. Polym., 255 (2021) 117479. https://doi.org/10.1016/j.carbpol.2020.117479.

[50] C.G. Perdani, S. Gunawan, A short review: Nanocellulose for smart biodegradable packaging in the food industry, In IOP Conference Series, IOP Publishing, Earth Environ. Sci., 924 (2021) 012032. https://doi.org/ 10.1088/1755-1315/924/1/012032.

[51] U. Qasim, A.I. Osman, A.A.H. Al-Muhtaseb, C. Farrell, M. Al-Abri, M. Ali, D.W. Rooney, Renewable cellulosic nanocomposites for food packaging to avoid fossil fuel plastic pollution: a review, Environ. Chem. Lett., 19 (2021) 613-641. https://doi.org/ 10.1007/s10311-020-01090-x.