

Effects of Different Drying Techniques on Pectin Extraction and Quality: A Review

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ABSTRACT

Fruit peels and other residues from the processing of fruits are often thrown away although they are rich source of many beneficial compounds such as pectin. The purpose of this review project was to analyze the use of food wastes and agricultural residues as source of natural pectin extraction. It specifically looked at how drying methods such as solar dryer and hot air oven drying affected the process of extracting pectin. Drying method is an important factor to consider during pectin extraction because it affects the physical structure of the plant which will then affect the extraction process. The study discussed the acid extraction of pectin and purification of the extracted pectin. Results indicated that when drying is done under controlled conditions, a high quality pectin can be extracted. However, when there is too much heat, the quality of pectin extracted is low. Once we have extracted pectin we can use it in foods as a thickening agent, to set foods as gels, and can be used to create edible films.

Keywords- Pectin; Drying methods; Food waste; Extraction; Biopolymers.

I. INTRODUCTION

Millions of tonnes of fruit and vegetable residues from the worldwide food processing industry are produced annually. Citrus peels, pomace, seeds and pulp are generally regarded as waste products, although they are a source of several bioactive compounds such as dietary fibre, polyphenols, essential oils, and polysaccharides. An increasing focus on sustainable food processing and valorisation of food industry waste streams has led to numerous studies investigating fruit and vegetable residues as low-cost sources of value-added functional ingredients. Pectin has received significant interest from both researchers and industry due to its various applications and multifunctional properties.

Pectin is a heteropolysaccharide derived from plants that consist mainly of α -(1→4)-linked D-galacturonic acid residues that are methyl esterified. It is present in primary cell walls and middle lamella of higher plants. Commercial production mainly uses citrus peel and apple pomace as raw material but other sources such as mango peel, banana peel, sugar beet pulp, pumpkin residues and passion fruit peel have also been considered for pectin extraction since they are abundantly available and environmentally friendly.

The functionality properties of pectin such as gelation, viscosity, water holding capacity, emulsification and film forming are highly dependent on its molecular structure, degree of esterification, molecular weight and conditions used during extraction. For this reason great importance should be given to the

extraction process so that the conditions are optimized for the pectin to be used in an industrial application.

Drying is one of the most important pretreatments prior to extraction. The moisture content of fresh fruit residues is normally high. The high moisture content can lead to microbial spoilage and enzymatic activity while stored. Proper drying decreases moisture content allowing for better storage conditions and less biological activity, easier grinding, better solvent penetration and increased extraction. When too high drying temperatures or extended drying times are used there can be depolymerization, degradation of galacturonic acid chain, decrease in degree of esterification and loss of functional properties. Consequently, the choice of drying process plays a crucial role in optimizing drying efficiency while maintaining pectin quality.

Many drying technologies have been implemented for pectin extraction including traditional sun drying, hot-air oven drying, microwave drying, vacuum drying, and freeze drying. Each drying process varies from one another in terms of energy requirement, drying time, cost, operational feasibility, and impact on the quality of pectin. Emerging technologies in drying pectin aim to increase the extraction yield while reducing degradation losses and environmental impact.

Hence, the purpose of this review paper is to provide a critical overview of the impact of drying technologies on pectin extraction from fruit processing by-. Additionally, this review paper will summarize recent developments in extraction technologies, compare advantages and disadvantages of drying methods, and explore future research opportunities for sustainable production and application of pectin.

II. CHEMISTRY AND STRUCTURE OF PECTIN

Pectin is a highly structured heterogeneous polysaccharide of plant origin. Pectin is found in primary cell walls and middle lamella of higher plants where it acts as glue between neighbouring plant cells and plays a role in plant tissue firmness and mechanical strength and stress resistance. Due to its properties, it is considered one of the most significant hydrocolloids and finds widespread use in food technology.

Chemically, pectin is largely composed of α -(1→4)-linked D- galacturonic acid residues. Many of these galacturonic acid residues are esterified with methanol. The percentage of carboxyl groups which are esterified is called **Degree of Esterification (DE)**. As esterification affects gelation properties, pectin is

categorized as either high-methoxyl pectin (DE > 50%) or low-methoxyl pectin (DE < 50%) depending on the DE. Each type has unique gelation mechanisms and different industrial uses.

The pectin molecule is actually divided into several domains. The largest fraction is **Homogalacturonan (HG)**. HG is a linear polymer and accounts for much of the gel forming ability. The next largest domain is **Rhamnogalacturonan-I (RG-I)**. RG-I consists of repeating residues of rhamnose and galacturonic acid with side chains of arabinose and galactose sugars. **Rhamnogalacturonan-II (RG-II)** is another highly branched domain with numerous unusual sugars.

The main physicochemical parameters affecting the functional properties of pectin are molecular weight, degree of esterification (DE), acetylation and branching. Important functional properties of pectin are water-binding capacity, viscosity, gel strength and interaction with calcium ions. They define the applications of pectin in food and pharmaceutical industries.

Manipulating pectin's structure through controlled extraction and drying conditions has attracted significant interest over the past years.

III. SOURCES OF PECTIN

Citrus processing waste and apple pomace are the major sources of commercial pectin because they are rich in pectin content, available throughout the year and possess standardized processing techniques. Recent trends in food waste disposal and sustainability of resource consumption have paved the way for exploring other sources of agro-industrial residues for possible extraction of pectin.

Studies reveal that mango peel, banana peel, passion fruit peel, guava peel, pumpkin peel, papaya peel, pomegranate peel, sugar beet pulp are few examples of fruit waste or by-products having a considerable amount of pectin in them.

Pectin content can vary with fruit variety, maturity level, place of origin, storage duration, pretreatment drying techniques, extraction technique, and purification method etc. This makes choosing the right raw material pivotal in the process of commercial pectin production aimed at food industrial uses.

Hence the extraction of pectin from agro-residues will help to attain zero food processing waste goals which shall help prevent environmental pollution, cost-effectiveness and contribute to circular bioeconomy.

Major Sources of Commercial Pectin

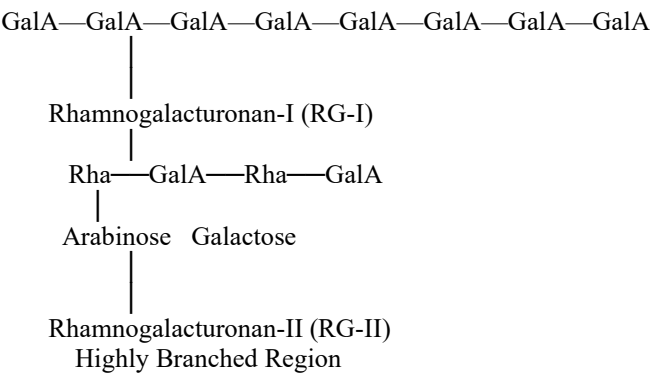
Table 1. Major Sources of Commercial Pectin

Raw Material	Approximate Pectin Content (%)	Major Advantages	Industrial Use
Citrus Peel	20-35	High yield, abundant availability	Commercial pectin production
Apple Pomace	10-20	Readily available from juice	Jam, jelly and beverage

		industry	industries
Mango Peel	15-25	Rich in dietary fibre	Functional foods
Banana Peel	10-21	Low-cost agricultural waste	Food additives
Passion Fruit Peel	18-30	Excellent gelling properties	Food hydrocolloids
Sugar Beet Pulp	15-25	Large industrial availability	Pharmaceutical applications
Pumpkin Peel	8-15	Sustainable raw material	Edible coatings
Guava Peel	12-18	Rich in bioactive compounds	Nutraceutical products

General Structure of Pectin

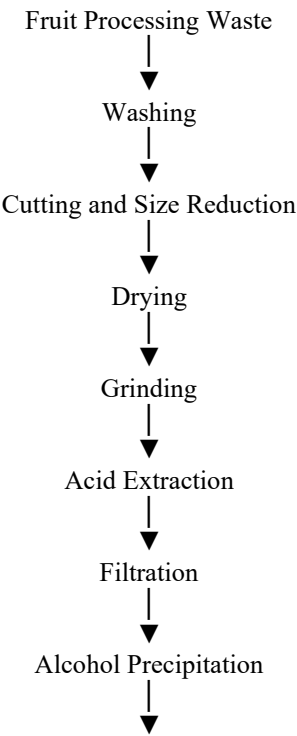
PECTIN MOLECULE
Homogalacturonan (HG)



GalA = Galacturonic Acid
Rha = Rhamnose

Figure 1. Simplified schematic representation of the principal structural domains of pectin.

General Process for Industrial Pectin Extraction



IV. CLASSIFICATION OF PECTIN

Classification of pectin is usually based on its **Degree of Esterification (DE)** which indicates the percentage of galacturonic acid residues in pectin that are esterified with methanol. Degree of esterification determines the physicochemical properties, gelation mechanism and industrial application of pectin significantly. Pectin is divided into two main categories based on its degree of esterification. These are **High Methoxyl (HM) Pectin** and **Low Methoxyl (LM) Pectin**.

V. HIGH METHOXYL (HM) PECTIN

High methoxyl pectin has degree of esterification greater than 50%. In HM pectin most of the carboxyl groups are methyl-esterified and there is

little interaction with calcium ions. Gelling takes place in acidic pH (2.8-3.5) and presence of high sugar levels (~55-65%). Hydrogen bonding and hydrophobic interaction between methyl ester groups stabilize the gel network.

HM pectin is widely utilized in the production of jams, jellies, marmalades, fruit preserves, confectionery products, and bakery fillings because it produces transparent and firm gels with desirable sensory characteristics.

Advantages

- Excellent gel strength
- Smooth texture
- High consumer acceptance
- Suitable for traditional fruit products

Limitations

- Requires high sugar concentration
- Unsuitable for low-calorie formulations
- Sensitive to pH variations

Low Methoxyl (LM) Pectin

Low methoxyl pectin contains a degree of esterification below 50%, resulting in a greater number of free carboxyl groups. Unlike HM pectin, LM pectin forms gels through ionic cross-linking with calcium ions according to the well-known **Egg-Box Model**.

Since sugar is not essential for gel formation, LM pectin is increasingly used in reduced-sugar foods, diabetic formulations, dairy products, fruit beverages, edible coatings, and pharmaceutical formulations.

Advantages

- Forms gel without high sugar
- Suitable for diabetic foods
- Better calcium responsiveness
- Greater application versatility

Limitations

- Calcium concentration must be controlled
- Gel strength varies with mineral composition

Comparison between High Methoxyl and Low Methoxyl Pectin

Table 2. Comparative characteristics of high methoxyl and low methoxyl pectin.

Parameter	High Methoxyl Pectin	Low Methoxyl Pectin
Degree of Esterification	>50%	<50%
Gelation Mechanism	Sugar + Acid	Calcium ions
Sugar Requirement	High	Low
Optimum pH	2.8-3.5	3.0-6.5
Main Applications	Jams, Jellies	Dairy Products, Low-sugar Foods
Gel Strength	High	Moderate - High
Commercial Importance	Traditional products	Functional foods

Drying Methods Used Prior to Pectin Extraction

Drying is believed to be one of the most critical pretreatment operations during pectin extraction as it affects the extraction efficiency, physicochemical properties and storages stability of raw materials. The moisture content reduction, retarding microbial growth, decrease enzymatic degradation and readiness for

grinding before extraction are the basic aims of drying treatment.

Different drying technologies used for pectin production exhibited various advantages and disadvantages.

Comparison of Drying Methods Used in Pectin Extraction

Table 3. General comparison of drying methods used for pectin extraction.

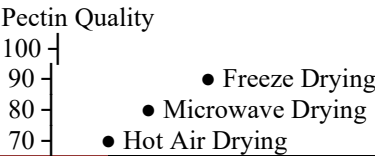
Drying Method	Temperature	Drying Time	Pectin Quality	Cost	Industrial Suitability
Sun Drying	Ambient	Long	Low	Very Low	Limited
Hot-Air Drying	50-70° C	Moderate	Good	Moderate	High
Microwave Drying	Variable	Very Short	Very Good	High	Increasing
Freeze Drying	Low Temperature	Long	Excellent	Very High	Specialized

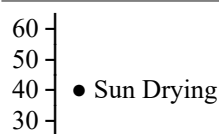
Effect of Drying on Pectin Yield and Quality

Drying conditions influence pectin yield, molecular weight, degree of esterification, viscosity, and

gel-forming ability. Moderate drying conditions generally provide superior quality.

Effect of Drying Temperature on Pectin Quality





Drying Method

Figure 2. Conceptual comparison of overall pectin quality obtained using different drying methods.

Applications

Pectin have been applied as a gelling agent, stabilizer, thickener, edible film ingredient, biodegradable packing materials and pharmaceutical excipients.

Future Scope

Future work should focus on extraction technologies, industrial scale, biomedical applications, sustainable packing materials should be considered in further studies.

VI. CONCLUSION

Pectin is a natural polysaccharide used as food additives because of its properties as gelling agent, thickener, stabilizer and film former. The applications of pectin are numerous in food industry, pharmaceutical, biomedical and packaging industries. The ever increasing volume of agro-industrial fruit waste generation has opened new horizons for sustainable pectin production from various waste raw materials such as citrus peel, apple pomace, mango peel, banana peel, and fruit processing waste. Efficient valorization of these residues will help to reduce pollution and also add value in building circular bioeconomy.

Pectin recovery has also been influenced by drying pretreatment as it has a role in extraction efficiency and physicochemical properties of extracted pectin. Extraction efficiency and physicochemical properties including moisture removal rate, cell wall disruption, degree of esterification (DE), molecular weight, viscosity, colour, and gel-formation ability are affected by drying method. Sun drying and hot-air drying are some conventional methods that are commonly used due to being simple and inexpensive drying methods. Freeze drying and microwave drying are examples of modern drying techniques that allow for higher quality preservation of extracted pectin and improved extraction efficiency. Criteria such as processing cost, energy requirement, feasibility on an industrial scale, and application should be considered when choosing a drying method.

Incorporating recent advancements in green extraction technologies, such as microwave-assisted extraction (MAE), ultrasound-assisted extraction (UAE), enzyme-assisted extraction (EAE), and vacuum-assisted extraction, further enhances pectin yield. These methods not only shorten processing times but also reduce solvent consumption and environmental impact. These

innovative extraction approaches show promise for sustainable industrial production of high-quality pectin.

In conclusion, optimizing drying pretreatment and extraction conditions can significantly improve pectin yield and maintain its functional properties. Future research should explore energy-efficient drying technologies, the integration of environmentally friendly extraction methods, and the utilization of a wider range of agricultural residues. Advancements in these areas will contribute to sustainable food processing, waste valorization, and the broader commercial application of pectin in various industries.

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