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EFFECTS OF DIFFERENT TYPES OF STARCHES ON HEAT PENETRATION, COLOR
AND VISCOSITY ON RETORT PROCESSED ALFREDO SAUCE

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Science
Food Science

by
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May 2024

Accepted by:
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ABSTRACT

The purpose of this study was to examine how retort processing affects the heat penetration and rheological characteristics of starches, such, as corn, tapioca, potato and native rice starches in Alfredo sauce. Modified corn starch is commonly used in sauces. The aim was to explore alternatives and compare how different starches behave in terms of viscosity changes, color variations and processing times. The study also looked at the time needed to achieve a $F_0=6$ for *Clostridium botulinum*. The results showed that modified corn starch had an increase in viscosity from 3,328 cP to 13,296 cP, with a relatively short processing time of around 31.33 minutes. Modified tapioca starch displayed a rise in viscosity from 3,440 to 8,176 cP over the processing duration of approximately 38.38 minutes indicating its thermal stability. Native rice and modified potato starches showed changes in color with decreases in lightness and shifts in chromaticity suggesting alterations to pigments during processing. Interestingly native rice starch exhibited increased surface smoothness after retort treatment due to the decomposition of starch granules. These findings highlight the importance of selecting the type of starch for Alfredo sauce formulations considering their reactions during retort processing. Overall modified potato starch emerged as an alternative to corn starch due to its rheological properties. This research study presents findings for the food industry by enhancing processing techniques and selecting starches to maintain the quality and safety of thermally processed Alfredo sauce.

Keywords: Retort Processing, Alfredo Sauce, Heat Penetration, Modified Starch, Thermal Processing.

DEDICATION

This work is dedicated to my parents, Katty Romero Vera and Manuel Jimenez Mendoza, whose unwavering support and profound love have been the fundamental pillars of my life.

To my sisters, Connie and Katty, I owe my deepest gratitude for their continuous presence, companionship, and the countless moments of joy we have shared.

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TABLE OF CONTENTS

INTRODUCTION	10
1.2 Research objectives	12
LITERATURE REVIEW	15
2.2 Types of Thermal Processing	15
2.3 History of Canning.....	17
2.4 Retort Processing	18
2.5 Types of Retorts.....	20
2.6 Heating Medium	21
2.7 Agitation Methods	25
2.8 Heat Penetration Studies	30
2.8.1 Temperature Measurement and Data Acquisition	30
2.9 Critical Factors.....	33
2.10 Food Safety Calculations	34
2.11 Concern and Target microorganism	35
2.12 Toxin.....	36
2.14 Treatment and Prevention.....	37
2.15 Alfredo sauce	37
2.16 Starch	39
2.17 Gelatinization.....	42
2.18 Retrogradation	42
2.19 Modification of Starch	43
2.19.1 Chemical Modification	43

2.19.2 Acetylation	44
2.19.3 Hydroxypropylation	44
2.19.4 Acid/Alkaline Treatment	44
2.19.5 Oxidation	45
2.19.6 Stabilization and Cross-linking	45
2.19.7 Physical and Enzymatic Modification	45
2.20 Types of Starches	46
2.21 Corn Starch	46
2.22 Potato Starch	49
2.23 Rice Starch	54
2.24 Tapioca Starch	58
3. MATERIALS AND METHODS	80
3.1 Ingredients (materials)	80
3.2 Methods	80
3.2.1 Alfredo sauce preparation	80
3.2.2 Retort pouches and thermocouple preparation	81
3.2.3 Packaging (Pouch filling)	82
3.2.4 Retort Processing	83
3.2.5 Calculating processing times	85
3.2.6 Viscosity	85
3.2.7 Statistical analysis	86
4. RESULTS AND DISCUSSION	87
4.1 Same starch concentration	87

4.1.1 Visual inspection.....	87
4.1.2 Heat penetration analysis	90
4.1.3 Viscosity Analysis	93
4.1.4 Colorimetric Analysis	96
4.2 Analysis of viscosities at different starches concentration	99
4.2.1 Heat penetration analysis at different concentration of starches	100
4.2.2 Heat penetration results	101
4.2.3 Visual inspection different concentration	108
5. Conclusion and Future Perspective	111
6. References	113
APPENDIX A: Heat penetration location of thermocouples in retort basket	121
APPENDIX B: pH levels before and after process Alfredo sauce.....	121

LIST OF TABLES

Table 1. Methods of heating.....	24
Table 2. Agitation methods	29
Table 3. Omnibus Table of Modified Corn Starch in Retort Applications.....	47
Table 4. Influence of Corn Starch on the Quality of Retort Processed Foods	48
Table 5. Omnibus Table of Potato Starch in Retort Applications	51
Table 6. Influence of Rice Starch on the Quality of Retort Processed Foods.....	55
Table 7. Omnibus Table of Rice Starch in Retort Applications	57
Table 8. Omnibus Table of Tapioca Starch in Retort Applications	59
Table 9. Influence of Tapioca Starch on the Quality of Retort Processed Foods.....	62
Table 10. Alfredo sauce retort recipe	85
Table 11. Average holding times (Pt) for different starches.....	93
Table 12. Comparative analysis of viscosity changes in different starches due to retort processing	95
Table 13. Sauce Viscosity at Various Concentrations of Different Starches.....	100
Table 14. Different Cooking times of Alfredo Sauce at Different Concentrations of Starches	101
Table 15. Comparative analysis of viscosity changes in different starches with different concentrations	105
Table 16. Average holding times (Pt) for different starches with different concentrations ..	106
Table 17. Color changes before and after retort for each starch with different concentrations	107

LIST OF FIGURES

Figure 1. Type of motions	25
Figure 2. Assemble thermocouples in glass jars and metal cans. (Photo courtesy of Cryovac® Flavour Mark® Retort Laboratory, Clemson University, SC).....	31
Figure 3. Microscopic pictures of starch granules (A. Swinkelse, ABC om stärkelse, Malmö)	46
Figure 4. Composition of Native Starch Granules.....	58
Figure 5. Thermocouple in container.....	82
Figure 6. Arrangements of pouches filled with alfredo sauce in the retort.....	84
Figure 7. Visual inspection.....	89
Figure 8. Mean heat penetration curves with same starch concentration	90
Figure 9. Color changes before and after retort for each starch.....	98
Figure 10. Mean heat penetration curves with different rice starch concentration.....	102
Figure 11. Mean heat penetration curves with different tapioca starch concentration	103
Figure 12 Mean heat penetration curves with different corn starch concentration.....	104
Figure 13. Mean heat penetration curves with different potato starch concentration.....	104
Figure 14. Visual inspection	110

CHAPTER ONE

INTRODUCTION

Retort processing is a method for preserving food products by subjecting them to heat and pressure. Its primary objective is to ensure that the food remains safe while preserving its quality and value. The main purpose of this treatment is to eliminate microorganisms like *Clostridium botulinum* to achieve "status for the food. With the increasing demand for lasting and high-quality food items retort processing has gained importance in the food industry. This technique has adapted well to changing consumer preferences and technological advancements showcasing its development (IFTPS, 2014; Jimenez et al., 2023). The effectiveness of retort processing depends on factors such as the temperature of the retort usually (240-250°F or 115-121°C), pressure settings (around 15-20 psi or 1-1.4 bar), processing time duration and the composition of the food item itself (FDA, 2014; Singh et al., 2017).

Alfredo sauce is known for its creamy and rich texture, which is due primarily to the dairy-based ingredients, which typically include heavy cream, butter, and Parmesan cheese. This combination not only gives the sauce its distinctive richness, but also contributes to its smooth texture and flavor. A creamy texture and a balance of cheesy and buttery flavors are particularly important for the overall enjoyment of these sauces (Childs et al., 2009).

And the adaptation of sauces for retort processing is fundamental for preserving quality and ensuring safety (Durch, 2020). The success of the sauce and

process depends on the interaction between heat penetration and interaction with ingredients, especially starches. During retort processing starch granules undergo changes as they are subjected to heat and moisture. This causes gelatinization and the formation of a starch paste, which are essential for achieving the desired thickness of Alfredo sauce (characteristic of the sauce); additionally, it highlights the importance of selecting the right ingredients to have commercial success (Punia & Whiteside 2023).

Corn starch is commonly used in Alfredo sauce due to its thickening properties. This application of cornstarch is consistent with the general use of starches in sauces and food products to improve texture and consistency. The current study explores how different types of starches affect the heat penetration of Alfredo sauce during retort processing. Given the challenges faced by the cornstarch market, such as fluctuating prices due to weather conditions disruptions, in supply chains and geopolitical issues, it becomes necessary to explore sources of starch (ChemAnalyst, 2023; Rabobank, 2021).

The global corn starch market is undergoing changes driven by evolving consumer preferences, technological advancements and environmental considerations. This availability and price volatility has led to an upward in corn starch prices in American and European markets, impacting industries dependent on this ingredient (ChemAnalyst, 2023). To address these market challenges, this study examines how different starch thickeners affect heat penetration in alfredo sauce, providing a replacement of traditional corn starch with tapioca, potato, and rice due to their potentially more stable pricing and availability in different regions

(Organic-Way, 2023). This research aligns with the trends in the food industry where there is a focus on finding cost ingredient solutions while also optimizing the safety and quality of Alfredo sauce.

1.2 Research objectives

1. Investigate the impact of different types of starches, including modified corn, tapioca, potato, and native rice starch, on heat penetration of Alfredo sauce.
2. Study how the use of different types of starches affects the properties of the final product.

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The main aim of this literature review is to explore and assess previous studies on the impact of heat processing in Alfredo sauce with four different types of starches. This examination plays a crucial role in comprehending the broader effects of high temperature processing on dairy based sauces and the stabilizing function of starch. The canning procedure, which involves subjecting Alfredo sauce to high temperatures, has the potential to modify its dairy components, potentially influencing the taste, texture and nutritional content of the sauce. Understanding how this processing affects dairy components like proteins and fats is essential as these elements are prone to denaturation and separation under high heat, which could result in unwanted changes in consistency and mouthfeel (Mehra et al., 2021).

2.2 Types of Thermal Processing

Cooking is a common practice in daily life that serves various purposes beyond enhancing taste. It aids in breaking down complex molecules, tenderizing food items and most importantly, eliminating harmful microorganisms. When food is cooked, the heat used not only kills bacteria and breaks down toxins but also speeds up the breakdown of food, making it more vulnerable to spoilage by microbes (Silva & Gibbs, 2012). This is why cooked food usually needs to be stored in the refrigerator or freezer to keep it fresh for longer. Different thermal

processing methods come into play here. Three common methods that involve heat are blanching, pasteurization and canning.

- Blanching is a process commonly used in the food industry to deactivate enzymes, reduce microbial content and soften tissues. It entails immersing food in boiling water or steam for a short time and then quickly cooling it down in cold water. The temperature typically ranges from 85°C to 100°C (185°F to 212°F), with varying times depending on the type and size of the food (Mancini et al., 2019).

- Pasteurization is a heat treatment process that eliminates harmful bacteria in certain foods and beverages to ensure they are safe to consume. There are two primary types of pasteurization: High Temperature Short Time (HTST) and Ultra High Temperature (UHT) (Silva & Gibbs, 2012).

HTST pasteurization usually involves heating the product to 72°C (about 161°F) for 15 seconds. This method is widely used in milk pasteurization. It effectively reduces microbial load while maintaining the sensory and nutritional quality of milk. According to research, HTST pasteurization can also deactivate enzymes such as alkaline phosphatase, which are indicators of successful pasteurization and milk safety (McKellar et al., 1994).

UHT pasteurization is the process of heating a product to at least 135°C (275°F) for a short period of time, typically 2-5 seconds. This process is used to extend the shelf life of products by reducing the number of microbes. UHT treatment has a greater impact on the flavor and nutritional content of milk than HTST, producing a cooked flavor and minor changes in the milk's proteins and vitamins (Lee et al., 2017).

- Canning is a preservation method where food is processed and sealed tightly in containers. This method involves placing various foods in jars or similar containers and heating them to a temperature that eliminates harmful microorganisms responsible for food spoilage. The usual procedure includes heating the food to temperatures ranging from 240-250°F or 115-121°C for a duration of several minutes to an hour, depending on the specific type of food and canning technique employed (Jimenez et al., 2023).

2.3 History of Canning

The history of canning dates back to the late 18th century when a skilled confectioner and chef named Nicolas Appert from France investigated into innovative methods to preserve food. This endeavor became particularly crucial during the Napoleonic Wars, as the French government sought ways to sustain their military troops and navy (Evancho et al., 2009, Christensen, 2023). To address this pressing need, a reward of 12,000 francs was offered for anyone who could devise an effective food preservation technique. After numerous experiments, Appert made a significant breakthrough by discovering that sealing food in glass jars maintained its freshness as long as the seals remained intact. Building on this discovery, he developed a method involving sealing food in jars with airtight precision by corking them securely, sealing with wax, wrapping in canvas and subjecting them to boiling. This sterilization process, known as "appertization," successfully eliminated harmful bacteria and slowed down decay (Middleton, n.d.).

The French government acknowledged the significant impact of his work by awarding him the prestigious prize they had previously announced. Over the following years, improvements to the canning process were driven largely by Peter Durand's dedication. Durand introduced tin cans as a more practical alternative to glass jars, making preservation techniques more efficient for both large scale production and transportation purposes (Christensen, 2023). This innovation made canning more accessible and easier to manage on a broader scale. In summary, Nicolas Appert's efforts and Peter Durand's subsequent contributions were pivotal in revolutionizing food preservation practices. Starting with Appert's clever method of sealing food in glass jars and culminating with Durand's introduction of tin cans as containers, these pioneers forever changed the way we preserve food. Their advancements not only sterilized food, eradicating harmful bacteria and preventing spoilage but also transformed how preserved foods are mass produced and transported. The lasting influence of their work continues to shape modern approaches to food preservation today (Christensen, 2023; Cutter, 2002).

2.4 Retort Processing

Retort processing is a complex technique that not only ensures the safety of food but also significantly prolongs its shelf life without the constant need for refrigeration. It signifies an advancement in cooking methods, involving precise control over temperature, pressure and timing to preserve food for longer periods. Raw food ingredients naturally contain microorganisms, but these can be eliminated through heat treatment. By employing appropriate processing and packaging methods, the growth of these microorganisms in processed food can be

prevented. The objective of retort processing is to achieve commercial sterility in food items. According to the Food and Drug Administration's (FDA) Code of Federal Regulations title 21 (21 CFR 11.3), commercial sterility refers to a state attained by using heat alone or in combination with other treatments to produce food that lacks pathogenic microorganisms capable of multiplying under typical non-refrigerated conditions during storage and transportation. A commercially sterile product is considered safe for consumption as it does not contain viable disease-causing microorganisms, provided that the package's seal remains intact (Somerville & Balasubramaniam, 2009).

One significant risk associated with low acid canned foods is the presence of botulinum toxin produced by *Clostridium botulinum* spores, which can thrive in the oxygen deprived environment present in canned food products. The toxin produced by *Clostridium botulinum* can cause serious health issues and even be deadly. To neutralize *Clostridium botulinum*, it needs to be heated above 121°C for spores, while heating at 85°C to destroy the toxin (Maier et al., 2017).

In the retort processing technique, raw or partially cooked food items are placed in a sealed container and then undergo thermal treatment in a retort. Steam is commonly used as the heating medium, but others can be used like steam air, steam spray depending on the type of packaging, and food product to be processed (Jimenez et al., 2023).

When a can undergoes thermal processing in a retort, transient heat transfer plays a key role. Two types of heat transfer take place within the can during heating; conduction and convection. Conduction dominates when the content is

solid or semi solid. If it's a mix of solid and liquid, both conduction and convection contribute to heat transfer. In a stationary retort, conduction is the main mode as there is no liquid motion. In an agitated retort, both conduction and convection play roles due to can rotation (Jimenez et al., 2023)..

Research indicates that retort processing can alter the protein composition of dairy products like bovine milk serum, affecting protein levels. This suggests that sterilization in retorts can impact the nutritional and sensory characteristics of dairy items crucial for creating good quality of Alfredo sauce (Wei et al., 2021). Additionally, using semi rigid and flexible containers to package retort processed dairy products implies that similar techniques could be utilized for Alfredo sauce to preserve its quality for extended durations.

2.5 Types of Retorts

Still batch-retort systems operate differently based on various factors such as the type of heating medium, rates of processing and speed used. Batch Retort Systems that remain stationary may not be the best choice for Alfredo sauce due to their potential limitations in ensuring uniform heat distribution needed to keep the sauce viscosity. The lack of rotational movement in these systems could lead to uneven heating, impacting the overall texture of the sauce (Holdsworth & Simpson, 2015).

Rotational batch retort systems (axial, end-over-end) rotate entire baskets of product during processing. While container agitation can provide faster rates of heat penetration to the container cold spot compared to still cooks, caution

identifying the slowest heating containers within a load. Data collection at small time increments (15 s) is recommended, especially for viscous fluids where the cold spot may move in relation to a fixed thermocouple during rotation, producing erroneous results. Slip-ring connectors should be cleaned, and thermocouple calibration verified regularly. On the other hand, the rotating motion helps prevent separation of dairy components and ensures even cooking of starches, maintaining the desired texture and taste of the sauce. The gentle mixing provided by water immersion rotary retorts can be advantageous for delicate products like the sauce that require careful handling (Dwivedi & Ramaswamy, 2010).

Continuous retort systems move containers through the processing vessel along a spiral track or in chain-driven flights. It is difficult to use thermocouples to collect heat-penetration data in these systems, and self-contained temperature measurement and data storage modules or process simulators may be used to obtain data (Durance, 1997).

2.6 Heating Medium

Saturated Steam (Jimenez et al., 2023): A saturated steam retort is a simple type of autoclave that is usually vertical and uses steam as heating medium. It is crucial to remove air during the ventilation stage using venting, an injected steam method, to prevent cold zones from forming. The use of saturated steam in retort processing has been found to be cost-effective and energy-efficient compared to other heating methods. However, this type of retort poses several challenges to processors, such as pressure fluctuations, which make it challenging to process

pouches, semi-rigid containers, and trays without package distortion or cold spot formation.

Water Cascade/Spray (Jimenez et al., 2023): The cascading water technique is a type of indirect steam heating where water is sprayed under pressure onto the top trays of retort carts. This method evenly distributes heat across a large volume of water, allowing heat to pass through the sidewalls of the container as water passes through the containers. Studies have shown that concerns about insufficient temperature dispersion are unfounded, as the variation in processing lethality throughout the retort is minor, and there are significant temperature variations during the cooking period. Furthermore, atomizing nozzles positioned around the chamber can be used to enhance the retorting process by providing excellent heat transmission and quick heating without requiring a fan to circulate air.

Water Immersion: Water is first heated and then pumped into the retort for processing. The container is typically fully submerged in water during processing, with overpressure created by blowing air or steam for improved heat transfer patterns (Adepoju et al., 2017). However, in certain situations, such as with half-immersion, packages are only partially submerged in water (less than half). This can be advantageous for high rotational speeds, as the cage creates less turbulence (Featherstone, 2015; Holland, 2008).

Water is recirculated during the heating process to ensure uniform heat distribution throughout the retort. Researchers have found that the position of products in a tray and the tray's height can impact heat transfer coefficients (Ramaswamy et al., 1991). Poor circulation can result in insufficient heat transfer.

Controlling the float of packs can be a challenge, and pouches and trays have often impeded this process, increasing basket manufacturing expenses and reducing adaptability. Half-immersion occurs when the vessel is half-filled with water and part of the rotation occurs in and out of the water. This method is beneficial for high rotational speeds because the cage creates less turbulence. Manufacturers such as Stock Inc., FMC, Lagarde, and Lubeck are noted manufacturers of this types of retort systems (Holland, 2008).

Steam Air: The use of steam and air is another popular medium for thermal processing. Lagarde Autoclaves patented this process in 1972, and it is highly efficient. The process differs significantly from the steam retort, with a horizontal vessel that has quick-opening doors for easy loading and unloading of baskets, forced steam circulation, and most crucially, independent control of temperature and pressure (Holland, 2008). Steam and air are continuously supplied to the retort vessel to create a homogeneous mixture. When water and steam are combined, the retort is pressurized, resulting in an overpressure situation that causes continual venting. This continuous flow of heated steam past the containers prevents the formation of cold spots (Adepoju et al., 2017). The technique was initially designed for flexible and semi-rigid containers, such as military rations in aluminum foil packs, but it has since been adopted for pouches and ready-to-eat food (Holland, 2008).

Early studies of steam air processing media revealed the possibility of producing a non-homogeneous mixture of steam (Ramaswamy et al., 1991). Europe and Japan used the method for commercialization for a long time before North

America adopted it. Later research revealed that the heat transfer pattern would be adequate if there was enough mixing (Ramaswamy et al., 1991).

The type of airflow is determined by the retort's design. Positive-flow retorts create upward flow and are intended for vertical retorts. Horizontal flows are used in Lagarde retorts, which are intended for horizontal retorts. A study comparing these two styles found that the overall mean heating rate index for positive flow was only slightly higher than that of the Lagarde retort .

Steam Water Spray: In 1983, Surdry of Spain patented the atomizing steam and water method, which is a relatively new batch-retorting technique. This method utilizes atomized air to provide excellent heat transfer to rigid containers, and a fan is not used to circulate the air. Instead, water is drawn from a pump and combined with condensate from the retort's center and recirculated condensate before being supplied directly into the chamber via atomizing nozzles located around it. While the atomizing nozzles allow for rapid heating, they tend to obstruct water flow during cooling, resulting in longer processing times compared to cascading water, immersion, or water spray retorts (Holland, 2008).

Table 1. Methods of heating

Method	Process	Advantages	Disadvantages
Water Immersion	Whole or partial immersion of container in heated water through processing	Suitable for most products, water recirculation ensures uniform heat distribution, can control container float, and immersion is more efficient at high speeds.	Requires water circulation to ensure uniform heat distribution, increased basket manufacturing cost for complete immersion, less adaptable.
Steam air	The method uses a mixture	Offers rapid heating, which results in shorter process times compared to traditional steam retorts	Independent control of temperature and pressure in the process requires a high

	of steam and air.		degree of technical knowledge.
Saturated steam	Injection of saturated steam, pure steam	It requires careful control to ensure it does not overheat or underheat the product.	Requires evacuation of air
Water cascade/spray	Water sprayed under pressure on top trays of retort to create indirect steam heating	Evenly distributed indirect steam heat, popular in industry, similar to water spray	Requires pressurized water supply

Sources: (Holland 2008, Mosna and Vignali 2015)

2.7 Agitation Methods

The first type of retort used for canning, known as static, has some limitations like slow heat penetration creates different temperature zones within the package, which can lead to overcooking, uneven texture, and flavor.

Different agitation techniques (as shown in Flow chart 2) include end-over-end, fixed axial, biaxial, and reciprocal agitation. When the container is agitated, air bubbles move around it, leading to a more uniform distribution of heat (figure 1).

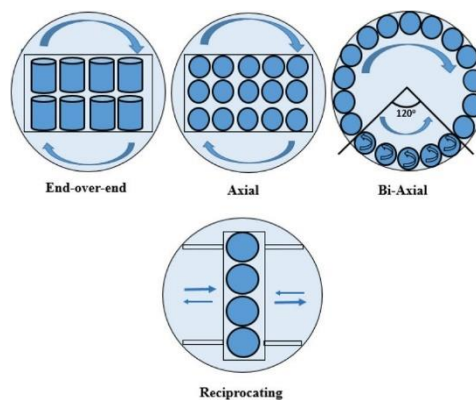


Figure 1. Type of motions

Sources: (Pratap Singh, Yen, Ramaswamy, & Singh, 2018)

End-Over-End/ Axial: End-over-end (EOE) or axial mode pack rotation is a popular technique that has gained popularity in recent years, where packages are rotated in limited-rotation baskets or crates. This batch method allows for greater manufacturing adaptability and is not restricted to cylindrical metal cans (Zhu et al., 2022). Commercial rotary retorts such as Sterilmatic, Steristar, and Rotomat operate on EOE rotation. Researchers have discovered that particles accumulate at the edge of the container after a specific speed, which interferes with the headspace bubble movement within the can due to the equal centrifugal and gravitational forces within the can. The EOE rotation technique involves rotating cans in a circular motion, which requires headspace in the container (Singh & Ramaswamy, 2015a).

Biaxial: Another method for agitation is biaxial agitation, which is commonly used in continuous retorts. In this method, cans change their direction of rotation twice during the revolution of the cage, which cancels out the centrifugal issues found in EOE rotation and improves heat transfer (Dwivedi & Ramaswamy, 2010; Singh et al., 2015). The use of horizontal axial rotation for agitation dates back to the 1920s, where cans were rolled to produce agitation. In the 1950s, vertical rotation was suggested as a means to improve heat transfer in canned products.

Intermittent: Involves intermittently stopping the agitation during continuous processing. This technique is used commercially in the FMC Sterilmatic, which processes cans using intermittent axial rotation (Tattiyakul et al., 2002). This method is appropriate for products that may be harmed by the shearing

force inherent in constant agitation. When starch granules are heated, for example, they expand and form a thickened dispersion (Tattiyakul et al., 2002). This results in hydrogen bond breakdown, depolymerization, and decreased viscosity.

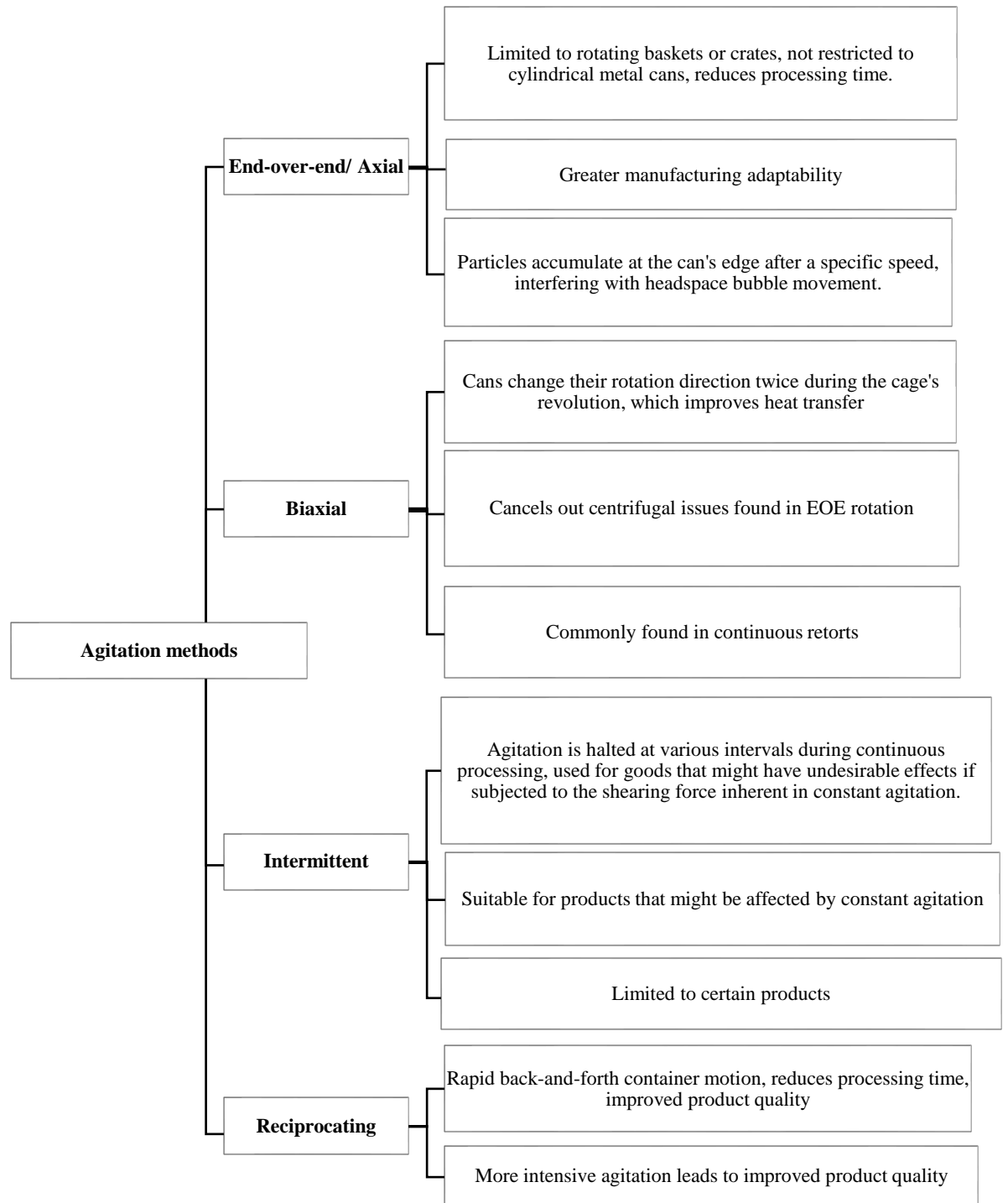
Reciprocating: Reciprocation agitation, which involves rapid back-and-forth motion of containers, is a promising type of agitation. A patent for a reciprocating cooker was first established in 1938 by Gerber, but it was not implemented into a retort until 1999 by Walden (Singh et al., 2015). Reciprocal agitation has grown in popularity since the invention of the Shaka and Gentle Motion retorts. The optimal shaking rate for a reciprocal agitation sterilization system is determined by factors such as the food product, container size and shape, and the desired level of microbial inactivation.

The Shaka process is used only for liquid products with fast agitation rates greater than 1 Hz, whereas the Gentle Motion method is used for liquid-particulate products with slower agitation rates. Many recent studies on this technique have been conducted, including investigations into reciprocation intensity, amplitude, frequency, container placement, headspace, and particle size. According to one study, the most significant effect on thermal transfer was reciprocation speed, followed by amplitude and frequency. Another study discovered that thermal processing canned shrimp with reciprocal agitation resulted in superior product quality, improved process parameters, and potential energy savings (Walden & Emanuel, 2010).

Oscillating: According to a study conducted by McNaughton in 2018, the use of oscillating motion during thermal processing can significantly reduce the

average calculated process time by 10% to 27% compared to static mode with the same thermal process parameters. The study utilized a two-basket water spray retort and calculated process times using Ball's formula method. The oscillating method utilized a speed of 10.5 RPM with an oscillating angle of 15°. The study also observed that depending on the amount of residual air in the pouch, there was a significant difference in the average slope value of the heating curves within the static motion, within the oscillating motion, and between the static and oscillating motions (Flow chart 1) (MacNaughton et al., 2018).

Table 2. Agitation methods



2.8 Heat Penetration Studies

A major concern in thermal processing revolves around the issue of thermal non-uniformity, which can result in the formation of cold spots within the product. These cold spots pose a threat to microbiological safety. To solve this problem, two key variables during thermal processing need consideration: heat distribution and heat penetration. Heat distribution refers to the transfer of heat to the product area through retort equipment, while heat penetration entails the transfer of heat from the product area to its coldest point. The design of an effective sterilization process requires gathering information about the time-temperature distribution profile within the food product and delving into the kinetics of thermal inactivation, including thermal death and thermal destruction (Smout et al., 2000).

2.8.1 Temperature Measurement and Data Acquisition

The accuracy and precision of the data acquisition system (datalogger) used for heat-penetration studies will affect temperature readings. The datalogger is typically a multi-channel temperature-measuring and digital-data-output system that should be calibrated, including verification of the data-acquisition rate.

Thermocouples should be calibrated against a traceable calibration standard frequently to provide reliable data. Some precautions when using thermocouple-based data-acquisition systems include minimizing multiple connections on the same wire, cleaning all connections, grounding the thermocouples, and recording device, slitting thermocouple outer insulation outside the retort, and using properly insulated thermocouple wires (IFTPS, 2014).

Thermocouple sensing junctions should be positioned in the slowest heating component of the food product and situated in the slowest heating zone within the container, ensuring an airtight seal without physical changes to the product. The method employed for adding the thermocouple into the container should not affect the container geometry that could influence heat-penetration data collection (Smout et al., 2000).

Temperature monitoring systems use various sensors throughout the retort to collect data for temperature distribution and heat penetration studies. Thermocouples (TMD) are the most widely used instruments made from two dissimilar metals connected at two junctions. The T-type (copper-constantan) and K-type (chromel-constantan) are the most popular types (Forney & Fralick, 1994). They are widely accepted due to their low cost, precision within the desired temperature range, responsiveness, and ability to be assembled on different types of containers, such as jars and pouches, as shown in Figure 2 (Berrie, 2001).

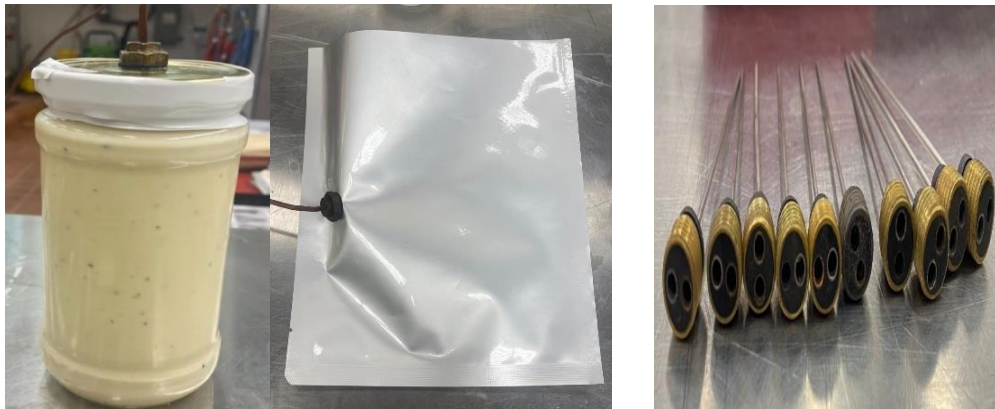


Figure 2. Assemble thermocouples in glass jars and metal cans. (Photo courtesy of Cryovac® Flavour Mark® Retort Laboratory, Clemson University, SC).

Modern data loggers are equipped with sensors to collect data and can be either connected or wireless. They are multi-channel systems with digital responses, allowing readings to be sent directly to a laptop for collection and storage (Awuah et al., 2007b; Berrie, 2001).

Thermal processing is typically carried out with the help of an onboard control system or a computer. The LOG-TEC Process Management System was the first commercial system introduced, and it is still in use today. The HP-85 desktop computer with an HP-3497 datalogger was the first computer used for this purpose (Gill et al., 1989). Regulatory agencies such as the FDA/USDA in the United States and the FSA in the United Kingdom recommend additional data collection to improve thermal processing control and protect customers. A host computer with customized product recipes is used to store data and meet the regulators' requirements for data sent electronically in a specific format and by a PC. This document can then be filed, either directly from the computer or via a remote PC, in an easily readable form that requires no extra software (Mosna & Vignali, 2015).

The Institute for Thermal Processing Specialist (IFTPS, 2014) states using thermocouples, wireless data loggers, and other comparable devices to monitor temperatures during thermal processing. All instruments used must be of high precision and size, as well as be available in significant amount for analysis, to ensure proper and safe observation of the process environment (IFTPS, 2014; Llosa Sanz, 2017).

2.9 Critical Factors

Study design needs to carefully account for all critical factors related to the product, package, and process, as these factors can affect heating rates. Include an adequate number of containers per test run and conduct multiple tests runs to account for statistical variability. Identifying these critical factors and understanding how altering them within and beyond established limits impacts the heat-penetration process requires both expert judgment and reliable experimental data. It is required to record quantitative data on variability and document all relevant information to better comprehend and accommodate possible variations in heat-penetration behavior (IFTPS, 2014).

- Product-related factors contributing to variations in time-temperature data collected during heat-penetration tests include product formulation, weight variation, fill weight, solids content, consistency, size, shape, integrity of solid components, product preparation prior to filling, rehydration of dried components, product heating behavior, and other characteristics such as salt content, water activity, pH, specific gravity, preservative concentration, and acidification methods (IFTPS, 2014).

- Container-related factors that can influence heating behavior encompass manufacturer and brand information, container type, size and dimensions, profile of containers, vacuum and headspace, maximum flexible package thickness, and container orientation within the retort (IFTPS, 2014).

2.10 Food Safety Calculations

There are two common approaches, namely the General and the Ball formula method, used to determine the minimum thermal process needed to achieve commercial sterility. The effectiveness of thermal processing is measured through the sterilization value, also known as lethality (F_0). This value indicates whether a thermal process successfully eliminates microorganisms in the food. Calculated based on time temperature data from the coldest point, the sterilization value is crucial for modern thermal processing calculations (Stoforos, 2010, Devadason et al., 2013).

General Approach: Developed by Bigelow, this method for creating sterilization processes determines processing time by calculating the area under a curve that represents lethality plotted against time. This technique forms the basis for current thermal food processing designs, incorporating the concept of decimal reduction time (D) and its dependence on temperature (zT) (Serment-Moreno & Welte-Chanes, 2016).

Ball's Formula Method: A refinement and simplification of the general approach, it was introduced by Ball to simplify process lethality calculations using charts and tables that link the food product's temperature profile with data on microbial inactivation kinetics. The lethal rate (LL) for each temperature at the can's center is determined using Equation 1 from heat penetration data (Ball, 1927). In this formula, T stands for the temperature at the cold point at a specific time (t), T_r is the reference temperature and z indicates the temperature adjustment leading to a tenfold decrease in the D value, which is unique to the thermal resistance of the

microorganism being studied and varies among different microorganisms (Stoforos, 2010).

F₀ value required for a particular food to achieve commercial sterility can be calculated using:

$$F \frac{Z}{T_{ref}} = D_{TREF} \cdot \text{Log (No/N)}^{[1]}$$

It required to know:

- Reference temperature from TDT studies
- D value at reference temperature
- Desired log reduction of microorganism ('Log (No/N)')
- Z value of target microorganism

(IFTPS, 2014)

2.11 Concern and Target microorganism

Clostridium botulinum is a rod-shaped bacterium that thrives in environments without oxygen, such as in canned foods. This bacterium is known for producing botulinum toxin, one of the most dangerous neurotoxins known, which can cause botulism—a serious and often deadly illness affecting both humans and animals. The presence of *Clostridium botulinum* spores in soil, water, and on fruits and vegetables emphasizes the need for strict food safety practices to prevent contamination and ensure public health (Mertaoja et al., 2023).

Clostridium sporogenes, particularly the strain PA 3679, is a non-toxic, spore-forming microorganism widely used in the food processing industry as a surrogate or target m.o to validate thermal processing strategies. Unlike *C. botulinum*, which is known for producing neurotoxins that cause botulism, *C. sporogenes* does not produce these toxins, making it a safer option for testing. The PA 3679 strain is notable for producing spores with exceptionally high heat resistance, allowing for more rigorous testing of food processing methods to ensure the safety of shelf-stable products against botulinum spores without risking the introduction of neurotoxic organisms into food processing facilities (Brown et al., 2012).

2.12 Toxin

The botulinum toxin impacts nerve functionality by disrupting acetylcholine release, a crucial neurotransmitter for muscle movement. This disruption leads to muscle paralysis and, in severe cases where respiratory muscles are compromised, botulism can become a medical emergency with potentially fatal outcomes. Botulism in humans is primarily caused by botulinum toxin types A, B, E, and F (Luvisetto, 2021).

2.13 Sources of Infection

According to the CDC (n.d.-b), there are several types of botulism, each associated with different modes of exposure to *Clostridium botulinum* or its toxins:

- ***Foodborne botulism*** occurs from eating foods contaminated with botulinum toxin, often due to improper canning or preservation methods.
- ***Infant botulism*** happens when infants ingest spores that germinate and produce toxin within their intestines.
- ***Wound botulism*** is caused when the bacteria's toxins are produced inside an infected wound.
- ***Inhalation botulism***, although very rare, can occur if the toxin is inhaled, which is a potential risk for bioterrorism.
- ***Iatrogenic botulism*** can occur from an accidental overdose of botulinum toxin administered medically, such as in treatments involving Botox. This form of botulism, while also rare, underscores the importance of precise dosing and monitoring in medical contexts.

2.14 Treatment and Prevention

Timely diagnosis and treatment are important for surviving botulism.

Antitoxin administration aims to neutralize the toxin; however, recovery from paralysis can take weeks to months. Prevention focuses on vigilant food handling and preparation, especially during home canning. Heating food to a sufficiently high temperature for an adequate duration effectively destroys the toxin at least 85°C (185°F) for a minimum of 5 minutes (Chellapandi & Prisilla, 2017).

2.15 Alfredo sauce

Alfredo sauce, a staple of Italian cuisine known for its simplicity and rich flavor, originated in Rome and has become a beloved component of both Italian

and Italian-American cooking. The primary ingredients are butter, cream, and Parmesan cheese, which combine to create a smooth, velvety sauce. The traditional recipe involves gently melting butter and blending it with fresh cream, followed by stirring in grated Parmesan cheese to add a rich, slightly salty flavor. Some variations might include garlic, parsley, nutmeg, or black pepper to enhance the sauce's complexity (Rosso, 2022).

The sauce is named after Alfredo di Lelio, a Roman restaurateur who devised the recipe in 1914. According to culinary lore, di Lelio created the sauce to entice his pregnant wife to eat during a difficult pregnancy. The dish soon became a fixture at his restaurant, "Alfredo alla Scrofa." Alfredo sauce gained international fame when Hollywood celebrities Mary Pickford and Douglas Fairbanks sampled it on their honeymoon in Rome and subsequently introduced it to the United States, helping to popularize it globally (Borghini, 2015).

Today, Alfredo sauce is a standard offering in Italian restaurants worldwide, testament to its enduring appeal. While specific research on Alfredo sauce may be limited, there is ample documentation on the general importance and traditional preparation methods of Italian sauces. For example, studies on the quality and sensory profiles of Italian tomato sauces highlight the critical role of using high-quality ingredients to achieve rich flavors, a principle central to Alfredo sauce (Bendini et al., 2017).

Additionally, the cooking techniques employed in traditional Italian dishes like spaghetti alla carbonara, which involves delicately cooked eggs, offer insights

relevant to Alfredo sauce, where dairy components are similarly gently cooked to maintain their integrity (Lopes & Tondo, 2020).

Also, Alfredo sauce, like many culinary sauces, likely exhibits non-Newtonian properties, specifically shear thinning behavior. This means that the sauce becomes less viscous under stress (e.g., stirring) and returns to its original thickness when at rest, aiding in its ability to cling to and coat food effectively. Similar behaviors have been observed in other condiments like ketchup and mustard, suggesting comparable properties in Alfredo sauce due to its thick, creamy texture (New Food, 2018; Centre for Industrial Rheology, 2021).

2.16 Starch

Starch, a complex carbohydrate presents in various plant-based foods like grains, potatoes and legumes, holds a vital role in both the food industry and human diet. Starches are comprised of amylose and amylopectin, forming a semi crystalline structure with crystalline and amorphous regions that influence each particular starch's individual. Starch sources range from traditional options like corn and wheat to unconventional ones such as chestnut and banana. These sources find diverse applications such as thickeners, stabilizers, and gelling agents in food products. Physical treatments can enhance properties like digestibility and gelation. Classification based on digestion speed—rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS)—underscores its impact on blood glucose levels and health. Advanced microscopic techniques have revealed the detailed morphology and molecular structure of starch granules, shedding light on

its functional abilities and how it can be modified (Zhong et al., 2021; Chakraborty et al., 2020).

The composition and structure of starch vary depending on the source, impacting its physical characteristics and uses. The ratio of amylose to amylopectin as well as the branching degree in amylopectin influence its crystalline patterns and functionality. A range of advanced analytical methods have been used to uncover the intricate details of amylose's structure, leading to a better grasp of how starch is formed in plants and algae. Despite the seemingly simple nature of its glucose components, the complex makeup of starch, including its various crystalline forms and how it reacts to changes like gamma irradiation, continues to be a topic under active investigation.

Starch consists primarily of two types of glucose polymers. Amylose and amylopectin. Each polymer has unique structures that play a significant role in determining the physical attributes and functions of starch. Amylose is a straight chain polymer connected by α 1,4 glycosidic bonds, which contributes to creating firm gels and films due to its ability to form helical structures. Amylopectin, found in most starches, is a highly branched molecule with short chains linked by α 1,6 glycosidic bonds that create a complex three-dimensional arrangement. This branching gives amylopectin greater flexibility and solubility compared to amylose, impacting the texture and shelf life of products made from starch (Seung, 2020; Bertoft, 2017).

The proportion of amylose versus amylopectin differs among various sources of starches and affects properties such as gelatinization behavior,

retrogradation tendencies and digestibility levels. For example, high amylose starches are recognized for their enhanced resistance to digestion, leading to the creation of resistant starch that offers health benefits. The shape and size of starch granules vary depending on their source, ranging from small to large and from round to irregular shapes. This diversity in granule morphology influences the surface area of starch and its interaction with water, thereby impacting its usability in both food and nonfood sectors (Hanashiro, 2015; Moran, 2019).

The internal structure of starch granules exhibits a high level of organization, where amylose and amylopectin molecules form a semi crystalline structure. This structured layout plays a vital role in determining the functional characteristics of the granule, particularly its behavior during thermal processing. The crystalline segments made up of densely packed glucose units provide strength and stability to the granule, while the amorphous areas promote flexibility and swelling (Zhu, 2018; Cheng et al., 2020).

2.17 Gelatinization

The process of gelatinization, an important step in altering starch properties, involves starch granules absorbing water, swelling and losing their semi crystalline structure. This results in the release of amylose and amylopectin molecules and is influenced by factors such as the type of starch used, additional ingredients present and the way it is processed. The temperature at which gelatinization starts varies depending on the type of starch. Higher temperatures and longer processing times typically lead to more extensive gelatinization. This process is crucial in various industries that utilize starch for making food products, paper and adhesives (Rittenauer et al., 2021; Sknar et al., 2023).

2.18 Retrogradation

Retrogradation plays a significant role in understanding the chemistry of starch, affecting the texture, shelf life and nutritional qualities of foods containing starch. This process involves the reconnection of starch components—amylose and amylopectin—in gelatinized starch as it cools. Researchers have extensively studied this process to uncover the functions of amylose and amylopectin.

Amylose, with its linear structure and fewer branches, tends to retrograde faster than amylopectin. The quick retrogradation of amylose leads to the formation of firmer gel structures. Studies by Wang et al. (2015) analyzed this, highlighting how high amylose starches retrograde more rapidly and impact food texture and stability. On the other hand, amylopectin's branched nature results in a slower retrogradation process and softer gels. This distinction showcases the intricate nature of starch behavior influenced by its molecular components. The storage

environment, especially temperature conditions, significantly influences starch retrogradation. Vamadevan and Bertoft (2018) emphasize how storage conditions affect this process, stressing the importance of considering these factors when producing or preserving starch-based products.

Moreover, the occurrence of syneresis, which involves the removal of water from the gel structure, is a typical outcome of starch retrogradation. This phenomenon can pose challenges in specific food items like canned soups, where it is typically deemed unfavorable. In their study from Karim (2000) explore into the factors that trigger syneresis, offering valuable guidance on strategies to reduce its impact on food items.

2.19 Modification of Starch

Native starches often have restricted applications in the food industry due to their inherent properties. While these starch granules hydrate and swell quickly, they tend to lose viscosity and form pastes with weak bodies that are overly stringy and cohesive. To overcome these limitations, starches can be modified to enhance their performance. The primary methods for modifying starch include chemical, physical, and enzymatic processes, each tailored to improve specific characteristics such as stability, texture, and reactivity (Singh, Kaur, & McCarthy, 2007).

2.19.1 Chemical Modification

Chemical modification of starch can significantly improve its properties by either substituting the hydroxyl group in the starch chain, or by breaking the chain into smaller fragments. The degree of substitution (DS) measures the extent of

hydroxyl group substitution per glucose in the starch chain, with a maximum DS value of three indicating full substitution (Masina et al., 2017)

2.19.2 Acetylation

Acetylation is a common chemical modification in the food industry, used in products like baking, frozen food, sauces, and baby food. It replaces hydroxyl groups with acetyl groups, creating steric obstacles that decrease the gelatinization temperature and improve stability at cooling and freezing points (Subroto et al., 2023).

2.19.3 Hydroxypropylation

Hydroxypropyl modification, through the reaction of starch with propylene oxide and a base catalyst (NaOH), reduces the interaction among starch chains, making it easier for water molecules to assimilate. This modification lowers the gelatinization temperature and increases viscosity, and reduces starch retrogradation (Subroto et al., 2023).

2.19.4 Acid/Alkaline Treatment

Acid treatment, one of the oldest modification methods, hydrolyzes starch in the presence of water and acid, breaking down starch chains into smaller fragments, and is often used in frozen food applications. Alkaline treatment involves treating starch granules with an inorganic alkali, resulting in hydrolysis and negatively charged starch chains that absorb water easily and have a low gelatinization temperature (Wang & Copeland, 2015).

2.19.5 Oxidation

Oxidation, involving agents like sodium hypochlorite, converts hydroxyl groups in starch molecules into carbonyl and carboxyl groups, shortening the polymer chain. This modification produces a homogenous gel with good retrogradation stability but reduces the strength of the gel. Oxidized starch is commonly used as a replacement for acacia gum in candy and bread baking (Vanier et al., 2017).

2.19.6 Stabilization and Cross-linking

Stabilization, by reacting to the starch chain with bulky groups, and cross-linking, through multifunctional reagents, strengthen starch granules, increasing their resistance to shear stress, high boiling temperatures, and acid hydrolysis. These modifications are crucial for enhancing the functional characteristics of starch for diverse applications (Compart et al., 2023).

2.19.7 Physical and Enzymatic Modification

Physical modification, such as heat-moisture treatment and annealing, changes the physicochemical properties of starch without altering its molecular composition. Enzymatic treatment with enzymes like endoamylase and exoamylase modifies starch for various applications, including the food industry (Fonseca et al., 2021).

2.20 Types of Starches

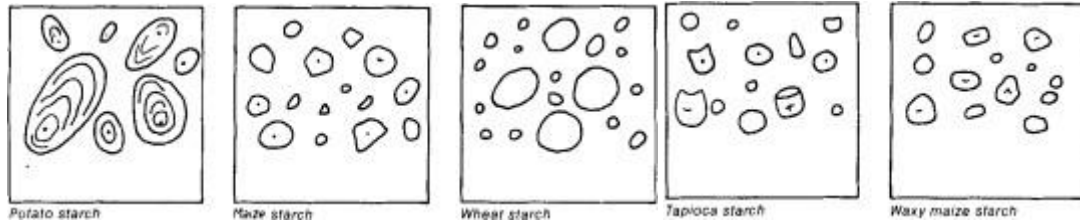


Figure 3. Microscopic pictures of starch granules (A. Swinkelse, ABC om stärkelse, Malmö)

2.21 Corn Starch

Corn starch is derived from the endosperm of corn kernels. Corn, also known as maize (*Zea mays*), is a staple crop grown extensively around the world, with the United States, China, Brazil, and Argentina being some of the largest producers. Corn starch is utilized across various industries, including food, pharmaceuticals, and manufacturing, owing to its thickening, binding, and stabilizing properties (table 3). It plays a crucial role in producing a wide range of products, from processed foods to biodegradable materials (Eckhoff & Watson, 1984).

Commonly used starch in retort food applications due to its ability to withstand high temperatures and pressures during processing (Wu & Zhou, 2018). It is a modified form of corn starch that has been treated with heat and/or chemicals to improve its functional properties, such as its thickening and gelling abilities. This starch is often used as a thickener and stabilizer in sauces, gravies, and soups (Collado & Corke, 2003; Yu & Moon, 2021).

Maize starch granules exhibit significant differences in their crystalline and amorphous zones, which impact their behavior under hydrolytic treatments. The

growth and development of maize starch granules during maturation depend on the maize varieties and the tissue site in the kernel, affecting the distribution of amylose and amylopectin ratios (Gallant et al., 1986).

Its ability to maintain viscosity and gel strength under high temperatures and pressures makes it indispensable for ensuring consistency in soups, gravies, and sauces designed for retort processing. The unique hexagonal shape of corn starch granules, ranging between 15 to 25 μm , not only contributes to its aesthetic appeal but also to its functional superiority in retort applications. The modifications applied to corn starch, enhancing its heat penetration and resistance to high pressure, are pivotal in delivering stable and uniform retort products (Gallant et al., 1986; Wu & Zhou, 2018)

Table 3. Omnibus Table of Modified Corn Starch in Retort Applications

Aspect	Detail
Corn Starch Type	Modified corn starch
Function in Retort Applications	Acts as a thickener and stabilizer
Typical % Used	2-5% depending on desired thickness
Impact on Texture	Increases viscosity and gel strength
Impact on Flavor Release	May affect flavor release depending on the concentration and type of modification
Heat Penetration	Modified to withstand high temperatures without breaking down
Resistance to High Pressure	Enhanced stability under retort conditions
Applications	Soups, gravies, and especially sauces requiring stability throughout the retort process

Corn starch has a bland taste and odor and is easily dispersed in water. It has a high gel strength and viscosity, which makes it a good thickener and stabilizer (table 3). Corn starch is also resistant to acid and shear, which makes it a good choice for acidic and high-shear retort applications (Eliasson, 2004).

Table 4. Influence of Corn Starch on the Quality of Retort Processed Foods

Study	Key Findings	Impact on Retort Processed Foods	% of Starch Added
Tattiyakul, J., Rao, M. A., & Datta, A. (2002)	Heat transfer from the hot wall to the canned corn starch dispersion improved considerably in intermittent rotation because the boundary layer region was not covered with a thick layer of gelatinized starch.	This study provides insights into optimizing heating protocols for canned starch dispersions under retort conditions, potentially leading to more uniform cooking and improved product quality.	Not specified
Lubowa, M., Yeoh, S.-Y., & Easa, A. (2018)	Pregelatinized high-amylose maize starch improved the texture and brightness of rice noodles both before and after retort processing. Chilling treatment combined with high-amylose starch addition positively affected the texture, with a notable decrease in retort cooking loss and increased noodle hardness.	Demonstrates the beneficial effects of modified corn starch on improving the quality of retort-processed foods by enhancing texture and reducing quality loss through retort processing.	0%, 5%, 10%, 15% (wt/wt)

Devadason, I. P., Anjaneyulu, A., & Babji, Y. (2010)	Corn starch as a binder produced a more stable emulsion, higher shear force, and better sensory scores for texture and overall acceptability compared to other binders. Fat content was higher in products with corn starch.	Highlights the utility of corn starch as a binder in retort-processed foods, improving texture, emulsion stability, and sensory acceptance, particularly in meat products.	Not specified
Durch, N. (2020)	TI corn starch blended with 15% waxy rice offers an optimal balance of viscosity, starch granule integrity, and textural appearance in retort-processed cream of chicken soup. Both native starches improved the granule integrity of TI corn starch in the soup samples throughout 5 freeze-thaw cycles, with waxy rice starch blends having the best textural appearance.	Provides evidence of the potential of thermally inhibited (TI) corn starch, especially when blended with waxy rice starch, to enhance the quality of retort-processed foods, improving granule integrity and textural properties over multiple freeze-thaw cycles.	

2.22 Potato Starch

Potato starch is derived from the tuberous crop *Solanum tuberosum*, an essential global food source. The extraction process involves crushing potatoes to release starch grains from the disrupted cells. In the food industry, potato starch is highly valued for its excellent gelling, thickening, and moisture-retention

capabilities, making it ideal for use in soups, sauces, and baking. Beyond food, it finds applications in the textile and paper industries (Table 5). One of the distinguishing features of potato starch is its high amylose content, which contributes to its high viscosity and ability to form clear gels. Additionally, potato starch is naturally phosphorylated, enhancing its functionality and performance in various applications (Singh et al., 2007).

Potato starch is well known for its use in retort food processing because of its high amylose content and strong ability to form gels, making it an excellent thickener and stabilizer for various retorted food items. The neutral taste of potato starch and its capacity to create sturdy gels play a crucial role in improving the texture and durability of products like instant mashed potatoes, potato chips and snacks that undergo retort sterilization. Studies show that potato starch demonstrates remarkable resistance to heat and shear forces, making it a top choice for applications involving high temperatures and intense shearing. Its exceptional freeze thaw stability further highlights its suitability for use in retort food processing, ensuring that the texture and viscosity are preserved after processing and thawing, giving it an edge over other starch types such as tapioca starch (Ruzaike et al., 2015; Altemimi, 2018).

Potato starch stands out for its high amylose content and substantial granule size (15 to 80 μm), traits that endow it with exceptional gelling abilities. These characteristics are particularly beneficial in retort food processing, where the starch's neutral taste and ability to form sturdy gels contribute significantly to product texture and durability. Studies highlight its remarkable resistance to the

thermal and shear stresses of retort sterilization, making potato starch a preferred choice for ensuring the texture and viscosity of retorted food items remain intact through processing and thawing (Ruzaike et al., 2015; Altemimi, 2018).

Table 5. Omnibus Table of Potato Starch in Retort Applications

Aspect	Detail
Potato Starch Type	Native and modified potato starch
Function in Retort Applications	Used as a thickener, stabilizer, and to enhance texture
Typical % Used	Varies; specific percentages depend on the product formulation and desired outcome
Impact on Texture	Contributes to a smooth and creamy texture; modified forms help maintain consistency under retort conditions
Impact on Flavor Release	Neutral flavor profile, does not significantly alter the taste of the final product
Heat Penetration	Modified potato starches are designed to endure high-temperature processes without losing functionality
Resistance to High Pressure	Shows good resistance to degradation under the high pressures typical of retort processing
Applications	Ideal for use in canned soups, sauces, gravies, and other retort-processed foods where texture and viscosity are critical

Food Product	Retort Conditions	Findings	References
Canned Potatoes	Temperature: 115–125°C; Rotation speed: 20 rpm; Can headspace: 10 mm; Agitation modes: end-over-end, fixed and free axial	Higher temperatures and better agitating conditions during retort processing demonstrated better quality retention in canned potatoes, optimizing color and textural attributes.	Rattan, N., & Ramaswamy, H. (2014).
Potato Products in Retort Packaging	Room temperature storage up to 90 days	Facultative thermophilic <i>Bacillus licheniformis</i> bacteria were isolated from thermally treated potato products in retort packaging, emphasizing the importance of microbial safety.	Ruzaike, A., Muizniece-Brasava, S., & Kovalenko, K. (2015).

However, challenges arise from the inherent characteristics of starch granules like their quick hydration, swelling and subsequent loss of viscosity which make it difficult to maintain the desired quality of retorted food products. To address these obstacles, modifications are often made to starches like potato starch to improve their functional properties, such as enhancing viscosity and maintaining texture stability during and after retort processing (Mandlawy, 2013).

In the context of retort processing, the research aimed to find a suitable starch that could act as a filler or enhance the desired viscosity and texture in the final product, keeping these qualities intact throughout storage. After assessing various starch samples from different suppliers and modifications, it was found that certain modified potato and waxy maize starches, especially those modified with E1442 (hydroxypropyl di starch phosphate), exhibited the highest viscosity post retort processing and during storage. This modification method involves treating the starch with propylene oxide and phosphoric acid to stabilize the molecule by introducing steric hindrances and enhancing its interaction with water, thereby improving the viscosity and stability of retorted food products (Mandlawy, 2013).

Moreover, the study emphasized understanding how starch behaves under different processing conditions like variations in pH levels and added ingredients to ensure that the chosen starch meets all requirements for retort applications. The results indicate that although natural potato starch works well as a filler before the retorting process, it deteriorates considerably afterward, requiring the use of modified starches to maintain the desired product quality in retort applications (Mandlawy, 2013).

2.23 Rice Starch

Rice starch originates from rice grains (*Oryza sativa*), a staple food for more than half of the world's population. It is a major agricultural product with a wide range of applications in both food and non-food industries. The structure, functionality, and applications of rice starch have been extensively researched, revealing its unique physicochemical properties and suitability for specific industrial applications (Amagliani et al., 2016).

Rice starch is known for its mild taste and scent, easily mixing in water. It boasts high gel strength and thickness, making it a reliable thickening agent and stabilizer, especially for processes involving intense heat and mixing. Its uses extend beyond traditional dishes like rice noodles, crackers and snacks. Various studies have uncovered the wide-ranging potential of rice starch across different industries. Particularly, its ability to withstand heat and shear makes it a preferred option for applications requiring high temperatures and intense mixing (Singh and Kaur, 2016). Amagliani et al. (2016) investigated into the composition, structure, functionality and applications of rice starch in food production and industrial settings. Their findings shed light on how non starch components like fats and proteins influence the physical and chemical properties of rice starch, highlighting its unique functional properties.

Furthermore, Bao and Bergman's (2018) research on rice flour and starch underscores that rice starch is both hypoallergenic and gluten free. This study emphasizes the diverse functional characteristics associated with its amylose and

amylopectin content, positioning it as a suitable choice for specific industrial applications.

The versatility of rice starch, with its granule size ranging from 2 to 8 μm and polygonal shape, is evident in its hypoallergenic and gluten-free nature, making it suitable for a wide array of industrial applications. Its ability to endure intense heat and shear conditions without compromising on whiteness or neutrality in taste underlines its importance in the food production sector, especially in retort processing where maintaining sensory and quality attributes is paramount (Singh and Kaur, 2007; Amagliani et al., 2016).

Table 6. Influence of Rice Starch on the Quality of Retort Processed Foods

Study	Key Findings	Impact on Retort Processed Foods	% of Starch Added
Lubowa et al. (2018)	Pregelatinized high-amylose maize starch and chilling treatment improved texture and reduced quality loss in retort-processed rice noodles.	Enhances texture and mitigates quality loss in rice-based retort products.	0%, 5%, 10%, 15% (wt/wt)
Dixon et al. (2020)	Rice hydration during retort processing with reciprocal agitation-maintained aroma, starch, and color quality comparable to static or rice cooker methods.	Maintains sensory and quality attributes of rice in retort-packaged products.	Not specified

Yu et al. (2017)	Processing technologies including retorting affect rice's physical properties and sensory attributes.	Indicates potential quality improvements or declines in retorted rice products.	Not specified
Isaka et al. (2018)	Retort treatment of high-amylose rice gels prepared using high-speed shear showed varying viscoelastic properties and retrogradation behaviors.	Suggests modifications to processing for improved quality of retorted rice starch products.	Not specified
(Gobikrishnan et al., 2019)	Retort processing increased the shelf life of Indian traditional rice dumplings from one day to four weeks.	Extends shelf-life while maintaining the nutritional and sensory quality of rice products.	Not specified

Ding Chang (2012) offers an overview of techniques for extracting rice starch and highlights the versatility of both natural and modified rice starch in the food industry. The review underscores the significance of rice starch in enhancing the texture and stability of food products, especially during retort processing. In a study by Wani et al. (2012), insights into rice starch are provided by examining how various types of rice plants and farming conditions impact the structure, appearance, heat resistance and chemical properties of rice starch. Their findings suggest diverse potential applications for rice starch, particularly in food and pharmaceutical sectors.

The advancements made in augmenting the functionality of rice starch through blending with biopolymers, as explored by Tiozon et al. (2021), introduce fresh possibilities for its utilization in ecofriendly packaging materials and

pharmaceutical nutraceutical products. This innovative method to enhance both physical and chemical attributes of rice starch demonstrates its promising prospects beyond traditional culinary uses, expanding into environmentally conscious industrial applications.

Table 7. Omnibus Table of Rice Starch in Retort Applications

Aspect	Detail
Rice Starch Type	Native and Modified Rice Starch
Function in Retort Applications	Used as a thickener, stabilizer, and to enhance texture
Typical % Used	Varies; specific percentages depend on the product formulation and desired outcome
Impact on Texture	Contributes to a smooth and creamy texture; modified forms help maintain consistency under retort conditions
Impact on Flavor Release	Neutral flavor profile, does not significantly alter the taste of the final product
Heat Penetration	Modified rice starches are designed to endure high-temperature processes without losing functionality
Resistance to High Pressure	Shows good resistance to degradation under the high pressures typical of retort processing
Applications	Ideal for use in canned soups, sauces, gravies, and other retort-processed foods where texture and viscosity are critical
Citations	Lubowa et al. (2018), Dixon et al. (2020), Yu et al. (2017)

The properties of starch are influenced by these factors. The moisture content in starch is determined by the amount of water absorbed by the starch granules, alongside the relative humidity and temperature conditions. Typically, native starch has a moisture content of 10-20% under standard atmospheric conditions.

Composition of Starch Granules (Average Values).					
Starch Components	Potato starch	Maize starch	Wheat starch	Tapioca starch	Waxy maize starch
Moisture at 65% RH and 20 °C.	19	13	13	13	13
Lipids (% on dry substance)	0.05	0.7	0.8	0.1	0.15
Proteins (% on d.s.)	0.06	0.35	0.4	0.1	0.25
Ash (% on d.s.)	0.4	0.1	0.2	0.2	0.1
Phosphorus (% on d.s.)	0.08	0.02	0.06	0.01	0.01
Amount of taste and odour substances	low	high relative	high relative	low	medium

Figure 4. Composition of Native Starch Granules

2.24 Tapioca Starch

Tapioca starch, also known as cassava starch, is extracted from the root of the cassava plant (*Manihot esculenta*). It is a major starch produced in Indonesia and other Southeast Asian countries. Tapioca starch is favored in various applications for its neutral taste, thickening properties, and ability to form strong gels. It is commonly used as a feedstock in food and non-food industries and has potential as a raw material for bioethanol production (Sugih et al., 2015).

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Tapioca starch plays a crucial and versatile role in modern food production and recipe creation, as noted by Ruzaike et al. (2015) and Altemimi (2018). One of the key reasons tapioca starches is preferred in retort food applications is its neutral taste and thickening properties, which are valuable for products like puddings, pie fillings and sauces that undergo the retort process. Its ability to dissolve smoothly in water and form strong gels ensures that food items maintain their desired texture even under the harsh conditions of retort sterilization.

Table 8. Omnibus Table of Tapioca Starch in Retort Applications

Aspect	Detail
Tapioca Starch Type	Native and Modified Tapioca Starch
Function in Retort Applications	Used as a thickener, stabilizer, and to enhance texture
Typical % Used	Varies; specific percentages depend on the product formulation and desired outcome
Impact on Texture	Contributes to a smooth and creamy texture; modified forms help maintain consistency under retort conditions

Impact on Flavor Release	Neutral flavor profile, does not significantly alter the taste of the final product
Heat Penetration	Modified tapioca starches are designed to endure high-temperature processes without losing functionality
Resistance to High Pressure	Shows good resistance to degradation under the high pressures typical of retort processing
Applications	Ideal for use in canned soups, sauces, gravies, and other retort-processed foods where texture and viscosity are critical

Sources: (Hsieh et al. 2019)

Unmodified waxy tapioca starch creates thick, transparent pastes with good durability and stability when exposed to freeze thaw cycles, resisting retrogradation. The cold resistance of waxy tapioca starch presents a natural option for frozen or refrigerated. foods without resorting to chemical or genetic modifications (Hsieh et al., 2019).

Tapioca starch, characterized by its granule size of 20 to 35 μm and a hexagonal (truncated) oval shape, is prized for its neutral taste and thickening properties. Its unparalleled solubility and gel formation capabilities, even under the stringent conditions of retort sterilization, ensure that food items maintain their desired texture. The stability and durability of unmodified waxy tapioca starch, particularly its resistance to freeze-thaw cycles, render it an excellent candidate for retorted foods, offering a natural solution for enhancing food quality without the need for chemical or genetic modifications (Hsieh et al., 2019).

Moreover, tapioca starch demonstrates excellent freeze thaw stability, making it ideal for retort food items that may go through freezing and thawing before consumption. This attribute contributes significantly to preserving the quality and longevity of retort foods by maintaining their texture and viscosity during storage and distribution. The process of preparing tapioca for consumption involves boiling it in guar gum and storing it in durable polypropylene containers. By subjecting it to heat at 121.1°C for specific durations, the tapioca becomes softer and less chewy, indicating the opportunity to enhance retort processing parameters for tapioca-based dishes (Dinakaran et al., 2017).

With the increasing demand for gluten free alternatives, tapioca starch has become a popular choice in gluten free food products as a replacement for wheat flour. Its ability to bind and thicken makes it essential in crafting gluten free versions of traditionally wheat-based foods while maintaining their texture and flavor. The cold stability of waxy tapioca starch presents an appealing substitute to chemically modified or genetically engineered starch in frozen/refrigerated foods, showcasing its adaptability and potential across various food applications, particularly those involving retort processing (Hsieh et al., 2019).

Table 9. Influence of Tapioca Starch on the Quality of Retort Processed Foods

Study	Key Findings	Impact on Retort Processed Foods
Hsieh et al., 2019	Unmodified waxy tapioca starch produces thick, clear pastes with excellent shelf life and stability under freeze-thaw conditions, showing resistance to retrogradation.	Indicates that unmodified waxy tapioca starch can be used in frozen or refrigerated foods without needing chemical or genetic modifications, suitable for retort processing due to its stability and durability.
Dinakaran et al., 2017	Processing tapioca in retort at 121.1°C for optimized times leads to decreased hardness and chewiness, enhancing the texture suitable for retort foods.	Shows that optimized retort processing parameters can improve the texture of tapioca-based dishes, making tapioca starch a versatile option for retort applications.

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3. MATERIALS AND METHODS

3.1 Ingredients (materials)

Food-grade ingredients were sourced from Amazon for our formulation: water, modified corn starch (1.90%), modified potato starch, native rice starch, modified tapioca starch, grated Parmesan, grated Romano, cheddar cheese, non-grated Parmesan, unsalted butter, heavy cream (36% fat), fine sea salt, white pepper powder, disodium phosphate, emulsa enzyme-modified egg yolks, natural lactic acid, and xanthan gum.

3.2 Methods

3.2.1 Alfredo sauce preparation

Different starch types (modified corn starch, modified potato starch, native rice starch, modified tapioca starch) were individually hydrated (26.32%) in water to initiate the sauce preparation. A consistent starch concentration of 1.90% (as a reference from commercial Alfredo sauce) was maintained for each starch type in this study. For the Alfredo sauce preparations, the first melted butter and heavy cream were mixed. The cheeses were added incrementally to the mixture to ensure a consistent melt without fat separation. Further, the egg yolks, pre-tempered with a portion of the heated cream mixture, were steadily incorporated under continuous agitation to prevent protein denaturation. This was followed by the introduction of the measured dry ingredients (sea salt (0.22%), pepper powder white (0.02%), disodium phosphate (0.45%), and black pepper (0.14%) and the xanthan gum emulsifier (0.18%), ensuring an even distribution throughout the sauce. The sauce was then heated to 180°F for 10 minutes and cooled to 120°F (flow chart 1).

Further investigation was conducted to closely match the viscosity characteristic of commercial Alfredo sauce by examining the selected starch types. At levels of Tapioca (3%), Corn (1.9%), Rice (2.5%), Potato (2.38%). This aspect of the study aimed to identify which starch, at the specified concentration, would best replicate the desired commercial sauce's texture and consistency. Additionally, the impact of these starches on heat penetration within the sauce was analyzed.

3.2.2 Retort pouches and thermocouple preparation

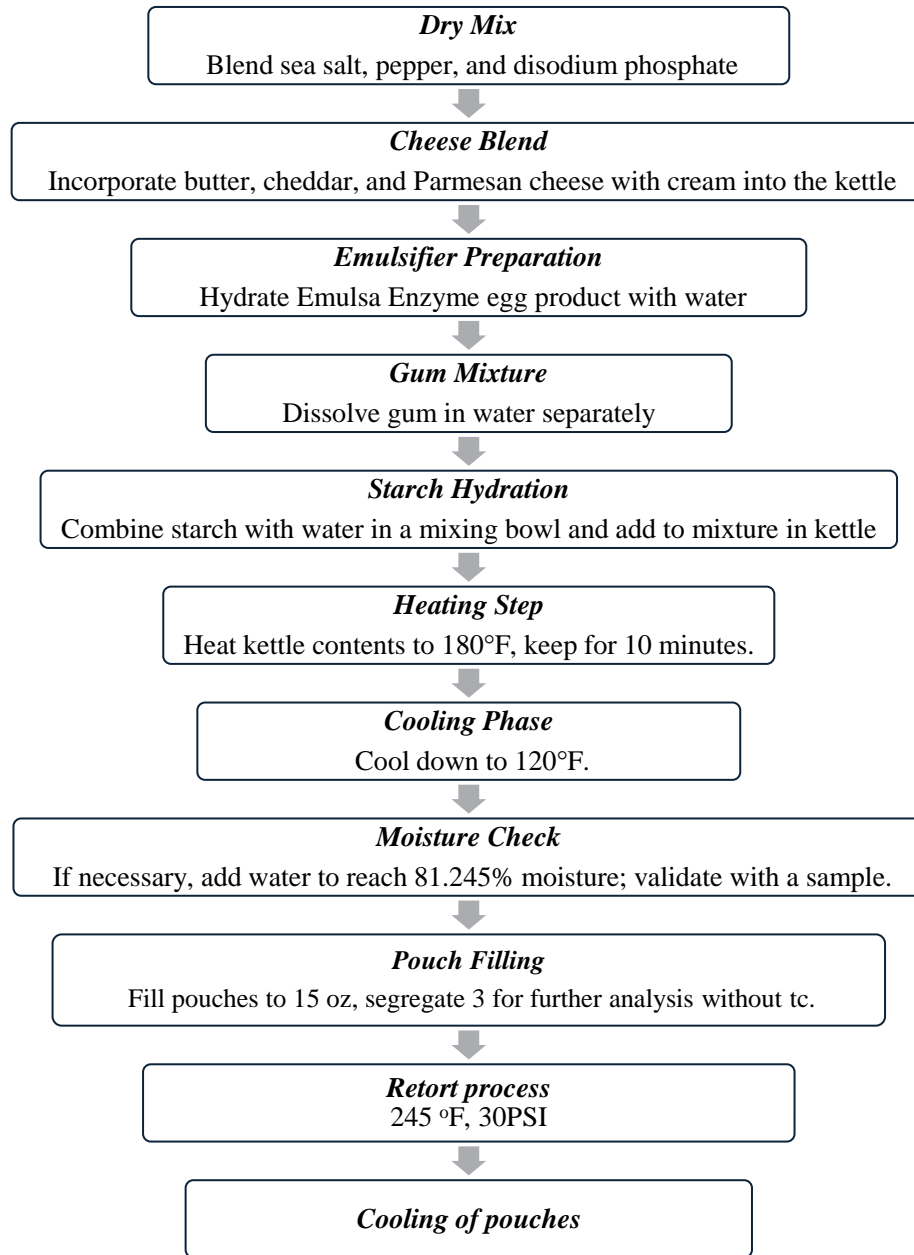
For the experiment, a total of 176 retort pouches with dimensions of 8x8 inches (W × L) manufactured by HPM Global Inc. were used (figure 5). For each starch type, 22 pouches were used, 16 pouches equipped with thermocouples, and six pouches without thermocouples were set aside for further analyses. Each pouch exhibited the laminate composition from the outermost to innermost layers: a layer of poly(ethylene terephthalate) PET, followed by an Aluminium layer, a nylon layer, and a layer of retortable cast polypropylene (CPP). Heat penetration was monitored in thermocouple pouches, each fitted with a type T Lead wire from Ecklund Harrison thermocouple in the geometric center of the pouch with a thermostable plastic washer (Fort Myers, Fla., USA) connected to a CALplex™ data logger (TechniCAL, Metairie, La., USA). Two free lead wires were strategically placed in the center of the rack amidst the filled and sealed pouches, ensuring accurate data collection of internal retort temperature.



Figure 5. Thermocouple in container

3.2.3 Packaging (Pouch filling)

Retort pouches with and without thermocouples were filled with Alfredo sauce containing 15oz and sealed using an impulse heat sealer (Toyo Jidoki Co., Tokyo, Japan) set at 275°F. The sealing procedure involved a 2-second heating time and a 1-second cooling time. After sealing, the pouches were cooled before the retort process.



Flow chart 1. Elaboration process of alfredo sauce

3.2.4 Retort Processing

A Sundry AO-142 two-basket water spray retort (Stock America, Grafton, Wis., USA) was used for the retort processing following the retort process conditions detailed in Table 10, designed for oscillating motion at 10.5 rpm and a

15° angle. The configuration of each retort basket was precise: 13 racks measuring 95.88 cm x 99.69 cm x 6.35 cm (WxLxH), all facing the retort door. For each batch, the 10th rack, closest to the door, held eight pouches, complemented by three additional pouches without thermocouples (figure 6).



Figure 6. Arrangements of pouches filled with alfredo sauce in the retort.

Table 10. Alfredo sauce retort recipe

Process Phase	Temperature (°F)	Pressure (PSI)	Temperature Ramp (°F min⁻¹)	Pressure ramp	Duration (min)	Rotor Speed (rpm)	Oscillation (°)
Come Up	180	15	18.3	3	5	10.5	15
	246	25	22	1.67	6	10.5	15
	245	30	1	5	1	10.5	15
Hold	245	30	0	1	19-27	10.5	15
Cooling	180	25	6.5	0.5	10	10.5	15
	80	15	7.3	1	11	10.5	15
	70	10	2	1	5	10.5	15

3.2.5 Calculating processing times.

Mean processing durations were established using CALsoft™ software, which applied Ball's formula method. Ball's formula is a critical component in thermal processing, particularly for calculating the necessary time to achieve a specified level of microbial inactivation in food products (Ball, 1927). Utilizing this method with CALsoft™ software was instrumental in accurately determining the processing times for each treatment combination, an essential factor in ensuring the safety and quality of the Alfredo sauce.

3.2.6 Viscosity

The viscosity of the Alfredo sauce was measured using a Brookfield Dial Reading Viscometer (Model LVTD CP; Middleboro, Mass., USA). The measurements were taken at a room temperature of 21 ± 2.2 °C, with spindle #4 rotating at a speed of 2.5 rpm. After allowing the sauce to stabilize for 5 minutes its viscosity was recorded. To ensure consistency these measurements were conducted both before and after the retort processing. A 250mL beaker to hold the sauce

samples fully immersing the spindle at the designated notch mark. For each batch of Alfredo sauce performed three viscosity measurements to ensure reliable data.

3.2.7 Color

To analyze the color properties of the Alfredo sauce before and after retort processing, it was employed a HunterLab™ Aeros Spectrophotometer (Reston, VA). Using the L* a* b* color space to evaluate its color characteristics. In this color space the L* value indicates how light or dark an object appears on a scale from black (0) to white (100) allowing us to assess brightness levels in the sauce. The a* value represents an axis that helps determine whether there are green tones present, in the sample, and the b* value is associated with yellow or blue shades (Stafford et al., 2022).

3.2.8 Statistical analysis

Statistical calculations were performed using JMP® software PRO 17.0.0. Comparisons among starches were conducted using ANOVA, and LSMEANS were employed to compare specific starches at a significance level of $\alpha=0.05$.

4. RESULTS AND DISCUSSION

4.1 Same starch concentration

4.1.1 Visual inspection

The retort processing of Alfredo sauce, containing a standard starch concentration of 1.90%, has distinctive impacts on the gelatinization and subsequent textural properties of different types of starches: modified corn, modified tapioca, native rice, and modified potato (figure 7).

Arocas et al. (2010) provides insights into the behavior of corn starch in sauces under extended cooking times, indicating that corn starch experiences significant granule swelling and solubilization of starch polymers, contributing to a continuous phase and potentially enhancing the creamy texture of Alfredo sauce post-retort. This aligns with the expected complete gelatinization of modified corn starch, which forms a stable, continuous network for the sauce's texture and visual appeal.

Modified tapioca starch, known for its high amylopectin content, is likely to exhibit increased translucency and reduced retrogradation, as noted by Jane (2009). This characteristic would contribute to a glossy appearance and smooth texture in retorted Alfredo sauce, aligning with findings from Lubowa et al. (2018) that high-amylose starches can influence the texture and brightness of noodle products, suggesting a similar impact in sauce applications.

The inherent larger granule size of modified potato starch means it significantly contributes to sauce viscosity upon gelatinization. The research by









Arocas et al. (2010) indicates that potato starch is profoundly affected by cooking times, undergoing complete disruption after extended heat treatment, which could lead to a pronounced thickening effect in Alfredo sauce, beneficial for achieving a dense consistency.

The minimal change in translucency but increased surface smoothness of native rice starch post-retort suggests partial gelatinization, which may limit its capacity to contribute to sauce viscosity, as highlighted by Kong et al. (2015). This characteristic requires a careful balance with other ingredients to achieve the desired consistency in the sauce.

The interplay between starch type, modification, and retort processing conditions underscores the complexity of achieving desired textural and rheological properties in retorted food products like Alfredo sauce. The partial gelatinization observed at specific precooking temperatures (Koyama et al., 2012) highlights the potential to control the viscosity and texture of starch-containing retort foods through strategic precooking operations.

Comparing these observations with Mandlawy's findings and other research, it is evident that the extent and nature of gelatinization, and thus the final properties of starch in retorted products, depend significantly on the type of starch, its origin, and modification. The structural differences between amylose and amylopectin, the granule size, and the presence of other components such as lipids and proteins can influence water interaction, thermal properties, and the overall behavior of starch during retort processing (Mandlawy, 2013).

Figure 7. Visual inspection

Starch	Pre-retort	After-process
Modified Corn		
Modified Tapioca		
Modified Potato		
Native Rice		

4.1.2 Heat penetration analysis

Different types of starch, including corn starch, modified tapioca, modified potato, and native rice, each bring unique properties to the sauce. For instance, corn starch is known for its ability to thicken and create a texture, while modified tapioca starch can give the sauce a glossy finish and freeze-thaw stability. Modified potato starch adds a hearty texture, while native rice starch contributes to a light consistency (Mishra & Rai 2006).

Heat penetration analysis is an integral part of understanding the thermal behavior of starches in food products, especially during the retort process. Different starches have properties and undergo specific modification processes, resulting in distinct thermal behaviors during cooking or processing (Yashini et al., 2022). These behaviors directly impacts the final texture, consistency and overall quality of the food product (Oyeyinka et al., 2021). Conducting studies on heat penetration is crucial when changing starch composition in food products. Wang et al.

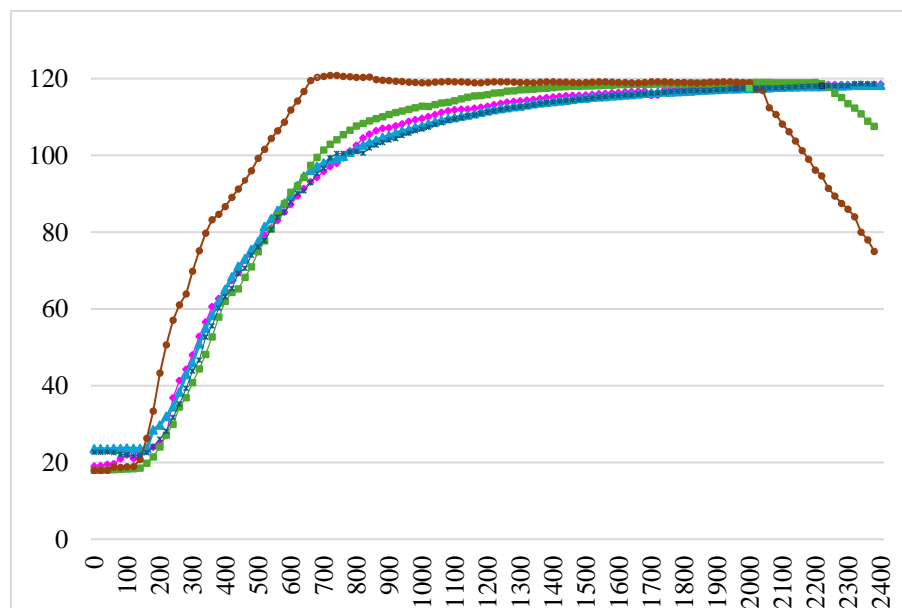


Figure 8. Mean heat penetration curves with same starch concentration

(2021) emphasized that even slight modifications in starch structure caused by processing can significantly affect its properties and heat transfer efficiency. Modified corn, tapioca, native rice, and potato starches, all with the same concentration (1.90%), provide an illustrative example of how variations in starch structure and processing can lead to differences in cooking times and heat penetration rates.

Figure 8 illustrates differences in thermal behavior among types of starch. Modified tapioca starch appear to have a slower heat transfer rate, necessitating up to 38.38 minutes to reach target $F_0=6$. This is likely due to the complex internal structure of the starch gel arising from dual modifications, which should foster the formation of amylose-lipid complexes. Such modifications have been shown to elevate the pasting temperature and enhance thermal stability, as highlighted by Yassaroh et al. (2019). The creation of a more thermally stable network within the granules, as discussed by Pérez & Bertoft (2010), coupled with increased granule size and a higher degree of molecular branching, significantly hinders rapid heat penetration. This is because the structural changes induced by thermal processing, such as gelatinization and retrogradation, alter the molecular architecture of starch granules, increasing their resistance to breakdown under heat (Wang et al., 2021). Moreover, the modifications resulting from thermal treatment, like enhanced granule aggregation and altered crystallinity, contribute to this phenomenon by creating a structure that slows down heat transfer throughout the starch matrix (Zou et al., 2019). These factors collectively extend the cooking duration required for

sterilization, offering potential benefits for product stability and texture. On the contrary, modified potato and corn starches exhibit a markedly faster heat penetration, with cooking times of 31.93 and 31.33 minutes, respectively. This efficiency is attributed to structural modifications, such as cross-linking and hydroxypropylation, which are known to enhance water interaction and solubility, thereby facilitating quicker heat conduction. The research by Singh, Kaur, & McCarthy (2007) underscores how such modifications contribute to the starches' improved thermal processing characteristics. Moreover, the study by Tong et al. (2023) suggests that granule size variation in potato starch influences functionality, particularly swelling power and solubility, further affecting thermal behavior. Native rice starch is distinguished by its slightly shorter cooking time of 36.75 minutes, thanks to an optimal balance between granule size and amylopectin ratio. This balance ensures efficient heat penetration and gelatinization, crucial for achieving desired cooking and texture outcomes. As noted by Juliano (1984) and Tester and Debon (2000), the inherent structural attributes of rice starch significantly contribute to its favorable thermal processing behavior, emphasizing the importance of starch selection based on intrinsic properties. Mandlawy (2013) expands the discussion to the post-retort processing phase, examining how the viscosity, texture, and overall quality of soups containing these starches vary. The findings indicate that native potato starch experiences significant breakdown during retort processing, affecting viscosity. In contrast, modified starches maintain higher viscosity levels post-retort, highlighting the role of starch modifications in preserving product consistency and quality during and after thermal processing.

Table 11. Average holding times (Pt) for different starches

Starch	Hold time (Pt-min)
Modified Tapioca	38.38 (± 4.06) ^a
Native Rice	36.75 (± 1.92) ^b
Modified Potato	31.93 (± 1.88) ^c
Modified Corn	31.33 (± 1.05) ^c

For all variables with different letter, means the difference between the means is statistically significant ($p < 0.05$).

4.1.3 Viscosity Analysis

Corn starch's dramatic increase in viscosity after retort processing, from 3,328 cP to 13,296 cP, can be primarily attributed to its amylose content. Amylose is known for its propensity to leach out of starch granules and interact with water to form a gel network. This process is particularly pronounced under the high-temperature and high-pressure conditions of retort processing, which not only accelerates gelatinization but also promotes the rapid formation of a robust gel network. Such networks are integral to the texture and stability of food products, offering increased resistance to mechanical stress and deformation (Jane, 2009; Singh & Kaur, 2009). Research by Sulaiman and Dolan (2013) indicates that the gelatinization rate constant and gelatinization activation energy are significantly affected by amylose content, highlighting the impact of amylose on the pasting characteristics of corn starch.

The significant viscosity increase observed in modified tapioca starch post-retort processing, as illustrated by Guinee, O'Brien, and Dawe (1994), could be attributed to its resilience and structural adaptability to thermal processing. The formation of amylose-lipid complexes, which is a characteristic attributed to the dual modifications of tapioca starch, plays a significant role in this behavior. These

complexes enhance the thermal stability of the starch, contributing to the maintenance of sauce consistency under retort conditions. Additionally, the capacity of modified tapioca starch for substantial water retention, as noted by Mishra and Rai (2006), further suggests its ability to increase viscosity by swelling. This characteristic makes modified tapioca starch particularly suitable for sauces requiring consistent texture and viscosity after thermal processing.

Rice starch, with its increase in viscosity from 3,616 cP to 9,696 cP post-retort processing, showcases a balanced amylopectin ratio conducive to efficient gel network formation. This balance ensures that the gel network is strong enough to contribute to the desired textural properties without becoming overly firm or gelatinous. The efficient heat distribution during gelatinization, characteristic of rice starch, further aids in achieving a uniform texture, making it particularly suitable for delicate sauces and dressings where a smooth consistency is paramount (Tester & Morrison, 1990).

Potato starch presents a modest viscosity increase following retort processing, from 1,200 cP to 4,656 cP. This behavior can be attributed to its larger granule size and high amylopectin content, which lead to a thicker gel formation, albeit less pronounced than in other starch types. The unique structural characteristics of potato starch, including its granule morphology and amylopectin branching pattern, influence its gelatinization and retrogradation behaviors, impacting the final viscosity and texture of food products (Eliasson & Gudmundsson, 2006). Studies like that by Basilio Cortés et al. (2019) underscore the importance of structural properties in preserving starch functionality during

intense processing, suggesting that modified tapioca starch is suitable for products requiring consistent texture and viscosity over extended storage periods.

Table 12. Comparative analysis of viscosity changes in different starches due to retort processing

Starches	Viscosity Before retort (cP)	Viscosity After retort (cP)
Modified Tapioca	3,440 (± 456.30) ^a	8,176 (± 321.76) ^c
Modified Corn	3,328 (± 329.84) ^a	13,296 (± 575.03) ^a
Native Rice	3,616 (± 386.50) ^a	9,696 (± 494.66) ^b
Modified Potato	1,200 (± 417.22) ^b	4,656 (± 341.76) ^d

For all variables with different letter, means the difference between the means is statistically significant ($p < 0.05$).

Tapioca starch significant increase in viscosity post-retort aligns with Koyama et al. (2012), who explored the effect of partial gelatinization on retort product viscosity. Tapioca's superior performance can be linked to its structural integrity under thermal stress, which partially gelatinizes without losing its thickening power, hence maintaining a high viscosity.

Corn starch robust viscosity increase, although slightly lower than tapioca's, supports the findings of Ramaswamy et al. (1993), which discussed the influence of thermal processing on starch-based products' viscosity. Corn starch's modified forms likely offer enhanced thermal stability, suggesting that certain chemical modifications can optimize its performance under retort conditions.

Rice starch performance reflects the insights from Abbatemarco & Ramaswamy (1993), highlighting that starch concentration and thermal processing significantly impact gelatinization and viscosity. The moderate increase in viscosity post-retort suggests that rice starch's gelatinization is less influenced by retort conditions, possibly due to its lower amylose content and unique granule structure.

Potato starch commendable viscosity increase, despite a lower concentration, can be linked to its high amylose content, resonating with Ramaswamy et al. (1993). This indicates that potato starch's molecular structure may be more conducive to forming stable gels under retort conditions, suggesting that its modifications could further enhance this property.

4.1.4 Colorimetric Analysis

The study focused on examining the color properties of starches. After undergoing retort processing. Specifically samples were analyzed for L^* , a^* and b^* values, which indicate lightness and chromaticity. The L^* value represents lightness, a^* corresponds, to the spectrum green-red and b^* relates to the blue-yellow spectrum. It is important for consumer acceptance and product appeal that these color parameters remain stable after processing. The findings revealed that retort processing had an impact on the color values of starches with variations observed depending on how they were exposed to heat during processing. Modified corn starch initially had an L^* value of 92.27 which slightly decreased to 90.50 after retort processing indicating that its color remained relatively stable under conditions (see Table 5). The changes in a^* and b^* values for corn starch were minimal suggesting that there may have been some caramelization or due to a possible maillard reaction. On the hand modified potato starch experienced noticeable changes after undergoing retort processing; a decrease in its L^* value from 90.49 to 86.43 reflecting a darker sauce, an increase in its a^* value from 3.04 to

3.41 reflecting more reddish color and an increase in its b^* value from 15.69 to 19.08 as a result of a more yellow sauce after thermal process.

These changes indicate a change in color profile likely caused by alterations, in pigments during retort process. Based on the research conducted by Simpson et al. (2020) it is consistent, with their findings that thermal process leads to changes in color. The native rice starch experienced color changes with a decrease in the L^* value from 88.68 to 83.25 and increases in both the a^* and b^* values indicating caramelization effects. These extensive color changes can be attributed to the hold time of 36.75 minutes for the rice starch as supported by Dixon et al. (2020) study on the stability of processed rice. Modified tapioca starch had had a hold time of 38.38 minutes and showed moderate color changes with a decrease in the L^* value from 88.41 to 85.38 and increases in both the a^* and b^* values. This suggests that there was a transformation within the structure of tapioca starch possibly due to its ability to maintain structural integrity during processing

as indicated by Benjakul et al. (2018) findings on thermal treatments impact on bioactive compounds in food.

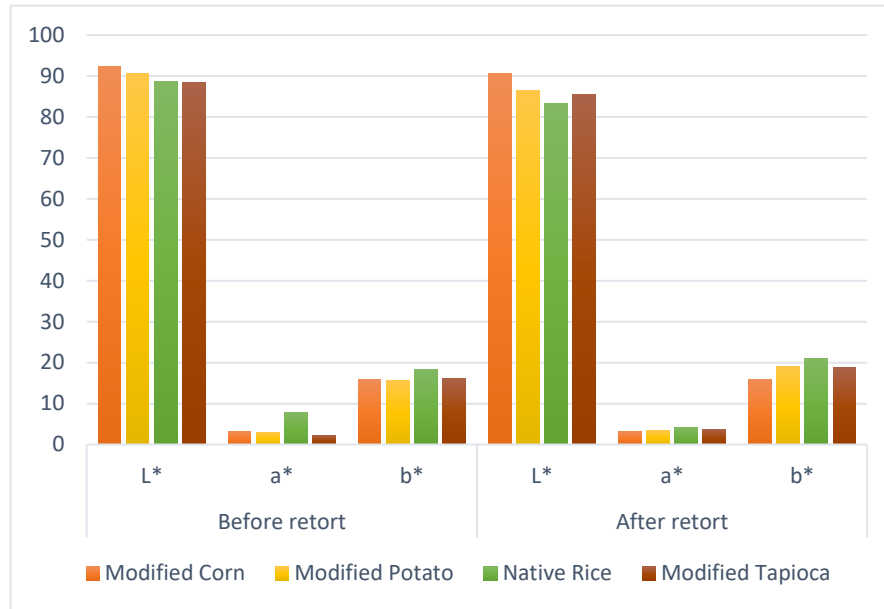


Figure 9. Color changes before and after retort for each starch.

After considering the viscosity properties it seems that using rice starch as a substitute for corn starch would be the best option. It has an increase in viscosity, which's like corn starch compared to modified potato starch. Additionally, its hold time is longer than corn starch but closer to modified tapioca starch, however still significantly different. Overall, modified potato starch has the potential to offer a balance of rheological properties and holding time during retort processing, like corn starch. This ensures a suitable texture without compromising the safety of the sauce. This substitution is supported by the mild increase in viscosity following a retort, which indicates the ideal thickening action and the required sauce texture. These qualities are crucial in culinary applications where texture and consistency greatly influence consumer acceptability and preference.

4.2 Analysis of viscosities at different starches concentration

The preliminary analysis of viscosities at different starch concentrations after retort processing involves understanding how various types of modified and native starches behave under specific conditions. In the context of starch behavior, viscosity is a key parameter that influences the textural properties of food products. Starch gelatinization, which occurs during retort processing (a method of sterilization involving high temperature and pressure), significantly affects the viscosity of starch-containing products. This change in viscosity is associated with the physical changes that starch undergoes during gelatinization, leading to an increase in viscosity. The type of starch (corn, tapioca, potato, rice) and its concentration significantly influence these changes. For example, research has shown that at a fixed starch concentration, corn gel displayed the highest viscosity, which can slow down the enzymatic hydrolysis of the starch. Higher viscosity was found to enhance the amount of slowly digestible starch (SDS) and reduce the kinetic constant of hydrolysis. However, when gels were prepared with constant viscosity across different starch types, the hydrolysis kinetics tended to be comparable, indicating a complex interaction between starch concentration, viscosity, and hydrolysis rate (Santamaría et al., 2022).

Another study focused on the pasting and rheological properties of gluten-free gels from different botanical origins (maize, rice, wheat, potato, tapioca) at various concentrations. This research aimed to understand how starch concentration and properties such as amylose content, thermal and hydration properties, affect the pasting and viscoelastic properties of starch gels. For instance, wheat starch,

followed by normal maize and rice starches, exhibited a greater capacity to modulate their gels' pasting and viscoelastic properties through concentration adjustments in water. Interestingly, waxy starches and those from potato and tapioca showed minimal changes in pasting properties with concentration adjustments, though potato and tapioca gels exhibited significant changes in their viscoelastic properties as a function of concentration. This suggests a nuanced relationship between starch type, concentration, and the resulting textural properties of the gels, which is critical for designing food products with specific texture requirements (Mauro et al., 2023).

Table 13. Sauce Viscosity at Various Concentrations of Different Starches

Starches	Viscosity (cp)			
	1.90%	2.50%	3%	3.50%
Modified Corn	13,296 (±575.03) ^a	14,240(±276.29) ^b	15,200(±217.18) ^b	17,056(±522.34) ^c
Modified Tapioca	8,176(±321.76) ^c	12,000(±277.41) ^d	14,400(±186.75) ^d	17,696(±624.65) ^c
Modified Potato	4,656(±341.95) ^d	24,000(±167.33) ^a	51,200(±172.35) ^a	59,200(±193.32) ^a
Native Rice	9,696(±494.66) ^b	13,600(±308.63) ^b	16,400(±395.67) ^c	20,800(±275.88) ^b

For all variables with different letter, means the difference between the means is statistically significant ($p < 0.05$).

The first letters show the differential between same starches across treatments.

Second letters show differential between samples at same level of concentration.

4.2.1 Heat penetration analysis at different concentration of starches

Comparatively, the data reflects the diverse gelation behaviors of different starch types at varying concentrations, influenced by their molecular structure, modifications, and interactions with water. The variability in hold times across concentrations and starch types underscores the importance of selecting the appropriate starch type and concentration for specific applications, balancing

factors such as gel strength, elasticity, and syneresis. Research such as that conducted by Lin et al. (2023) provides valuable insights into optimizing starch-based formulations for food and pharmaceutical products, emphasizing the impact of hydrocolloid interactions, ethanol exposure, and starch characteristics on gel properties.

Table 14. Different Cooking times of Alfredo Sauce at Different Concentrations of Starches

Starches	Hold time (Pt-min)		
	1.90%	2.50%	3%
Modified Corn	31.33(±2.98)_a^b	36.01(±2.62) _b ^a	35.20(±1.72) _b ^b
Modified Tapioca	38.38(±2.26) _a ^a	38.9(±2.43) _a ^a	39.37(±2.43)_a^a
Modified Potato	31.93(±1.55) _a ^b	34.4(±2.44)_a^b	33.50(±2.07) _a ^b
Native Rice	36.75(±2.81) _a ^a	38.00(±1.78)_a^a	35.60(±2.01) _a ^b

For all variables with different letter, means the difference between the means is statistically significant ($p < 0.05$).

The first letters show the differential between same starches across treatments.

Second letters show differential between samples at same level of concentration.

4.2.2 Heat penetration results

Modified Tapioca Starch, interestingly, has a notable increase in hold time at 2.50% concentration to 38.9 Pt-min before increasing again. This behavior might indicate an optimal concentration for certain desired properties, such as softness or spreadability, before increasing the firmness of the gel. The unique interaction between starch concentration and gel properties has been explored in various

studies, emphasizing the role of starch source and treatment in gelation behavior (Lin et al., 2023; Ekumah et al., 2023).

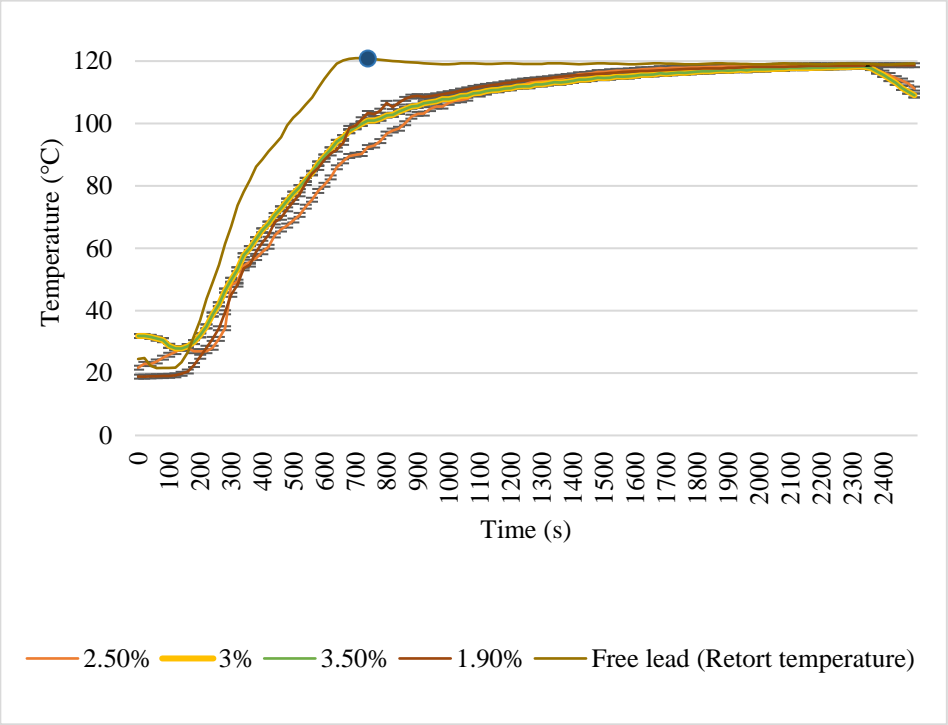


Figure 10. Mean heat penetration curves with different rice starch concentration

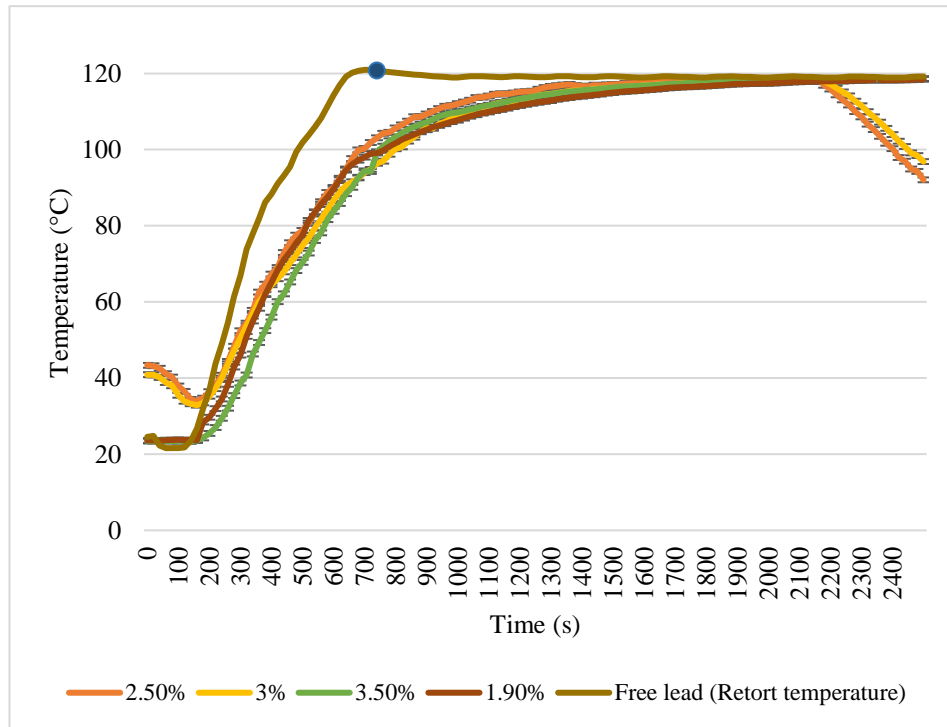


Figure 11. Mean heat penetration curves with different tapioca starch concentration

Modified Potato Starch shows a more gradual increase in hold time with concentration, hinting at a stable gelation process influenced by concentration. Potato starch, known for its high viscosity and gel strength, can be particularly useful in applications requiring thickening and stabilization (Ekumah et al., 2023).

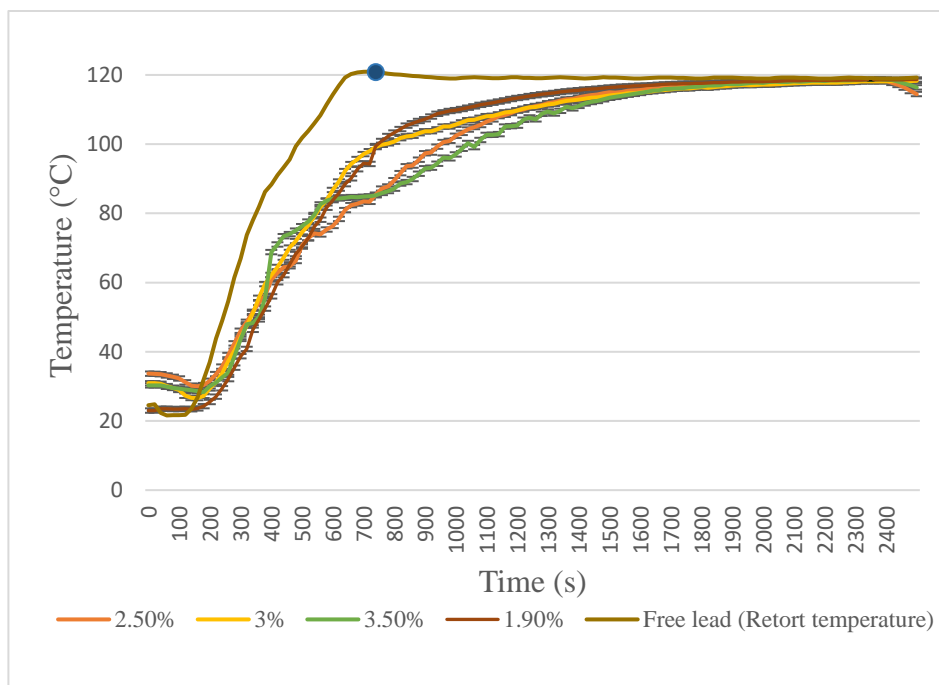


Figure 13. Mean heat penetration curves with different potato starch concentration

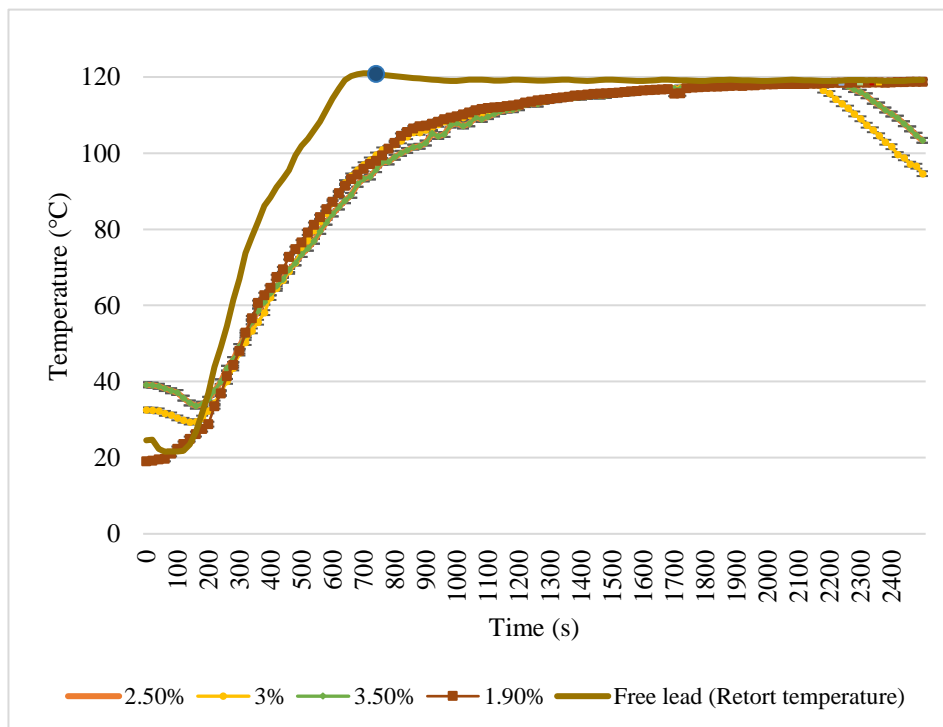


Figure 12 Mean heat penetration curves with different corn starch concentration.

Native Rice Starch presents an interesting pattern where the hold time decreases slightly at 3% before increasing significantly at higher concentrations. This could be attributed to the inherent properties of rice starch, including its amylose and amylopectin content, which affect gelation and retrogradation. The study by Kang et al. highlights the role of ethanol exposure in enhancing the mechanical properties of starch gels, which could also be relevant in understanding the behavior of native rice starch gels.

Modified Corn Starch shows an increasing trend in hold time as the concentration increases, starting from 31.33 Pt-min at 1.90% to 35.4 Pt-min at 3%. This pattern suggests that higher concentrations of modified corn starch result in stronger gels, which is consistent with the findings of Lin et al., who noted that modifications in starch can enhance gel strength, rigidity, and resistance to syneresis, important for product stability and texture (Lin et al., 2023, Tabasum et al., 2019)

Table 15. Comparative analysis of viscosity changes in different starches with different concentrations

Starches	Viscosity After retort
Tapioca (3%)	14,400(\pm 186.75)b
Corn (1.9%)	13,296 (\pm 575.03)b
Rice (2.5%)	13,600(\pm 308.63)b
Potato (2.3%)	16,336 (\pm 612.75)a

For all variables with different letter, means the difference between the means is statistically significant ($p < 0.05$).

Table 16 showcases the average holding times for various starches at different concentrations. The data indicates that Modified Corn and Native Rice

starches exhibit the highest hold times, with statistically significant differences when compared to Modified Potato starch, suggesting superior gel strength and stability under retort conditions. This aligns with the work by Singh, Kaur, & McCarthy (2007), who discussed the enhanced properties of chemically modified starches for food applications, including increased resistance to process stresses such as heat and shear.

Table 16. Average holding times (Pt) for different starches with different concentrations

Starches	Hold time (Pt-min)
Modified Corn (1.9%)	31.33(±2.98)^b
Native Rice (2.5%)	38.00(±2.01) ^a
Modified Tapioca (3%)	39.37(±2.43) ^a
Modified Potato (2.38%)	33.66 (±0.635) ^b

For all variables with different letter, means the difference between the means is statistically significant ($p < 0.05$).

Close performance between Modified Corn and Native Rice starches emphasizes the potential of native rice starch in applications traditionally dominated by modified starches, suggesting a part ripe for further exploration as per the insights by Wang & Copeland (2015) regarding starch structure and functionality.

Color changes before and after retort processing reveal significant variations across different starch types, as indicated by the L* (lightness), a* (red-green), and b* (yellow-blue) values. The observed changes in color metrics post-retort suggest alterations in the optical properties of starch gels, likely due to chemical reactions such as Maillard browning or caramelization under the high-temperature conditions of retort processing. Particularly, Modified Corn and Modified Tapioca exhibit significant

changes in lightness and hue, with the Modified Tapioca showing the least change in lightness (L*) and maintaining higher yellowness (b*) values. These findings reflect the differential impact of starch source and modification on color stability under retort conditions, a critical factor for product appeal. Subroto et al. (2023) discuss how acetylation and other modifications can impact the physicochemical properties of starches, potentially influencing their color stability during processing.

Table 17. Color changes before and after retort for each starch with different concentrations

Starches	Before retort			After retort		
	L*	a*	b*	L*	a*	b*
Modified Corn (1.90%)	92.27 ^a _a	2.84 ^a _a	15.78 ^d _a	90.50 ^a _a	3.18 ^b _b	15.98 ^d _b
Modified Potato (2.3%)	89.09 ^b _a	2.70 ^c _a	15.53 ^c _a	84.96 ^c _b	4.32 ^b _b	19.45 ^b _b
Native Rice (2.5%)	88.13 ^c _a	2.73 ^b _a	17.54 ^a _a	85.45 ^b _b	3.84 ^c _b	19.15 ^c _b
Modified Tapioca (3%)	89.02 ^b _a	2.84 ^a _a	16.99 ^b _a	83.67 ^d _b	4.47 ^a _b	20.14 ^a _b

For all variables with different letter, means the difference between the means is statistically significant ($p < 0.05$).

The first letters show the differential between same starches across treatments.

Second letters show differential between samples at same level of concentration.

The statistical significance ($p < 0.05$) across different treatments underscores the importance of starch type and modification in achieving desired product characteristics, with implications for texture, stability, and color. Masina et al. (2017) review chemical modification techniques, highlighting the versatility of starch modifications in tailoring properties for specific applications. Additionally, the work by Zavareze & Dias (2011) on the impact of heat-moisture treatment

further elaborates on how physical modifications can affect starch properties, including color and gelatinization behavior.

4.2.3 Visual inspection different concentration

Modified Corn Starch (1.90%) and Modified Tapioca (3%): Both modified corn and tapioca starches at a concentration of 3% undergo significant gelatinization during retort processing. Li et al. (2015) demonstrated that high starch concentrations can inhibit the swelling and disrupt starch granules, retaining starch crystallinity after heat treatment. This inhibition is crucial for ensuring the consistency and stability of Alfredo sauce, as overly disrupted starch granules could lead to an undesirable texture. Modified corn starch, known for its efficient thickening properties, likely contributes to a creamy and homogeneous sauce texture. Modified tapioca starch, with its high amylopectin content, might offer enhanced translucency and stability, resulting in a glossy sauce appearance post-retort.

Modified Potato Starch (2.38%): The slightly lower concentration of modified potato starch (2.38%) is expected to gelatinize effectively during retort processing, contributing to the sauce's viscosity. Potato starch's larger granule size can lead to a more pronounced thickening effect, beneficial for sauces requiring a dense consistency. However, Roberts & Cameron (2002) highlighted that starch concentration impacts gelatinization in the presence of additives, suggesting that the interaction of potato starch with other sauce components could influence its gelatinization behavior and the final sauce texture.

Native Rice Starch (2.5%): At a concentration of 2.5%, native rice starch might exhibit partial gelatinization due to its smaller granule size and higher crystallinity. This partial gelatinization suggests that native rice starch could contribute less to the sauce's viscosity compared to its modified counterparts. Baks et al. (2008) discussed the complex model required to describe gelatinization as a function of pressure, temperature, and starch concentration, indicating that native rice starch's behavior in Alfredo sauce could vary significantly based on processing conditions.









Starches	Pre-retort	After-process
Modified Corn (3.5%)		
Modified Tapioca (3.5%)		
Modified Potato (2.38%)		
Native Rice (3.32%)		

Figure 14. Visual inspection

5. Conclusion and Future Perspective

Modified corn starch is a common thickening agent used in Alfredo sauce due to its stability under retort processing conditions. However, market variability necessitates the exploration of alternatives. Native rice starch emerges as a viable option at same concentration analysis, presenting a moderate increase in viscosity that more closely aligns with that of corn starch compared to modified potato starch. While it requires a longer hold time than corn starch, it is still less cooking time than the needed for modified tapioca starch.

On the other hand, based on product safety modified potato starch offers a promising replacement at a similar concentration to the commercial standard for corn starch (1.90%). It achieves the right balance between color stability, and not difference in traditional cooking time in retort process used for alfredo sauce.

Considering commercial success, Rice starch at a 2.5% concentration reaches the viscosity essential for commercial standards, though it mandates an increase in cooking time to ensure food safety standards are met. This substitution aligns with current market trends and consumer expectations, offering a pragmatic solution in the face of fluctuating market conditions.

Future research is recommended to analyze the impact of varying starch concentrations on the sensory properties and shelf-life of food products. Investigations could provide valuable insights into how different starch types and concentrations influence the texture, taste, and stability of foods like Alfredo sauce. The outcomes of

such studies could offer comprehensive guidelines for starch selection, aiming to improve product quality, consumer satisfaction, and food safety in the food industry.

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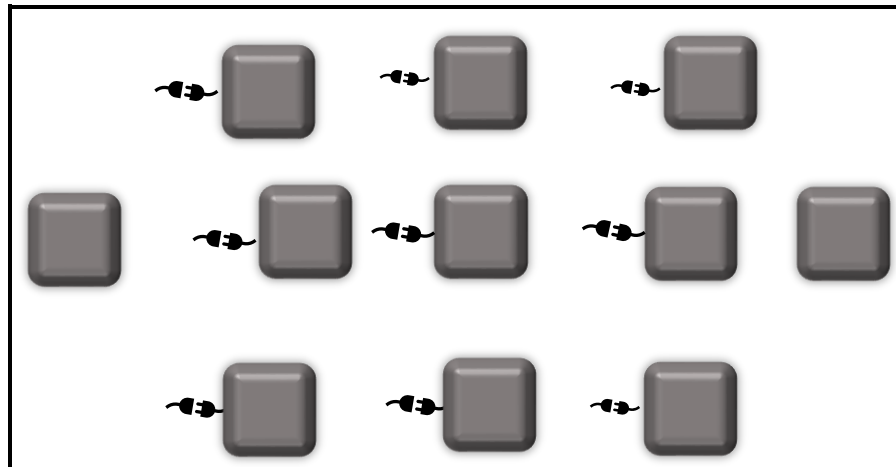
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APPENDIX A: Heat penetration location of thermocouples in retort basket



APPENDIX B: pH levels before and after process alfredo sauce

