Journal of Food Science and Technology (Iran)

Homepage:www.fsct.modares.ir

Scientific Research

The effect of ultrasound treatment on the physicochemical, rheological and structural properties of starches extracted from different legumes

Mohammadkazem Heydarian[1], Alireza Heydarian[2], Seyed Ali Mortazavi[*3]

1- Master's student, Department of Food Science and Engineering, Technology, Ferdowsi University of Mashhad, Mashhad, Iran

2 -Master's student, Educational Department of Food Science and Engineering, Biotechnology, Ferdowsi University of Mashhad, Mashhad, Iran

3- Professor, Department of Food Science and Engineering, Faculty of Agriculture, Ferdowsi University of Mashhad, Mashhad, Iran.

ABSTRACT

Starch is the most abundant carbohydrate in legumes. On the other hand, due to its non-reactive nature and insolubility in cold water, natural leguminous starch has limited use in the food industry. Natural legume starch can be modified by chemical, physical, and enzymatic methods. Modified legume starches have gained importance in the food industry due to their improved functional properties. Ultrasound is one of the physical methods of starch modification examined in this article. Also, ultrasound is increasingly used as a green technology for the physicochemical modification of food systems. This study aims to investigate the effect of ultrasonic treatment (bath-probe) on the functional, rheological, thermal, morphological, and crystal structure characteristics of modified starch samples. The change in the properties of ultrasonically modified starch is mainly due to the depolymerization of amylose and amylopectin chains. After ultrasound treatment, molecular weight, viscosity, and crystallinity decrease; Therefore, it can be concluded that ultrasound is an alternative technology for modifying the properties of leguminous starch.

ARTICLE INFO

Article History:

Received:2023/5/7
Accepted:2023/6/13

Keywords:

Legume starch,
ultrasound,
modification,
cavitation.

DOI: 10.22034/FSCT.20.137.156
DOR:20.1001.1.20088787.1402.20.137.12.2

*Corresponding Author E-Mail:
morteza@um.ac.ir

1- Introduction

1-1- Ultrasonic waves

Ultrasound consists of mechanical waves with a frequency higher than the range of normal human hearing (more than 16 kHz), which has the ability to pass through the environment (gas, liquid and solid) and propagates as sine waves [1].

2-1- Ultrasonic mechanism

Ultrasonic waves, like all sound waves, consist of periods of contraction and expansion, which periods of contraction create a positive pressure on the liquid and bring the molecules closer together, while the periods of expansion create a negative pressure and push the molecules apart, as a result of the unequal mass transfer rate. During the cycle of expansion and contraction, it causes the bubbles to collapse and release energy and the emergence of mechanical effects. On the other hand, sound waves released in the environment cause vibration and displacement of particles, which leads to an increase in pressure and a decrease in density; Therefore, due to the occurrence of cavitation phenomenon[1] There are changes in the physical and chemical properties of materials depending on the process parameters (frequency, power) [2]. On the other hand, ultrasound waves can cause changes in food by creating strong shearing force, increasing temperature and producing free radicals [3].. The effect of ultrasound by the phenomenon of cavitation includes the formation, growth and collapse of bubbles in the liquid medium [4].

3-1-types of ultrasound

Ultrasound waves can be classified into three categories based on their frequency range and power:

1- Low frequency ultrasound (10 to 20 kHz) 2- Medium power and medium frequency ultrasound (1 to 100 MHz) 3- Low power ultrasound with high frequency (more than 1 MHz)

The ultrasound used in the food industry is in the low and high frequency range, and this frequency range is also used as a simple and efficient method for polymer modification [5].

Ultrasound waves can also be classified into three frequency ranges based on application:

1- Power ultrasound[2] (6 to 100 kHz) 2- High frequency ultrasound[3] (100 kHz to 1 MHz) 3- diagnostic ultrasound[4] (1 to 10 MHz) [6].

4-1- Ultrasound equipment

Basically, the equipment producing ultrasound waves consists of an electric generator, a transducer and an emitter (Sonotrode[5] or probe) waves are formed, and in this system, the generator is responsible for supplying the system with energy. On the other hand, the transducer is responsible for converting electrical energy into sound energy through mechanical vibrations. Also, transducers can be divided into two categories: piezoelectric and magnetic. The wave emitter is responsible for emitting sound waves in the environment and is in direct contact with the fluid. Ultrasonic probe containing It is a piezoelectric crystal that is inside a metal shield and is narrowed at the end in order to increase the intensity of the waves produced by this probe [7]. The application of electric waves causes mechanical vibrations in the crystal Piezoelectricity and the production of ultrasound waves. The produced ultrasound

[1] - Cavitation

[2] - Power ultrasound

[3] - High-frequency ultrasound

[4] - Diagnostic ultrasound

[5] - Sonotrode

waves are transferred to the tip of the transducer and then transferred to the surrounding liquid medium. On the other hand, the continuous use of ultrasound waves leads to an increase in the temperature of the sample, and to prevent this, it is better to apply the ultrasound waves in a cross (pulse) manner [8]. On the other hand, ultrasonic waves have applications in the field of food processing such as extrusion, defoaming, viscosity change, filtration and separation, crystallization, homogenization and emulsification, extraction and inactivation of enzymes and bacteria [9].

2- Starch

Starch is a renewable, biodegradable polymer and a source of energy storage in plants and is the main component of many food products such as bread and rice. The properties and structure of starch have a significant effect on the quality of food products, and knowing the composition, structure and physicochemical properties of starch helps in the processing and applications of starch for various purposes. On the other hand, starch is an abundant biological molecule that is present in many crops. Starch has two main components, amylose and amylopectin, amylose is a linear polymer with small side branches, which consists of glucan chains with bonds$a(1\rightarrow4)$ It is formed [10]. Amylopectin is a highly branched polymer consisting of short cross-linked glucan chains$a(1\rightarrow4)$formed and their branches by$a(1\rightarrow6)$are connected to the main branch [11]. On the other hand, the properties of amylose and amylopectin have a great effect on the properties of starch, for example, the amount of amylose, in the intertwining between amylose-amylose and amylose-amylopectin, greatly affects the water binding capacity, thermal properties and enzyme sensitivity[12].

Due to its compact structure, starch has various functional properties and applications in different industries. On the other hand, due to its polymeric and branched nature, starch has a relatively low solubility in water and a relatively low ability to absorb water and oil [13]. Starch can form thin layers due to its relatively high viscosity, high swelling power, ability to gelatinize, and high adhesive properties, which make starch an excellent material for various food and industrial formulations in order to increase freeze-thaw stability and It is suitable for storage in cold warehouses. Natural starch is resistant to medium temperature and pressure, but it is sensitive to acid hydrolysis and enzymatic hydrolysis [14].also Starch can be used as a gelling, thickening, stabilizing, and flavor-encapsulating agent in baking, brewing, and confectionery processes, as well as as a coating and film in the food industry [15]. Non-food uses of starch include adhesives for making boards. It is an antifreeze and retarding agent for concrete, as well as fermentation raw materials for pharmaceutical products [16]. The starch market is also expected to grow at an average growth rate of 4.7% during 2020-2030. Market growth is primarily driven by consumer demand, research and development activities, and increasing awareness about the uses of starch [17]. In a recent study, Trade Market Profile(TMR[6]) It indicates that the value of the global starch market in 2020 is estimated to be more than 1.7 billion dollars. According to this report, it is expected that the global market value will exceed 2.7 billion dollars by 2030, with a growth of 4.7%, because starch has many applications in food and non-food industries[18].

On the other hand, legumes are the dicotyledonous seeds of plants that belong to

[6] -Trade Marketing Representative

the leguminous family[7] which includes about 600 genera with 13,000 species and legumes are rich sources of protein, dietary fibers, resistant starch, oligosaccharides and phenolic compounds[19]. Compared to cereals, legumes mainly contain slow-digestible starch, which is the most desirable form of dietary starch because it reduces plasma insulin levels [20]. As mentioned above, the amylose content of starch affects many of the properties of starch. On the other hand, the amylose content of legume starch varies from 18.7% to 49.7%, which is due to genotypic diversity, growth conditions, enzyme activity during starch synthesis, starch extraction method, etc. [21]. Compared to cereal starch, leguminous starch has a lower maximum viscosity and breakdown viscosity, and a higher return viscosity and final viscosity [22]. Also, legume starch has lower solubility and limited swelling power compared to cereal starch. This group of starches has a higher amylose due to a high tendency to staleness (retrogradation).[8]) show [23]. This feature makes legume starch suitable for making gel in many food products. Another difference between legume starch and cereal starch is the higher gelatinization temperature, which is related to the ratio of amylose and amylopectin [24]. On the other hand, this group of starches due to their slow digestion and high content of resistant starch in the food formula with glycemic index(GI) Low and digestible starch are used [25].

According to the wideness of the legume group, the following table briefly mentions the Persian and Latin names of the types of legume:

Table 1 types of legume starch

Types of legume starch sources
Lima bean (Phaseolus lunatus)
Garbanzo bean
Lentil bean
Red kidney bean- Red bean
Cowpea (Vigna unguiculata)
Velvet bean (Mucuna pruriens var. utilis)
Navy bean, Faba bean- Broad bean
Mung bean- Vigna radiata
Pinto bean
Adzuki bean
Field pea
Beach pea
Chickpea ram
Green pear
Soybean
Groundnut- Chickpea Peanut
Sword bean (Canavalia gladiata)
Jack bean (Canavalia ensiformis)
Pigeon pea - Cajanus cajan
Broad bean
White navy beans
Biglobose park
Black gram- Vigna mungo

[7] - Leguminous
[8] - Retrogradatio

Grass pea (Lathyrus sativus)
Bambara groundnut (Subterranean Vine)
Lablab bean (Purple Lablab)
Phaseolus vulgaris common bean
Lupine
Vetches
Bambara beans
Yellow peas

1-2-Modification of starch

Due to intermolecular and intramolecular hydrogen bonds and semi-crystalline structure, natural starch is impermeable to water at ambient temperature and insoluble in cold water [17]. On the other hand, starch easily becomes stale. Therefore, starches should be modified to increase solubility, improve textural properties, and increase heat tolerance for various industrial applications [18].

Starch modification is an important process to increase baking properties, reduce the tendency to staleness, increase freezing and thawing stability, reduce syneresis, improve paste or gel transparency, improve paste or gel texture, improve film formation and adhesion, and improve emulsion stabilization [26]. Also, starch modification not only leads to desirable functional properties of starch, but also makes starch an economical alternative to hydrocolloid compounds such as gums [27]. On the other hand, due to its low resistance to high temperatures, shear force and acid, leguminous starch limits the use of natural starches of this group as a thickening and stabilizing agent in food products such as soup, pudding and fried foods. Therefore, from this group of starches, like the starch of cereals and tubers, they need to be modified [28].

Modified starches from legumes are used in the preparation of several products such as ice cream, baked goods, baby foods, ready-to-eat foods, and foods containing resistant starch.(RS[9]) up withGI bottom, frozen foods, processed foods; Like candy, they have soup, pudding and salad dressing. These modified starches can also be used as thickeners, stabilizers and emulsifiers. The difference in the physicochemical properties of starch determines its specific use [29].

Usually, starch can be modified chemically, enzymatically, physically, or a combination of these three methods [30, 31]. Chemical modification includes oxidation, succinylation, esterification, esterification and phosphorylation [32]. In this starch modification method, by replacing the combination of different functional groups on the starch molecule, it improves the functional properties and changes in the starch gelatinization temperature.pH and rheological properties and pasting properties of starch [31].

Hover[10] et al. (1998), reported that the derivatization of starch molecules with phosphate ester, acetic ester or hydroxypropyl ester groups can prevent staleness, and esterification of legume starches increases dough viscosity, dough transparency, increases water retention capacity, and significantly reduces the amount Synergy and the amount of staleness compared to natural starch, this modified starch can be used in various industries (paper, food) [33].

Huang, on the other hand[11] et al. (2007), pointed out that the derivatization of starch molecules with vanilla acetate in order to increase the swelling power and increase the maximum viscosity can increase the

[9] -Resistant starch
[10] - Hoover
[11] - Huang

freezing stability, transparency and stability of the modified starch gel, which can be used as a thickening agent in the preparation of this type of starch. used baby food and frozen and dry food [34].

Ashogbon on the other hand[12] et al. (2014), found that esterification of natural starch with acetic anhydride or vinyl acetate in the presence of alkaline catalyst can make this modified starch suitable for various functions such as film formation, binding, thickening, stabilization and texture [35]. On the other hand, Galeria[13] et al. (2022), found that cross-linking in pigeon pea starch creates a more stable structure than natural starch. Also, this treatment reduces the clarity of the paste, gel hardness, swelling power, solubility, maximum viscosity, and the amount of staleness, and the paste obtained from starch modified in this way shows high resistance to shear force [36].

The most commonly used chemical modification techniquesand have the most efficiency; But there is a lot of concern about the issues of environmental pollution, wastewater treatment, food safety and high costs related to existing chemical modification methods [37].

An alternative approach is enzymatic modification, which is considered more environmentally safe compared to chemical modification. Amylases are enzymes that are usually used to hydrolyze starch molecules to a low dextrose equivalent, and by breaking the α(1→4) bond between two glucose molecules, they improve starch sweetening capacity, increase browning capacity, and improve gel texture [31]. But the use of dual enzyme modification may involve more measures and costs [38]. what[14] et al. (2009), reported that starch treated with a combination of alpha-amylases and beta-amylases or alpha-amylases and amylglucosidases improves sweetening capacity and browning capacity [39]. Also Hansen[15] et al. (2008), reported that potato, corn and pea starch treated with amylomaltoses improves gel texture (formation of gel network, increase in compression force and little or partial gel breakage) [40]. On the other hand, Ao[16] et al. (2007), found that the enzymatic hydrolysis of starch using amylases leads to a decrease in the digestion rate due to the increase in starch branch density and crystalline nature. Also, enzymatic hydrolysis leads to starch with a low glycemic index, which makes foods suitable for diabetics from this type of starch [41].

Cower[17] et al. (2012), pointed out that the addition of cyclomaltodextrinase enzyme to natural starch due to the cluster-like structure of this enzyme creates a highly branched structure that can delay starch staling [42].

go round[18] et al. (2019), found that the addition of cyclodextrin glycosyltransferase enzyme to natural Bambara peanut starch increases the viscosity breakdown, which leads to a decrease in the ability to shear stress and heat during cooking [43].

Physical modification can be thermal (wet heat treatment, spray drying, pre-gelatinization, etc.) or non-thermal (pulsed electric field, ultrasound, high hydrostatic pressure, cold plasma technology)[19] (CP) and...) be The methods of physical modification of starch are fast and environmentally friendly alternatives without producing chemical residues and

[12] -Ashogbon
[13] - Gloria
[14] - Chiu
[15] -Hansen
[16] - To the
[17] -Kaur
[18] - Group
[19] - Cold Plasma

toxic substances [35]. Physical methods can destroy or influence branching of amylose and amylopectin side chains of starch and influence the shape and size distribution of starch granules [31, 44].Han[20] et al. (2009), reported that pulsed electric field treatment causes reorganization and degradation of starch granules, leading to reduced crystallinity, gelatinization, and viscosity characteristics [45].

On the other hand, in 2017, Bashir et al investigated the effect of gamma radiation (0, 0.5, 1, 2.5, 5 and 10 kGy) on the physicochemical, functional and thermal properties of chickpea starch. The results of this report showed that increasing the dose of gamma radiation decreases the relative crystallinity while maintaining the type diffraction patternC follows Also, increasing the dose of gamma radiation leads to a decrease in maximum viscosity, fracture viscosity, recoil viscosity and final viscosity. On the other hand, this increase in radiation dose increases the solubility index, increases the capacity of water and oil absorption, decreases the amount of staleness, and increases the enthalpy of gelatinization, which means that this modified starch can be used in frozen foods [46].

Gail[21] (2009), reported that sonication can change the morphological characteristics of granules, crystallinity pattern, pasting properties (eg gelatinization), rheological behaviors and other characteristics of starch granules. Also, ultrasonic treatment can cause visible cracks and pores on the granule surface, decrease relative crystallinity, depolymerization, molecular chains, and increase the swelling power and solubility of starch granules from different sources, including corn, rice, wheat, cassava, and potato starch [47, 48].

On the other hand, Dave[22] et al. (2023), reported that moist heat treatment([23]HMT) It causes a decrease in solubility, a decrease in swelling power, a decrease in transparency, a decrease in freeze-thaw stability, and a decrease in the ability of chickpea starch to gel. While this treatment increases thermal stability, increases the content of resistant starch, increases the amount of staleness and synergism, and increases the content of amylose. This modified starch can be used in foods that require limited swelling power, such as noodles, vermicelli, rice noodles, etc., also due to the increase in the content of resistant starch, this treatment can be used to produce resistant starch. Kurd [49]. Therefore, physical modification methods can be declared as successful starch modification methods [50].

3-The effect of ultrasound on starch

Most of the application of ultrasound in starch is in the starch-water system. When the ultrasonic waves pass through the liquid in a sinusoidal manner, the ultrasonic sound energy cannot be absorbed by the molecules, and as a result, it is propagated through a number of rare and compact waves that are created in the molecules of the environment, and then it is converted into a chemically usable form through the phenomenon of cavitation [51].]. This phenomenon in effect

[20] - Him
[21] - Gill
[22] - Of
[23] - Heat-Moisture Treatment

Ultrasonic treatment occurs when the amplitude is high enough to cause bubbles to form in the system. The pressure caused by the wave motion causes the bubbles to grow during the expansion cycle and contract during the compression cycle. The bubbles continue to grow during many cycles, and when they reach a point where the frequency of the ultrasonic oscillation equals the bubble wall, the bubbles explode during the compression cycle [6]. The bursting of bubbles creates very high shear and turbulence with large energy waves and leads to a strong increase in temperature at the local level. This mechanism causes physical and chemical changes in the system. The explosion of the bubbles creates a jet of water to the surface of the granule. These "microjets" as well as "shear forces" caused by cavitation can damage starch granules [52]. In addition, cavitation dissociates water molecules, leading to the release of free radicals such as hydroxide radicals.(OH)and hydrogen(H)will be These radicals, in turn, cause changes in the system chemically [53, 54]. Also, many factors such as the frequency and power of ultrasound treatment, temperature and time of treatment and the properties of starch suspension, including the concentration and type of starch, are effective on the modification of starch with ultrasound treatment [55].

4-The effect of ultrasound on the properties of starch

1-4-Molecular structure

Iodine binding capacity(IBC[24])degree of polymerization(DP[25]) and the extent of amylolysisB For amylose of legume starch, it is in the range of 16-22, 1000-1900 and 79-86.9%, respectively. Also, the molecular weight of legume amyloses varies from 165,000 to 312,000. One of the important and influencing factors on the physicochemical properties of starch is the structure of amylopectin. Amylopectin chains are often divided into three main groups called amylopectin chainsA، B and C are classified [56].

ChainA are external chains that form links to other chains; But they don't carry other chains, while the chainsB They connect to other chains and also carry other chains. the chainC It is a single long chain that has a reducing end group in the amylopectin molecule [57, 58].

Also, based on the degree of polymerization, the amylopectin molecule can be divided into four types of chains:A (DP 6-12), the chain B_1 (DP 13-24), the chain(DP 24-36) B_2 and the chain(DP $\geq$ 37) B_3 that chainA It exists mainly in the crystalline region, while the chainsB_1، B_2 AndB_3 They are mainly located in the amorphous region [59].

The molecular structure of amylopectin can be determined by several methods such as size exclusion chromatography[26], high performance liquid chromatography[27] and high performance anion exchange chromatography with pulsed amperometric detection(HPAEC-PAD[28]) identified [60]. Amylopectins can be separated by isoamylase or pullulanase and their single chain profiles can be determined byHPAEC-PAD estimated [61].

On the other hand, billiards[29] et al. (1981), by gel and column chromatography[30] et al. (1984), by light scattering techniques, found that amylopectin of legume starch with an average molecular weight greater than 10^7It is ×1.9. They also reported that iodine affinity, average chain length, and chain

[24] - Iodine binding capacity
[25] - Degree of polymerization
[26] - Size exclusion chromatography
[27] - High-performance liquid chromatography
[28] - High-Performance Anion-Exchange Chromatography With Pulsed Amperometric Detection
[29] - Biliaderls
[30] - Coleenna

molar ratio ranged from 1.00 to 5.3, 20 to 26, and 4.2 to 9.6 for legume starch amylopectins, respectively. On the other hand, Colonna et al. (1981) have shown that the fine structure of amylose and amylopectin of broad bean and smooth pea starch is similar to that of common cereal starch [62].

4-1-1-The effect of ultrasound on the molecular structure of starch

The effect of ultrasound on the molecular structure of starch chains is investigated by different methods [63]. The starch chains of amylose/amylopectin can be complexed with iodine and show different colors that reflect the length and branching pattern of the starch molecule, which can be used to investigate the structure of starch molecules. Also Sujaka[31] et al. (2013), reported that ultrasound treatment can change the color of starch-iodine complex from blue to red. This color change phenomenon shows that ultrasonic treatment can cause starch chain depolymerization and weaken the ability of starch to form a complex with iodine [64].

On the other hand, by using the chromatography technique, the molecular structure of ultrasound-modified starches can be investigated in full detail. Ultrasonic treatment attacks the molecular chains of starch and causes the production of starch molecules with smaller molecular size, lower average molar weight and lower molecular weight [65]. Because ultrasonic treatment can reduce the dispersion of polymers through the competitive degradation process and cavitation process, and in addition, ultrasonic waves produce free radicals that can cause the depolymerization of starch molecules [66].

On the other hand, it is important to know that ultrasound treatment attacks mostly amorphous areas and causes minimal damage to crystalline areas. Researches show that ultrasound treatment has a different effect on the molecular size of starch chains from different sources, which depends on the experimental conditions and ultrasound parameters [67].

beatik[32] and colleagues in 2019 investigated the effect of ultrasound treatment with a total power of 400 watts, a frequency of 20 kHz and an amplitude of 30% for 15 minutes on chickpea and lentil starch. The results of this report showed that ultrasonic waves break the molecular bonds of starch and change the arrangement of starch granules. Also, ultrasonic treatment by depolymerizing starch molecules reduces the particle size, and this reduction depends on the power and source of starch. In this research, the reduction of particle size in lentil starch is more obvious than in chickpea starch because the ultrasonic energy can be easily absorbed by larger starch granules. The reason for the surface area is more trapping [68]. In addition, the different ratio of amylose to amylopectin plays an important role in reducing the particle size of starch molecules [69].

On the other hand, sand[33] and colleagues in 2021 investigated the effect of ultrasound treatment with a total power of 300 watts in pulse mode (4 seconds off and 4 seconds on) for 30, 10 and 50 minutes on mung bean starch. The results showed that with increasing duration of ultrasound treatment, the molecular weight of amylose and amylopectin decreased; Because the energy of the ultrasound waves is transferred to the starch granules and creates a strong shear force and high temperature, which causes the depolymerization of the starch molecule chains [70]. Also, by examining the amylopectin chain structure of starch treated

[31] - Sujka

[32] - Trap

[33] - Shen

with ultrasound for 10 minutes compared to natural starch chains.B_2 AndB_3 Reduction and chains$A$ AndB_1 increased while starch treated with ultrasound for 30 min increased chainB_1 and reducing the chainB_3 was accompanied by the starch treated with ultrasound for 50 minutes with increasing chainsB_1 And$B_2$and reducing chains$A$ AndB_3 was with us. The results of this report show that the ultrasound treatment time can affect the molecular structure of starch. Also increase chains$A$ AndB_1 Ultrasonically modified starch by chain destructionB_2 AndB_3 It is related, which shows that the ultrasonic treatment causes the depolymerization of the amorphous regions of starch and by increasing the ultrasonic treatment time, this treatment can be effective in addition to affecting the amorphous regions on the crystalline regions because sufficient energy is provided to open the double helices [71].

In 2021, Han et al. investigated the effect of ultrasound treatment with a total power of 300 watts, a frequency of 20 kHz for 20 minutes on chickpea starch. The results of this report showed that ultrasound treatment significantly reduces the molecular weight of amylopectin compared to the molecular weight of amylose; Because ultrasound treatment is preferred to break down larger polymer molecules [72].

Chan[34] et al. in 2010 investigated the physicochemical and structural characteristics of mung bean starch modified with an ultrasonic bath for 10 minutes. They found that physical damage to the granular structure of starch increases with the increase in ultrasound treatment time, and also that physical damage to the granular structure of starch decreases with the increase in starch concentration in the starch-water suspension, and the results obtained in this report are in agreement with the results of Gallant[35] et al. (2006), corresponds [51, 73]. On the other hand, in 2018, Majid et al investigated the effect of ultrasound treatment with low power, frequency of 33 kHz for 45 minutes on chickpea and vetiver starch. The results of this report showed that ultrasound treatment causes the polymerization of starch molecules and increases the molecular weight [74].

Hoor et al. in 2002 found that bean starch has significantly larger granule size, higher relative crystallinity, higher gelatinization transition temperature, narrower gelatinization temperature range, and lower swelling power than other legume starches. Also, the results of this report showed that bean starch crystals are more stable and homogeneous than the crystals in other legume starches, and the interactions related to amylose chains in the amorphous domains of bean starch are of a higher order. On the other hand, black bean starches are significantly different from other leguminous starches due to their higher swelling power, higher viscosity, greater syneresis and wider gelatinization temperature range. This difference indicates a more heterogeneous crystal structure and weaker interactions between amylose-amylose chains or Amylose-amylopectin is in the amorphous domains of black bean starches [75].

[34] - Chan

[35] - Gallant

We are working[36] et al. in 2016, the effect of ultrasound treatment with a fixed frequency of 22 kHz, frequency range of 40, 70, 100%, power of 100 W, 200-250 W, and 400-460 W, respectively, for 3.5, 2.5, and 1.5 hours in pulse mode (25 seconds off and 5 seconds on) on bean starch, pea starch, red and green lentil starch were examined. The results of this report showed that the damage to the structure of starch molecules increases with the increase in the power of ultrasound treatment, and the highest amount of damaged starch is in red lentils (2.04 percent) and then in beans (1.95 percent) [76]. On the other hand, Asudo[37] et al., in 2022, investigated the effect of ultrasound treatment with a frequency of 20 kHz, a frequency range of 80% in pulse mode (2 seconds on and 2 seconds off) and for 30 minutes on bean starch. The results of this report showed that ultrasound treatment causes the depolymerization of starch molecules and the destruction of amylopectin branches, which this report is in line with Zheng's research results.[38] et al. (2013), is similar [63, 77].

2-4-Amylose content

Amylose is one of the main components of starch granules, which greatly affects the functional properties of starch (swelling strength, gel strength, pastiness, sensitivity to enzymes, and thermal properties) [11, 78].

Amylose concentration in starch can be measured by different methods. One of the most common methods is the method of forming a complex with iodine, which shows the formation of a blue color iodine-amylose complex, which can be measured with a spectrophotometer. However, this technique is not very accurate due to many reasons such as the existence of long chain polymers, the selection of standards and the degree of polymerization, that is why this measured value is called the apparent amylose content [79].

Another method for measuring starch amylose is gel permeation chromatography (GPC[39]) maybe In addition to measuring the amylose content, this method allows the determination of different chain distributions such as amylopectin and long-chain amylose. However, this method is labor-intensive, time-consuming and expensive[80, 81].

Another method to measure amylose content can be called amylose kitMegazyme It is that the principles of this method are based on precipitation of amylopectin with concavalin lectinA is. However, this method requires precise experimental control and is expensive [80].

On the other hand, different sources of starch have different amylose content, which can be attributed to many factors such as genotypic differences, growth conditions, starch extraction conditions, and different measurement techniques [82, 83].

Also, starch can be divided into three main groups based on amylose content. The endosperm tissue of waxy starches contains less than 15% amylose, and the reason for the name "waxy" for this type of starch originates from the waxy appearance of the endosperm tissue. This group of starch has higher relative crystallization and also requires higher energy for gelatinization [84]. Another group is high amylose starch, which consists of 30% amylose or more. The granule structure of these starches may be due to having different types of polysaccharides such as intermediates between

[36] - Karaman
[37] - Acevedo
[38] - Zheng
[39] - Gel Permeation Chromatograph

Its two main components change shape. Subcomponents of starches can be divided into three different groups, which are: particulate matter, surface components, and internal components. While proteins, enzymes, amino acids and some nucleic acids are the basic surface components that can be extracted from starch granules, lipids are the major part of the internal components [85]. Among the starches of legumes, the amylose content of lentils such as chickpeas and garbanzo beans is a rich source of many essential nutrients that can provide an important part of human daily nutrient consumption. Also, the total amylose content of beans (35.0-35.5٪) is much more than other starches. This difference is due to the higher percentage of the complex formation of amylose chains with starch lipids compared to other legume starches [75].

1-2-4-Effect of ultrasound on amylose content

Ultrasonic treatment can increase the amylose content of starch by depolymerizing the amylose molecule, breaking the chain of starch molecules and increasing the production of linear molecules, because ultrasonic treatment can cause high pressure, strong shearing force and high temperature that breaks the molecular chains of starch [86].]. On the other hand, minor components such as protein and lipid in starch granules can affect the performance of starch. In addition, the residual protein strongly combines with starch granules and may inhibit starch enzymolysis [5].

In 2019, Bitik et al investigated the effect of ultrasound treatment with a total power of 400 watts, a frequency of 20 kHz and an amplitude of 30% for 15 minutes on chickpea and lentil starch. The results of this report showed that the cavitation force of ultrasound waves increases the content of amylose by depolymerizing the amylose molecule [69]. On the other hand, in 2021, Shen et al investigated the effect of ultrasound treatment with a total power of 300 watts in pulse mode (4 seconds off and 4 seconds on) for 30, 10 and 50 minutes on mung bean starch. The results showed that ultrasound treatment by depolymerization of amylopectin side chains increases the linear chains and increases the amylose content of starch. Also, the amylose content of starch increased with the increase of ultrasound treatment time. On the other hand, in millet, chickpea and potato starch, increasing the time of ultrasound treatment increased the amylose content of the mentioned starches [71, 72, 87].

In 2021, Han et al. investigated the effect of ultrasound treatment with a total power of 300 watts, a frequency of 20 kHz for 20 minutes on chickpea starch. The results of this report showed that ultrasound treatment significantly reduced the amylose content of chickpea starch from 34.08٪ to 37.82٪ Increasing; Because ultrasound treatment causes partial depolymerization of amylopectin chains. On the other hand, ultrasound treatment increased the amylose content of corn, mung bean and sago starches[72].

On the other hand, in 2010, Chan et al. investigated the physicochemical and structural properties of mung bean starch modified with an ultrasonic bath for 10 minutes. They found that ultrasound treatment increased linear chains and increased the apparent amylose content of starch through partial depolymerization of amylose [51]. In 2018, Majid et al investigated the effect of low-power ultrasound treatment with a frequency of 33 kHz for 45 minutes on chickpea and vetiver starch. The results of this report showed that the amylose content of chickpea and vetiver starch is between 28.52-31.08 grams per 100

grams, and this difference is related to the plant origin, weather conditions and soil type. On the other hand, ultrasound treatment does not cause any significant change in the amylose content of chickpea and vetiver starch [74, 88].

On the other hand, Karaman et al. in 2016, the effect of ultrasound treatment with a fixed frequency of 22 kHz, frequency range of 40, 70, 100%, power of 100 W, 200-250 W and 400-460 W for 3.5, 2.5 and 1.5 hours respectively. The pulse mode (25 seconds off and 5 seconds on) was investigated on bean starch, pea starch, red and green lentil starch. The results of this report showed that the amylose content of legume starch is between 11.6 and 88.0. Also, in this report, the amount of amylose of leguminous starch was reported in the following order: pea starch > bean starch > red lentil starch > green lentil starch. On the other hand, ultrasound treatment increased the content of amylose, and the highest amount of amylose is for red lentil and bean starch modified with ultrasound treatment with a frequency range of 100% [76, 89]. In 2022, Acevedo et al investigated the effect of ultrasound treatment with a frequency of 20 kHz, frequency range of 80% in pulse mode (2 seconds on and 2 seconds off) and for 30 minutes on bean starch. The results of this report showed that ultrasound treatment causes the depolymerization of starch molecules and the destruction of amylopectin branches and increases the content of amylose[77].

3-4- Crystallization

Starch granules have a semi-crystalline structure, which is related to the composition, structure of components and the difference in amorphous and crystalline regions. On the other hand, amylose and amylopectin belong to the amorphous and crystalline regions, respectively, and the short and external chains of amylopectin form the crystallites [84]. The relative crystallinity values vary from 17 to 50% depending on the plant origin of starch, and types of waxy starches (high amylopectin) have higher crystallinity values than starches containing amylose [90].

Relative crystallization of legume starches: broad beans > black beans > lentils > chickpeas > chickpeas. The difference in the relative crystallinity of leguminous starches is due to the following reasons: (1) crystal size (2) amount of crystalline areas (influenced by amylopectin content and amylopectin chain length) (3) orientation of double helices within crystalline areas (4) degree of interaction between double helices. 91].

On the otherX-ray diffraction is used to reveal the presence and characteristics of the crystalline structures of starch granules, and legume starch has a crystalline pattern of"C" It is that this X-ray diffraction pattern is intermediate between the type diffraction patternA (cereals) and typeB (gland) is. Also, the difference of these X-ray diffraction patterns is related to slight differences in the chain length and characteristics of the chains of the constituent amylopectin molecules[92]. On the other hand, X-ray diffraction of most legume starches with two lines with very strong intensity at angles of 17.2 and 18.1 degrees.2th Denoted. As mentioned above, starches from legumes have X-ray diffraction pattern type"C" but pea starch has X-ray diffraction pattern"B" is. On the other hand, the crystallinity of two types of chickpeas (Kabli and Desi) can be different, and this difference is due to the difference in amylopectin fraction, Kabli starch compared to Desi starch, and also that Kabli chickpea starch has a higher degree of crystallinity.

On the other hand, desi chickpea starches have higher amylose content and lower double helix content [93].

4-3-1-Effect of ultrasound on crystallinity

Ultrasonic treatment can attack the amorphous areas of starch granules in its initial process and increase the degree of crystallinity, but with the increase in power and time of ultrasound treatment, this treatment can also damage the crystalline areas of starch granules and decrease the degree of crystallinity. to follow Because the amorphous areas of the granules are more sensitive to ultrasound treatment than the crystalline areas, and starches with high amylose content are more easily affected by ultrasound treatment in terms of structure and characteristics [47, 94]. On the other hand, it can be said that ultrasound treatment affects starch crystallinity through changes in the morphology of starch granules. Also, ultrasound treatment conditions are one of the determining factors in changing the degree of crystallinity of starch granules.

Lee[40] et al. (2016), reported that ultrasound treatment (frequency 20 kHz, power 800 W, duration 4 h) did not change the type of crystalline pattern of corn starch; But this treatment causes destruction of approximately 25.1٪ It is from the crystal structure of starch that the reduction of this percentage of the crystal structure was attributed to the formation of very small crystallites and the reduction of the degree of crystal arrangement [65].

On the other hand, Huang et al. (2007) reported that ultrasound treatment increased the degree of crystallinity of corn starch in the initial treatment time of up to 3 minutes, but the degree of crystallinity decreased as the treatment time increased (15 minutes)[95].

In 2019, Bitik et al investigated the effect of ultrasound treatment with a total power of 400 watts, a frequency of 20 kHz and an amplitude of 30% for 15 minutes on chickpea and lentil starch. The results of this report showed that the cavitation force of ultrasonic waves decreases the degree of crystallinity through the destruction of the amorphous region and the formation of a smaller crystalline region, and did not cause any change in the crystallinity pattern [69, 96]. On the other hand, in 2021, Shen et al investigated the effect of ultrasound treatment with a total power of 300 watts in pulse mode (4 seconds off and 4 seconds on) for 30, 10 and 50 minutes on mung bean starch. The results of this report showed that the ultrasound treatment could not change the X-ray diffraction pattern, but this treatment caused a decrease in crystallinity due to the destruction of the amorphous region and the weakening of strong crystal structures, and this treatment also caused the rearrangement of the crystal structure and led to the formation of a crystalline region. became smaller [71, 87]. In 2021, Han et al. investigated the effect of ultrasound treatment with a total power of 300 watts, a frequency of 20 kHz for 20 minutes on chickpea starch. The results of this report showed that ultrasound treatment caused a decrease in crystallinity by damaging starch granules [97]. But this treatment did not change the crystallite pattern. On the other hand, Ho et al. in 2019 pointed out the relative reduction of crystallization of modified millet starch and potato starch with ultrasound compared to natural millet starch and potato starch [30, 72].

Chan et al. in 2010 investigated the physicochemical and structural characteristics of mung bean starch modified by ultrasonic bath for 10 minutes. They found that ultrasonic treatment reduced the relative crystallinity through the destruction of the amorphous structure of starch

[40] -That

granules, but did not cause any change in the crystallinity pattern [51]. On the other hand, in 2018, Majid et al investigated the effect of low-power ultrasound treatment with a frequency of 33 kHz for 45 minutes on chickpea and vetiver starch. The results of this report showed that ultrasound treatment does not change the relative crystallization and crystallite pattern [74]. In 2022, Acevedo et al investigated the effect of ultrasound treatment with a frequency of 20 kHz, frequency range of 80% in pulsed mode (2 seconds on and 2 seconds off) and for 30 minutes on bean starch. The results of this report showed that ultrasonic treatment can cause the rearrangement of starch chains in amorphous regions, which leads to the formation of a more complex crystal structure. Also, ultrasound treatment can increase the connection between starch chains and separate the double helices in the crystalline regions and lead to the formation of crystallites [77].

4-4-Gelatinization

When starch granules are heated in the presence of sufficient water, within a temperature range characteristic of the starch source, they swell and rapidly lose their semi-crystalline structure, a process called gelatinization. This process is associated with diffusion of water into starch granules, hydration and swelling of starch granules, absorption of heat, loss of crystallinity and washing of amylose. This process makes the use of starch important in both food and non-food applications[98].

The change of gelatinization enthalpy and gelatinization temperature of starch can be measured by differential scanning calorimetry.(DSC[41]) Determined while heating in excess water. Among the parameters that this device calculates are gelatin transfer temperatures such as the starting temperature(To[42]), peak temperature(City[43]), the final temperature(Tc[44]) and gelatinization enthalpy(ΔH) Cited [99].

ΔH indicating loss of molecular order,City It indicates the crystallinity related to the length of the double helix. Starch gelatinization temperature is affected by several factors such as molecular structure, presence of minor components and product growth environment [82].

In general, most starches have a gelatinization temperature between 60 and 80 °C, and starch typeA Often a higher gelatinization temperature than the typeB has it. Also, starches with high amylose have a much higher gelatinization temperature [100].

The gelatinization temperature of leguminous starch varies from 59.4 to 85 degrees Celsius. The gelatinization temperature parameters are influenced by the molecular structure of the crystalline region, which is related to the distribution of short amylopectin chains.(DP 6-11) is the starting temperature(To) Bean starch is much higher than other legume starches. This high value is due to the higher content of amylose chains, higher degree of crystallinity, longer and larger ratio of external branches.«A» It is amylopectin.

in legume starch,Tc-To It ranges from 8.0 (legumes) to 20.8 (black beans). DifferenceTc-To between leguminous and other legume starches, due to having a higher degree than

41 - Differential scanning calorimetry

42 - Onset Temperature

43 - Peak Temperature

44 - Conclusion Temperature

The homogeneity of the crystals in the granules of bean starch. On the other hand, the gelatinization enthalpy of legume starch fromJ/g 12.6 (chickpea, figDesiray) until theJ/g 24.9 (Lobiachiti) is variable due to different amylopectin content. High gelatinization enthalpy of legume starch due to long external branches«A» Amylopectin chains form longer double helices that require a higher level of thermal energy to break apart and melt [101].

1-4-4-Effect of ultrasound on starch gelatinization

At the initial time of ultrasound treatment, the destruction of amorphous regions in starch granules occurs, which leads to an increase in starch crystallinity and, as a result, an increase in gelatinization temperature and gelatinization enthalpy[95]. With the increase in the time of ultrasound treatment, the crystal structure of starch granules is gradually destroyed, which leads to a decrease in crystallinity and, as a result, a decrease in gelatinization temperature and gelatinization enthalpy [8]. On the other hand, depending on the type and composition of starch and the conditions of ultrasound treatment, the temperature change and gelatinization enthalpy can be different [102].

In 2019, Bitik et al investigated the effect of ultrasound treatment with a total power of 400 watts, a frequency of 20 kHz and an amplitude of 30% for 15 minutes on chickpea and lentil starch. The results of this report showed that ultrasonic treatment through the change in the structure of starch granules starting temperature(To) and final temperature(Tc) reduced Also, due to the gelatinization of starch granules, which depends on the organization of starch components (amylose, amylopectin), the peak temperature of this treatment(city) reduced On the other hand, this treatment decreased the gelatinization enthalpy by destroying the crystal structure of starch granules [69].

In 2021, Shen et al investigated the effect of ultrasound treatment with a total power of 300 watts in pulse mode (4 seconds off and 4 seconds on) for 30, 10 and 50 minutes on mung bean starch. The results of this report showed that ultrasonic treatment increases the starting temperature due to the weakening of the weak crystal structure of starch granules and the creation of more stable residual crystallites.(To), peak temperature(city), the final temperature(Tc) became. On the other hand, due to the destruction of the structure of the starch granules, this treatment caused the easy penetration of water into the starch granules and facilitated the exit of amylose molecules from the inside of the starch granules. The internal starch molecule was blocked by water molecules, which resulted in the increase of gelatinization enthalpy [71, 103]. On the other hand, Karaman et al. in 2016, the effect of ultrasound treatment with a fixed frequency of 22 kHz, frequency range of 40, 70, 100%, power of 100 watts, 200-250 watts and 400-460 watts for 3.5, 2.5 and 1.5 hours respectively. The pulse mode (25 seconds off and 5 seconds on) was investigated on bean starch, pea starch, red and green lentil starch. The results of this report showed that ultrasound treatment weakened the crystal structure of starch granules and created more stable residual crystallites of bean and green lentil starches modified by high temperature ultrasound treatment.(city)and final temperature(Tc) Also, the biggest change was related to soybean starch modified by ultrasound. On the other hand, pea starch due to the highest amount of amylose (with more amorphous and less crystalline area) has the lowest increase in the starting temperature.(To), peak temperature(city), the final temperature(Tc) showed [21]. On the other hand, the highest enthalpy of gelatinization

was related to green lentil, red lentil and chickpea starches modified with ultrasound (with frequency ranges of 100%, 40% and 70%). Also, the lowest amount of gelatinization enthalpy was related to pea starch modified by ultrasound. This value is due to the highest amylose content of pea among legume starches. This difference in gelatinization enthalpy is related to several factors such as the shape and size of the granule, the length of the amylopectin chain, the presence of phosphate esters and the degree of crystallization[76]. On the other hand, Acevedo and colleagues in 2022 investigated the effect of ultrasound treatment with a frequency of 20 kHz, frequency range of 80% in pulse mode (2 seconds on and 2 seconds off) and for 30 minutes on bean starch. The results of this report showed that the natural starch of nightingale's starting temperature values(To), peak temperature(city), the final temperature ((Tc It has higher than other legume starches, and this difference in gelatinization temperature parameters is due to the difference in starch crystallite depending on the origin of starch. On the other hand, ultrasonic treatment reduces the peak temperature by destroying the crystal structure and reducing the order of the crystal regions(city), the final temperature((Tc and the gelatinization temperature of the starch modified by ultrasound [77, 104].

5-4-Making dough

The process of measuring the viscosity of starch suspension during and after gelatinization is called pasting. To analyze the pasting properties of starch, a starch suspension is stirred and checked with a viscometer under programmed heating and cooling conditions. On the other hand, during heating, starch granules swell, lose their granular structure, and finally separate. Dough viscosity increases to a maximum when the percentage of swollen starch granules is at a maximum, but decreases as the starch granules separate [100]. On the other hand, during the cooling stage, due to the phenomenon of going back, starch forms a gel. A pasting diagram with common parameters measured by a rapid viscosity analyzer(RVA) It is shown in the figure below [78].

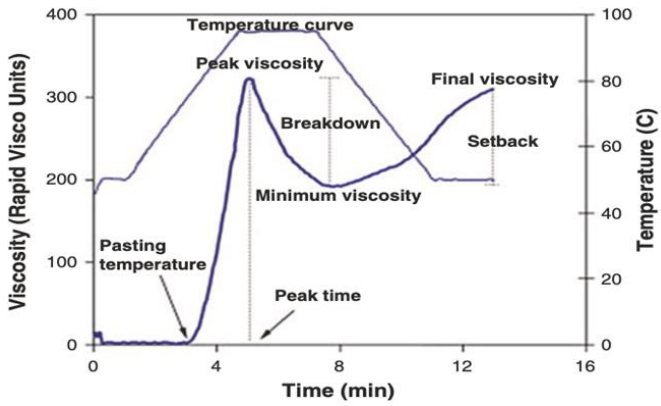

Fig1 Pasting profile of Legume starch measured by RVA

Viscosity max(PV[45]) It indicates the maximum swelling power of starch granules before decomposition, which is caused by the disruption of the internal network structure of starch. On the other hand, viscosity breakdown (BD[46]) It indicates the thermal stability of starch dough [103]. Breakdown viscosity (TV[47]) It shows a decrease in viscosity due to the decomposition of starch granules at high temperature.

[45] - Peak viscosity
[46] - Breakdown
[47] - Trough viscosity

Paste temperature(PT[48]) It is the minimum temperature required for gelatinization. Final viscosity(FV[49]) It shows the increase in the viscosity of starch paste in the cooling process due to the molecular accumulation of amylose. Many factors such as particle size, presence of impurities, amylose content, methods and different experimental parameters used in the test to measure the dough properties.pH, sample suspension concentration, temperature and shear rate) can affect starch pasting properties [83].

Starch staleness can be measured by the same techniques used for starch gelatinization. Starch staleness is a phenomenon in which the structure of gelatinized starch is partially rearranged and recrystallized during a period of storage. The change in the staleness of starches is related to many factors, including the ratio of amylose to amylopectin, presence of lipids, molecular size and temperature. The ratio of amylose to amylopectin is one of the most important factors affecting starch staleness; Because amylose becomes stale much faster than amylopectin. Starch staleness is an important feature for starch applications, because the properties of starchy foods such as stickiness, digestibility, and gel hardness are affected by starch staleness [105].

Also, bean starch has a higher pasting temperature, lower viscosity (at 95 and 50 degrees Celsius) and less staleness than other starches. Low viscosity at 95°C is due to higher crystallinity, lower swelling power, lower amylose content. On the other hand, the amount of staleness is less in bean starch compared to other legume starches due to less accumulation of starch chains in bean starch.

On the other hand, black bean starch has a higher viscosity at 95 degrees Celsius; Because black bean starch has less crystallinity, higher swelling power, and higher amylopectin content than other legume starches. Also, black bean starch has a higher rate of staleness than other starches. The higher rate of staleness of black beans compared to other legume starches is due to the high content of amylopectin and the stronger accumulation of starch chains [106].

1-5-4-Effect of ultrasound on starch paste

Ultrasonic waves damage the starch granules, the more water penetrates these damaged granules, which in turn facilitates the hydration and swelling of the granules and reduces the viscosity of the paste. Also, by controlling the ultrasonic conditions, damage to starch granules can be achieved without starch molecular chains, which can achieve a lower viscosity [65]. On the other hand, ultrasonic treatment can increase the viscosity of pasting, and these changes in the viscosity of pasting depend on the conditions of ultrasound treatment and starch composition. Because ultrasound treatment can cause different degrees of damage in the amorphous and crystalline areas of starch granules [107]. Also, under the same ultrasonic conditions, the pasting viscosity of starch with high amylose is much more affected by ultrasound than that of waxy starch (high amylopectin), because amylose in granules is more sensitive to ultrasound treatment [47].

In 2021, Shen et al investigated the effect of ultrasound treatment with a total power of 300 watts in pulse mode (4 seconds off and 4 seconds on) for 30, 10 and 50 minutes on mung bean starch. The results of this report showed that ultrasonic treatment of maximum viscosity (PV), fracture viscosity(TV) and final viscosity(FV) significantly increased because this

[48] - Pasting Temperature
[49] - Final viscosity

treatment causes the destruction of the crystal structure, the reorientation of starch molecules and the injection of more water into the starch granules and the increase of swelling [87]. On the other hand, ultrasonic treatment breaks viscosity(BD) and rebound viscosity(SBV) because ultrasound treatment reduces amylose washing and increases interactions between amylose chain and amylopectin. Also, by increasing the time of ultrasound treatment, viscosity breakdown decreases(BD) and rebound viscosity(SBV[50]) increased because the degree of degradation of starch chains is directly proportional to the treatment time. Reduce viscosity breakdown(BD) It indicates an increase in the stability of starch paste against heat and mechanical stirring [71]. On the other hand, in 2021, Han and colleagues investigated the effect of ultrasound treatment with a total power of 300 watts, a frequency of 20 kHz for 20 minutes on chickpea starch. The results of this report showed that ultrasonic treatment increases maximum viscosity, break viscosity, final viscosity and rebound viscosity. Because starches with higher amylose content have more viscosity, also ultrasound treatment increases the amylose content. On the other hand, ultrasound treatment causes depolymerization of amylopectin, which leads to better rearrangement of starch molecule chains and stability of amorphous regions in starch granules[30]. On the other hand, due to the strengthening of the amorphous region of the starch granules, the ultrasonic treatment makes it difficult to break down the swollen starch granules, which reduces the viscosity breakdown.(BD) follows[72].

Chan et al. in 2010 investigated the physicochemical and structural characteristics of mung bean starch modified by ultrasonic bath for 10 minutes. They found that ultrasonic treatment decreased the maximum viscosity by weakening the structure of starch granules and creating breaks in starch chains. On the other hand, ultrasonic treatment increases the breaking viscosity by weakening the structure of starch granules and making it easier to disrupt starch granules.(BD) became [51]. On the other hand, in 2018, Majid et al investigated the effect of ultrasound treatment with low power, frequency of 33 kHz for 45 minutes on chickpea and vetiver starch. The results of this report showed that the maximum viscosity(PV) natural pea starch (cP 3903.3) significantly more than vetiver starch (cP 3602.67 (Bud. Also, ultrasonic treatment through destruction of starch chains and reduction of swelling power, maximum viscosity and fracture viscosity(TV) reduced On the other hand, ultrasonic treatment did not change the breaking viscosity of chickpea starch, while this treatment reduced the breaking viscosity of chickpea starch due to the reduction of the maximum viscosity. On the other hand, ultrasonic treatment of the final viscosity(FV)Pea and vetch starch decreased due to the decrease in the degree of polymerization of starch chains, the breaking of starch chains and the reduction of dough viscosity. Also, ultrasound treatment reduced the return viscosity of chickpea and vetch starch due to the depolymerization of washed amylose and long linear amylopectin, which was more significant in the ultrasound-modified vetch starch compared to the ultrasound-modified chickpea starch. From

[50] - Setback viscosity

On the other hand, ultrasound treatment decreased the pasting temperature of chickpea and vetch starch, which indicates low swelling and tearing resistance [74]. In 2022, Acevedo et al investigated the effect of ultrasound treatment with a frequency of 20 kHz, frequency range of 80% in pulse mode (2 seconds on and 2 seconds off) and for 30 minutes on bean starch. The results of this report showed that ultrasonic treatment increased the temperature of bean starch pasting. Also, ultrasound treatment reduced the maximum viscosity by increasing intermolecular bonds in starch chains, limiting hydration and reducing swelling power [108]. On the other hand, ultrasound treatment formed a more stable structure by increasing interactions and strengthening the bond between amylose and amylopectin molecules, which resulted in a reduction in viscosity breakdown, limited swelling power, and greater thermal and mechanical stability in starch modified by ultrasound treatment. On the other hand, ultrasound treatment reduced the viscosity of the return [77].

6-4- Power of inflation

By heating the starch with an excess amount of water, the starch granules swell. Water retention properties of starch in general as swelling power(SP[51]) and water solubility index(WSI[52]) It is expressed [82].

The swelling power of starch is related to hydration, interaction between amylose and amylopectin molecules, intramolecular bonds and connection of crystal regions. In other words, swelling power and solubility provide measures of the degree of interaction between starch chains in amorphous and crystalline regions. Also, the swelling power of starch is highly dependent on temperature; Because with the increase in temperature, the crystal structure of starch is disturbed and the strengthening of the hydrogen bond between water molecules and amylose-amylopectin occurs [109].

The difference in the power of inflation(SP) and water solubility index(WSI) The difference between starches is due to the variation in their water holding capacity, and the water holding capacity is influenced by many factors, including the characteristics of amylose and amylopectin (ratio, molecular weight, chain length, etc.), the presence of minor components (lipids, phosphates) and the granular structure of starch. is. On the other hand, solubility is an essential indicator for the value of using starch soluble in cold water, which indicates the degree of dissolution and precipitation of molecular chains. Also, solubility is attributed to the presence of soluble molecules such as amylose, sugars in starch granules [10].

Due to having strong bonds between starch components that loosen at one temperature, not at several temperatures like corn[110], leguminous starches have limited swelling power, single-stage and low solubility power. Also, the strong bonds between legume starch components are due to the regular arrangement of polymer chains in the starch granule, which favors maximum interaction through hydrogen bonding. Also, leguminous starch has a large variation in swelling power(SP) and have solubility. At 90 degrees Celsius, the swelling power and solubility of leguminous starch are in the range of 26-11 and 25-8, respectively.٪ and with the increase in temperature (60-90 degrees Celsius) there is a rapid increase inSP And solvency is created. Because the increase in temperature (60-90 °C) leads to the melting of starch crystals, which leads to an increase in entropy and weakens the hydrogen bonds that exist in the crystalline areas [111].

[51] - Swelling power

[52] - Water-soluble index

On the other hand, the swelling power of legume starch is influenced by: (1) amylose-lipid complexes (this complex reduces swelling power) (2) a strongly cross-linked network (3) molecular structure of amylopectin. Also, the swelling power of leguminous starch at 60°C follows the following pattern: (black bean > pea)-chickpea > lentil > legume > navy bean), the difference in swelling power is more influenced by the difference in amylopectin chain length and less influenced by amylose-lipid complexes. Due to the presence of a large number of crystallites, which are formed by the connection between long chains of amylopectin, bean starch increases the stability of the granules and, as a result, reduces the swelling power of starch [112].

4-6-1-The effect of ultrasound on the swelling power of starch

Ultrasonic treatment increases the swelling power and solubility of starch due to increased water penetration and hydration of starch granules [63]. Also, the type and composition of starch can affect the change in swelling power and solubility of granules that are affected by ultrasound [8]. Ultrasound treatment increases the swelling power and solubility of starches with high amylose content more than waxy starches because amylose in starch granules is more sensitive to ultrasound. On the other hand, different ultrasound parameters are also effective on changing the swelling power and solubility of starch [47].

In 2019, Bitik et al investigated the effect of ultrasound treatment with a total power of 400 watts, a frequency of 20 kHz and an amplitude of 30% for 15 minutes on chickpea and lentil starch. The results of this report showed that ultrasound treatment decreased the solubility of both pea and lentil starch through the effect of cavitation forces on the orientation and arrangement of amylose molecules. On the other hand, this treatment increased the interaction with the hydroxyl groups of water molecules by reducing the size of starch granules, which increased the swelling power of both pea and lentil starch [113]. Also, a change in the arrangement of amylose and amylopectin molecules leads to a change in the arrangement of starch granules because ultrasound treatment is responsible for breaking molecular bonds. The increase in the swelling power of pea and lentil starch modified by ultrasound treatment is due to the change in the arrangement of starch granules [69]. On the other hand, in 2021, Shen et al investigated the effect of ultrasound treatment with a total power of 300 watts in pulse mode (4 seconds off and 4 seconds on) for 30, 10 and 50 minutes on mung bean starch. The results of this report showed that increasing the temperature from 50 to 90 °C due to the weakening of the hydrogen bond of starch granules accelerated the washing of amylose and increased the solubility and swelling power. On the other hand, ultrasound treatment caused damage to starch granules through cavitation force, and as a result, increased the solubility of mung bean starch. Also, the solubility of mung bean starch modified by ultrasonic treatment showed an increasing trend with increasing treatment time. On the other hand, ultrasound treatment facilitated the penetration of water molecules into the amorphous regions of starch granules by disrupting the molecular structure of crystalline regions, and as a result of this treatment, the swelling power of mung bean starch increased [114]. Also the swelling power of starch

The modified mung bean with ultrasound treatment showed an increasing trend with increasing treatment time [71].

In 2021, Han et al. investigated the effect of ultrasound treatment with a total power of 300 watts, a frequency of 20 kHz for 20 minutes on chickpea starch. The results of this report showed that ultrasound treatment has an insignificant effect on the swelling power of chickpea starch, except at 90°C, where ultrasound treatment decreased the swelling power of chickpea starch due to the depolymerization of starch molecules [115]. On the other hand, as the temperature increased from 50 to 90 °C, the solubility index of chickpea starch increased due to the washing of more amylose. Also, ultrasound treatment through the depolymerization of starch molecules increased the proportion of short chains, which resulted in an increase in the hydration and solubility of chickpea starch [72]. On the other hand, in 2010, Chan et al. investigated the physicochemical and structural properties of mung bean starch modified with an ultrasonic bath for 10 minutes. They found that mung bean starch had lower swelling power compared to potato starch, sago starch and corn starch due to higher amylose content. On the other hand, ultrasound treatment did not change the swelling power of mung bean starch. This non-change in swelling power is due to the presence of peptide cross-links in mung bean starch amylopectin, which preserves the structure of starch molecules. Also, ultrasound treatment increased the solubility of mung bean starch through depolymerization and structural weakening of starch molecules [51].

In 2018, Majid et al investigated the effect of ultrasound treatment with low power, frequency of 33 kHz for 45 minutes on chickpea and vetiver starch. The results of this report showed that the swelling power of natural vetch and pea starch samples increased significantly with increasing temperature (50 to 90 °C) due to the weakening of intermolecular interactions such as hydrogen bonding [116]. Also, the swelling power of ultrasonically modified peas and ultrasonically modified vetch starch did not decrease compared to natural starch, but when they were heated to 80 and 90 degrees Celsius, due toof theThe polymerization of starch molecules decreased the swelling power. On the other hand, the solubility index of pea starch and natural vetch increased with increasing temperature, respectively, and the highest solubility appeared at 80 and 90 °C due to the washing of amylose at higher temperatures. Also, ultrasound treatment increased the solubility index, which was the highest at 90°C and the lowest at 60°C[74]. On the other hand, Karaman et al. in 2016, the effect of ultrasound treatment with a fixed frequency of 22 kHz, frequency range of 40, 70, 100%, power of 100 watts, 200-250 watts and 400-460 watts for 3.5, 2.5 and 1.5 hours respectively. The pulse mode (25 seconds off and 5 seconds on) was investigated on bean starch, pea starch, red and green lentil starch. The results of this report showed that green lentil starch has the highest swelling power among bean starch, pea starch, and red lentil starch due to the lowest amount of amylose, both for natural samples and for samples treated with ultrasound. Also, the swelling power of chickpea starch decreased in proportion to the increase in ultrasound amplitude. While bean and red lentil starch did not show any significant changes as a function of the ultrasound amplitude, and among the mentioned starches, green lentil starch modified by ultrasound treatment (with a frequency amplitude of 40٪) showed the lowest power of inflation [74]. On the other hand, at temperatures below 60°C, no measurable granule swelling occurred in most of the legume starches, while at

temperatures above 70°C, the swelling power became measurable because it was necessary to break the strong interactions (hydrogen bonds) between the amylose chains located in the amorphous regions of the granules. have, high thermal energy is required [76].

7-4-Morphology

In general, starch granules have a semi-crystalline structure, which consists of amylopectin and amylose molecules. Starch granules are often described according to many characteristics, including their shape, size, distribution, polymorphism, and crystallinity. These characteristics are strongly related to a wide range of factors such as botanical origin, growth conditions and plant physiology. Various techniques to observe the morphology of starch granules such as light microscopy(LM[53])Polarized light microscope(PLM[54]), Scanning Electron Microscope(SEM[55]), transmission electron microscope(HE HAS[56]) And Laser light scattering technique(LLS[57]) There is. The size of starch granule varies widely and its diameter varies from 1 to 100 micrometers [11]. The size of starch granules is related to some functional properties of starch such as swelling power, solubility and enzymatic sensitivity. Many forms are found in starch granules. In general, most starch granules are oval, round and spherical, but polygonal and elongated oval shapes are also found [117].

The size of legume starch granules varies from 4 to 85 micrometers depending on the starch source. Most legume starch granules are oval, although spherical, round, and elongated oval granules are also found. Scanning electron microscope images(SEM) The surfaces of all legume starch granules are smooth and without any cracks. Also, most legume starches have simple granules, except for shriveled pea starch, which has a mixture of simple and complex granules. Legume starch shows the most diversity (length and width) in size distribution among legume starches [75].

1-7-4-Effect of ultrasound on starch granule morphology

Ultrasound treatment often leads to morphological changes of starch granules by creating cracks and pores and damaging the granules. Many factors can affect the morphology of starch granules due to ultrasound treatment:

1- The type and structure of starch granules and the concentration of starch suspension. By increasing the concentration of starch suspension, the damage to starch granules decreases [73].

2- Ultrasound treatment parameters: power, frequency, frequency range, duration of ultrasound treatment. Increasing the input power of ultrasound treatment, starch granules tend to accumulate, and also with increasing the duration of ultrasound treatment, more damage is done to starch granules[95].

On the other hand, two-frequency ultrasound treatment (25 and 80 kHz) compared to single-frequency ultrasound treatment (25

[53] - Light microscopy
[54] - Polarized light microscopy
[55] - Scanning electron microscopy
[56] - Transmission electron microscopy
[57] - Laser light scattering

kHz or 80 kHz) creates more depressions and pores on the surface of starch granules [63].

3- Conditions for applying ultrasound treatment: temperature, type of ultrasound equipment (probe or bath) and type of atmospheric gas. Also, high temperature increases the damage to starch granules and ultrasound treatment can cause more changes in the morphology of starch granules [67].

On the other hand, the type of gas affects the amount of damage to starch granules. For example, hydrogen atmosphere causes the most damage, followed by air and oxygen, carbon dioxide and vacuum [8].

In 2019, Bitik et al investigated the effect of ultrasound treatment with a total power of 400 watts, a frequency of 20 kHz and an amplitude of 30% for 15 minutes on chickpea and lentil starch. Scanning electron microscope images(SEM)sign showed that natural pea and lentil starches have uneven surfaces and spherical-oval shapes. On the other hand, due to the phenomenon of cavitation, ultrasound treatment changed the surface of pea and lentil starch granules from rough to smooth and created some cracks on the surface of pea and lentil starch granules. Also, ultrasound treatment reduced the size of starch granules, which is strongly dependent on the type and origin of starch chains, the ratio of amylose to amylopectin [69]. On the other hand, in 2021, Shen et al investigated the effect of ultrasound treatment with a total power of 300 watts in pulse mode (4 seconds off and 4 seconds on) for 30, 10 and 50 minutes on mung bean starch. Scanning electron microscope images(SEM)showed that natural mung bean starch has a spherical, oval shape with a smooth surface. On the other hand, ultrasound treatment did not change the shape of mung bean starch granules. However, this treatment created grooves and cracks on the surface of starch granules due to the rapid formation and collapse of cavitation bubbles and as a result, strong shear force [71].

In 2021, Han et al. investigated the effect of ultrasound treatment with a total power of 300 watts, a frequency of 20 kHz for 20 minutes on chickpea starch. Scanning electron microscope images(SEM)It showed that natural chickpea starch has a spherical or elongated oval shape and also has a smooth surface without grooves and cracks. On the other hand, ultrasound treatment did not cause any significant changes in the morphological structure of chickpea starch [72]. On the other hand, in 2010, Chan et al. investigated the physicochemical and structural characteristics of mung bean starch modified with an ultrasonic bath for 10 minutes. Scanning electron microscope images(SEM)The ultrasound-modified mung bean starch showed that the ultrasound treatment could not change the morphology of the mung bean starch and did not create any prominent cracks and pores in the starch granules [51].

Karaman et al. in 2016, the effect of ultrasound treatment with a fixed frequency of 22 kHz, frequency range of 40, 70, 100%, power of 100 W, 200-250 W and 400-460 W for 3.5, 2.5 and 1.5 hours respectively in pulse mode (25 seconds off and 5 seconds on) on bean starch, pea starch, red and green lentil starch were examined. Scanning electron microscope images(SEM)Bean starch, pea starch, red and green lentil starch showed that most legume starch granules have an oval or elongated oval shape. However, they are rarely seen as round. On the other hand, the results of particle size distribution showed that pea starch and red lentil have the largest and smallest granule

sizes, respectively, and the largest changes in terms of width and length are related to bean starch. Also, the surface of the natural starch granules mentioned above are relatively smooth, while the ultrasonic treatment created cracks on the surface of the granules of bean starch, pea starch, red and green lentil starch. Also, by increasing the range or power of ultrasound treatment, the damage on starch granules was intensified [76]. On the other hand, Acevedo and colleagues in 2022 investigated the effect of ultrasound treatment with a frequency of 20 kHz, frequency range of 80% in pulse mode (2 seconds on and 2 seconds off) and for 30 minutes on bean starch. Scanning electron microscope images(SEM)showed that natural bean starch has an oval shape with a smooth surface [118]. On the other hand, ultrasound treatment did not change the shape of starch granules, but it made the surface of bean starch granules uneven and irregular due to the collapse of cavitation bubbles and strong shearing forces, and this unevenness and irregularity created on the surface of starch granules leads to the formation of small pores [77].

4-8-Rheology

The starch flow behavior can be determined from the relationship between the starch shear rate and the apparent viscosity of the starch paste. Power law, Herschel-Bulkelley and Bingham models are common models used to express starch flow behavior. The flow behavior of starch is critical for many applications because it is related to the properties of the product behavior at different shear rates [119]. Also, starch pastes show non-Newtonian and shear-thinning behavior. The difference in viscosity between starch pastes is related to starch concentration, amylose content and temperature. Starch rheological measurement is routinely performed in the food industry to test the ability of starches to function effectively as thickening agents [120].

The rheological properties of starch cannot be determined using Brabander/visco/amylogram(BVA[58]) evaluated correctly, because the viscosity measurement is performed in non-laminar flow conditions and the starch paste is subjected to thermal and mechanical treatment, which is difficult to relate the pasting behavior to only one of these parameters. However,BVA In comparing the overall rheological behavior of starch (from different sources) under the same conditions (concentration,pH and cutting) is useful. Also, rheometers are used for rheological measurement of starch, and in rheometers, heat treatment is separated from shearing effects by using cone and plate or double cylinder geometry.

AtBVA All legume starches showed no peak viscosity, constant or increasing viscosity during the storage period (at 95 °C), high rebound and constant cold paste viscosity during stirring at 50 °C. Such behavior indicates a high degree of interaction between starch components. Most legume starches have a type viscosity patternC (limited inflation). However, bean and mung bean starches show a mixed viscosity pattern that typC In low concentrations and typesB (moderate swelling) in higher concentrations. However, shriveled pea starch has a type viscosity patternD (inflation is very limited) [110].

[58] - Brabender viscoamylograph

1-8-4-The effect of ultrasound on the rheology of starch gel

Ultrasound treatment causes the production of short starch chains due to the depolymerization of starch molecules, and these produced starch chains are no longer destroyed by ultrasound treatment due to their shortness. Also, ultrasonic treatment reduces the consistency coefficient, which depends on the ultrasonic power, and shows a flow index higher than 1 [8]. On the other hand, the flow behavior of starch gel modified by ultrasound treatment can be described by the power law equation [53].

In 2019, Bitik et al. investigated the effect of ultrasound treatment with total power of 400 watts, frequency of 20 kHz and amplitude of 30% for 15 minutes on pea and lentil starch. The results of this report showed that the viscosity of both starches decreased with increasing shear rate and both starches showed non-Newtonian and thinning behavior with shearing. Some factors such as the structure of the starch molecule and the amounts of amylose and amylopectin in starch play an important role in the shear thinning behavior. Also, the power law with high correlation coefficient was used to describe the flow behavior. On the other hand, ultrasound treatment did not show a change in the flow behavior index of pea and lentil starch; However, this treatment reduced the consistency coefficient of pea and lentil starch modified by ultrasound due to the creation of shear force that leads to the destruction of starch molecules [69].

4-9- gel texture

4-9-1-dynamic rheological analysis

used dynamic rheological analysis to characterize the viscoelastic properties of starch with continuous modulus analysis during temperature scanning and frequency scanning [89]. Storage module(G')، Dissipation module(G") and loss tangent((tan dthat ratioG"/G' is usually used to show the viscoelastic properties of starch. The energy stored and recovered in the starch gel in each cycle of deformation withG' is measured, while the energy dissipated or lost in each deformation cycle withG" It is measured and valuesG' AndG" They depend on several factors such as granule size, amylose/amylopectin ratio. Also the loss tangent (tan d) To show the relationship betweenG' AndG" It is used in starch gel with lower loss tangent, harder and more solid than starch gel with higher loss tangent [121].

4-9-2-starch gel texture

Tissue profile analysis device(TPA[59]) The produced starch gel is compressed using a probe after the analysis of pastiness, and in terms of texture, the resulting gel is examined and parameters such as hardness[60], adhesion[61] and gummy state[62] records or calculates On the other hand, the textural properties of starch depend on several factors, including amylose content, variety difference, and molecular weight of amylopectin [122]. In addition to the gel texture when using gelatinized starch paste for many industrial applications, transparency is one of the important properties to be considered.

4-9-3-Stability of gel freezing and melting

When the gelatinized starch paste is gradually cooled, the crystallinity, gel hardness and turbidity of the starch gel begin to increase, and polymorph typeB It appears in the system with other changes. These changes are the characteristics of the phenomenon defined as starch retrogression. Short-term staleness is mainly attributed to amylose recombination, while long-term

[59] -Texture Profile Analysis
[60] - Hardness
[61] - Adhesiveness
[62] - Chewiness

staleness is attributed to amylopectin recrystallization.

The freezing and thawing stability of starch gels is one of the important characteristics of food starches. This stability is determined by the gravimetric measurement of the exit water (synersis) from the gel after freezing and thawing of the starch gel. This secretion occurs due to the reconnection of amylose molecules. Also, the amount of starch gel syneresis depends on factors such as structural differences (degree of amylose polymerization, amylopectin chain length, ratio of short chains).

On the other hand, the amount of syneresis of leguminous starch at 16 °C in the range (72-14٪) is located and follows the following order: black beans, peas > lentils > flat peas > beans > beans.

Also, due to low interactions between starch chains and the slow occurrence of these interactions during frozen storage, bean starch has a much lower synergism rate (16-22%) than other legume starches [12].

4-9-4-Effect of ultrasound on starch gel tissue

Ultrasonic treatment improves light transmission through starch gel due to increasing water solubility and facilitating the hydration of starch chains, which leads to greater transparency of starch gel [123]. On the other hand, ultrasonic treatment allows more water to be absorbed by the starch granules and the granules swell more, which increases the swelling and increases the viscosity, which makes it harder for light to pass through the starch gel and reduces the transparency of the resulting gel. Also, the effect of ultrasound is influenced by the type and composition of starch[107].

In 2018, Majid et al. investigated the effect of ultrasound treatment with low power, frequency of 33 kHz for a duration of 45 minutes on chickpea and vetiver starch. The results of this report showed that the syneresis of natural pea and vetiver starch is from 47.82-60 g per 100 g of gel (pea) and 29.51-46.51 g per 100 g of gel (vegetable) after storage at 0-120 The clock increased. Also, ultrasound treatment increased syneresis due to increased interaction between secreted amylose and amylopectin molecule during storage[74]. On the other hand, Karaman et al. in 2016, the effect of ultrasound treatment with a fixed frequency of 22 kHz, frequency range of 40, 70, 100%, power of 100 W, 200-250 W and 400-460 W for 3.5, 2.5 and 1.5 hours respectively. The pulse mode (25 seconds off and 5 seconds on) was investigated on bean starch, pea starch, red and green lentil starch. The results of this report showed that the amount of gummy state did not change under the influence of starch type and ultrasound conditions. Although the hardness value changed under the influence of pulse type and ultrasonic conditions. Green lentil starch showed the highest hardness and red lentil starch showed the least hardness among the starches mentioned above. Also, the amount of hardness was directly related to the amount of damage to starch granules, for example, the most damage is related to the softest starch, red lentil starch, and the least damage is related to the hardest starch, green lentil starch. On the other hand, only the type of starch had an effect on the adhesion parameter value, and chickpea and red lentil starch showed more adhesion than bean starch and green lentil starch. Also, green lentil starch had the lowest adhesion. On the other hand, ultrasound treatment

The hardness of bean starch, red lentil starch and green lentil starch gels decreased due to mechanical vibrations, cavitation effects and reduction of double helix, but this treatment increased the hardness of pea starch gel. Also, ultrasound treatment reduced cohesion and springiness, and this reduction increased with increasing ultrasound frequency range[76].

۵- Ultrasonic applications in starch-related industries

Ultrasound has been widely applied in various industries, and the commercialization of sonication techniques for various food and other industrial applications such as defoaming and extrusion has been successful, so there is great potential for the commercialization of ultrasound for various starch applications.[124] Among the various applications of ultrasound in starch-related industries, the most reported application has been improving the extraction of starch from various botanical sources. Also, among other applications of ultrasound treatment in starch-related industries, we can mention the preparation of starch nanoparticles and the production of sugar and bioethanol from starch.[125]

1-5-Preparation of starch nanoparticles

Nanoparticles with special properties have been used in many aspects and their creation from biomacromolecules including cellulose and starch has been of interest to manufacturers and researchers.[126] On the other hand, ultrasound treatment can be used to produce nanoparticles mainly due to damaging starch granules and depolymerization of molecular chains in the amorphous regions of starch granules. Also, with the help of ultrasound treatment, nanoparticles can be produced from various starches with different sizes (about a few nanometers to hundreds of nanometers), which have a high potential to be used as materials for coating and film preparation.[127]

5-2- Production of sugar and biological ethanol from starch

Ultrasonic treatment can be used in liquefaction and sugar production. Ultrasonic pretreatment can be used in high concentrations of corn starch to improve liquefaction at high temperature. Because ultrasonic treatment increases the speed of enzymatic reaction and increases the speed of glucose release by creating a starch with an uneven and porous surface, a looser granule structure, less relative crystallization, and a higher amylose content.[128] On the other hand, bioethanol is considered as a promising alternative to the main sources of energy, especially fossil fuels, which are in short supply and are not environmentally friendly. Among the various substrates for bioethanol production, starch-based feedstocks are the most common in industry because they are easily obtained and inexpensive.[129] Usually, starch-containing raw materials are pretreated with ultrasound and then used for bioethanol production.، Because the ultrasound pretreatment accelerates the liquefaction, which leads to the improvement of the bioethanol conversion rate and efficiency, and reduces the cost of the whole process.[130]

6-Conclusion

Modifying the physicochemical and functional properties of legume starches using different physical or chemical methods may create new features for their wide applications. It has been proven that modification of legume starch using ultrasound technology is a new alternative to chemical modifications. It can also be concluded that ultrasound is a physical

modification technology with high efficiency, low production cost, easy operation and environmental friendliness. Also, ultrasound parameters such as application duration, power, frequency and frequency range can be effective on the properties of ultrasound-modified legume starch.

7- Resources

[1]Zhu, F. 2015. Impact of ultrasound on structure, physicochemical properties, modifications, and applications of starch. J. Trends Food Sci Technol, 43(1): 1-17.

[2]Feng, H., Barbosa-Cánovas, G.V., and Weiss, J. eds. 2011. Ultrasound technologies for food and bioprocessing (Vol. 1, p. 599). New York: Springer.

[3]Park, S., and Kim, Y.R. 2021. Clean label starch: production, physicochemical characteristics, and industrial applications. J. Food Sci. Biotechnol, 30: 1-17.

[4]Mallakpour, S. 2018. Ultrasonic-assisted fabrication of starch/MWCNT-glucose nanocomposites for drug delivery. J. Ultrasound. Sonochem, 40:402-409.

[5]Ogutu, F. O., Mu, T. H., Elahi, R., Zhang, M.,and Sun, H. N. 2015. Ultrasonic modification of selected polysaccharides-review. J. Food Process. Technol, 6(05): 446.

[6]Patist, A., and Bates, D. 2008. Ultrasonic innovations in the food industry: From the laboratory to commercial production. J. IFSET, 9(2): 147-154.

[7]Kentish, S., and Feng, H. 2014. Applications of power ultrasound in food processing. J. Annu. rev. food sci, 5: 263-284.

[8]Jambrak, A. R., Herceg, Z., Šubarić, D., Babić, J., Brnčić, M., Brnčić, S. R., Bosiljkov, T., Čvek, D., Tripalo, B., and Gelo, J. 2010. Ultrasound effect on physical properties of corn starch. J. Carbohydr. Polym, 79(1): 91-100.

[9]HerCeg, I. L., Jambrak, A. R., ŠubArIć, D., Brnčić, M., Brnčić, S. R., Badanjak, M., Tripalo, B., Ježek, D., Novotni, D., and Herceg, Z. 2010. Texture and pasting properties of ultrasonically treated corn starch. J. Czech. Food Sci, 28(2): 83-93.

[10]Hoover, R. 2011. Composition, molecular structure, and physicochemical properties of tuber and root starches: a review. J. Carbohydr. Polym, 45(3): 253-267.

[11]Zhu, F., and Wang, S. 2014. Physicochemical properties, molecular structure, and uses of sweetpotato starch. J. Trends Food Sci Technol, 36(2): 68-78.

[12]Zhu, F. 2017. Structures, physicochemical properties, and applications of amaranth starch. J. Crit Rev Food Sci Nutr, 57(2): 313-325.

[13]Boukhalfa, F., Kadri, N., Bouchemel, S., Ait Cheikh, S., Chebout, I., and Madani, K. 2018. Chemically modified starch and utilization in food stuffs. J. Mediterranean Journal of Nutrition and Metabolism, 11: 37-50.

[14]Liu, H., Ramsden, L., and H, Corke. 1999. Physical properties and enzymatic digestibility of hydroxypropylated ae, wx, and normal maize starch. J. Carbohydr. Polym, 40(3): 175-182.

[15]Mason, W.R. 2009. Starch use in foods. In Starch (pp. 745-795). Academic Press.

[16]Glittenberg, D. 2012. Starch-based biopolymers in paper, corrugating, and other industrial applications. 165-193.

[17]Majzoobi, M., and Farahnaky, A. 2021. Granular cold-water swelling starch; properties, preparation and applications, a review. J. Food Hydrocoll, 111: 106393.

[18]Laovachirasuwan, P., Peerapattana, J., Srijesdaruk, V., Chitropas, P., and Otsuka, M. 2010. The physicochemical properties of a spray dried glutinous rice starch biopolymer. J. Colloids Surf. B, 78(1): 30-35.

[19]Jeong, D., Han, J.A., Liu, Q., and Chung, H.J. 2019. Effect of processing, storage, and modification on in vitro starch digestion characteristics of food legumes: A review. J. Food Hydrocoll, 90: 367-376.

[20]Chibbar, R.N., Ambigaipalan, P., and Hoover, R. 2010. Molecular diversity in pulse seed starch and complex carbohydrates and its role in human nutrition and health. J. Cereal Chem, 87(4): 342-352.

[21]Kossmann, J., and Lloyd, J. 2000. Understanding and influencing starch biochemistry. J. CRC Crit Rev Plant Sci, 19(3): 171-226.

[22]Li, L., Yuan, T.Z., Setia, R., Raja, R.B., Zhang, B., and Ai, Y. 2019. Characteristics of pea, lentil and

faba bean starches isolated from air-classified flours in comparison with commercial starches. J. Food Chem, 276: 599-607.

[23]Keskin, S.O., Ali, T.M., Ahmed, J., Shaikh, M., Siddiq, M., and Uebersax, M.A. 2022. Physico-chemical and functional properties of legume protein, starch, and dietary fiber—A review. J. Legume Science, 4(1): 117.

[24]Hoover, R., and Sosulski, F.W. 1991. Composition, structure, functionality, and chemical modification of legume starches: a review. J. Can. J. Physiol. Pharmacol, 69(1): 79-92.

[25]Hoover, R., Hughes, T., Chung, H.J., and Liu, Q. 2010. Composition, molecular structure, properties, and modification of pulse starches: A review. J. Food Res. Int, 43(2): 399-413.

[26]Bemiller, J.N. 1997. Starch modification: challenges and prospects. J. Starch-Strength, 49(4): 127-131.

[27]Tharanathan, R.N. 2005. Starch—value addition by modification. J. Crit Rev Food Sci Nutr, 45(5): 371-384.

[28]Joshi, M., Aldred, P., McKnight, S., Panozzo, J.F., Kasapis, S., Adhikari, R., and Adhikari, B. 2013. Physicochemical and functional characteristics of lentil starch. J. Carbohydr. Polym, 92(2): 1484-1496.

[29]Chen, X., Zhang, Z., Ji, N., Li, M., Wang, Y., Xiong, L., and Sun, Q. 2022. The effect of ethanol solution annealing on the physicochemical properties of pea and potato starches. J. Food Hydrocoll, 125: 107428.

[30]Hu, A., Li, Y., and Zheng, J. 2019. Dual-frequency ultrasonic effect on the structure and properties of starch with different size. J. Lwt, 106: 254-262.

[31]Thirumdas, R., Kadam, D., and Annapure, U.S. 2017. Cold plasma: An alternative technology for the starch modification. J. Food Biophys, 12: 129-139.

[32]Neelam, K., Vijay, S., and Lalit, S. 2012. Various techniques for the modification of starch and the applications of its derivatives. J. IRJP, 3(5): 25-31.

[33]Hoover, R., Hannouz, D., and Sosulski, F.W. 1988. Effects of hydroxypropylation on themal properties, starch digestibility and freeze-thaw stability of field pea (pisum sativum cv trapper) starch. J. Starch-Strength, 40(10): 383-387.

[34]Huang, J., Schols, H.A., Jin, Z., Sulmann, E., and Voragen, A.G. 2007. Characterization of differently sized granule fractions of yellow pea, cowpea and chickpea starches after modification with acetic anhydride and vinyl acetate. J. Carbohydr. Polym, 67(1): 11-20.

[35]Ashogbon, A.O., and Akintayo, E.T. 2014. Recent trend in the physical and chemical modification of starches from different botanical sources: A review. J. Starch-Strength, 66(1-2): 41-57.

[36]Guleria, P., and Yadav, B.S. 2022. Effect of chemical treatments on the functional, morphological and rheological properties of starch isolated from pigeon pea (Cajanus cajan). J. CRFS, 5: 1750-1759.

[37]Chaiwat, W., Wongsagonsup, R., Tangpanichyanon, N., Jariyaporn, T., Deeyai, P., Suphantharika, M., Fuongfuchat, A., Nisoa, M., and Dangtip, S. 2016. Argon plasma treatment of tapioca starch using a semi-continuous downer reactor. J. Food Bioproc Tech, 9: 1125-1134.

[38]Gu, Z., Chen, B., and Tian, Y. 2021. Highly branched corn starch: Preparation, encapsulation, and release of ascorbic acid. J. Food Chem, 343: 128485.

[39]Chiu, C.W., and Solarek, D. 2009. Modification of starches. J. Food Sci. Technol, 629-655.

[40]Hansen, M.R., Blennow, A., Pedersen, S., Nørgaard, L., and Engelsen, S.B. 2008. Gel texture and chain structure of amylomaltase-modified starches compared to gelatin. J. Food Hydrocoll, 22(8): 1551-1566.

[41]Ao, Z., Simsek, S., Zhang, G., Venkatachalam, M., Reuhs, B.L., and Hamaker, B.R. 2007. Starch with a slow digestion property produced by altering its chain length, branch density, and crystalline structure. J. Agric. Food Chem, 55(11): 4540-4547.

[42]Kaur, B., Ariffin, F., Bhat, R., and Karim, A.A. 2012. Progress in starch modification in the last decade. J. Food Hydrocoll, 26(2): 398-404.

[43]Gulu, N.B., Jideani, V.A., and Jacobs, A. 2019. Functional characteristics of Bambara groundnut starch-catechin complex formed using cyclodextrins as initiators. J. Helion, 5(4): e01562.

[44]Guo, Z., Zeng, S., Lu, X., Zhou, M., Zheng, M., and Zheng, B. 2015. Structural and physicochemical properties of lotus seed starch treated with ultra-high pressure. J. Food Chem, 186: 223-230.

[45]Han, Z., Zeng, X.A., Zhang, B.S., and Yu, S.J. 2009. Effects of pulsed electric fields (PEF)

treatment on the properties of corn starch. J. Food Eng, 93(3): 318-323.

[46]Bashir, K., and Aggarwal, M. 2017. Physicochemical, thermal and functional properties of gamma irradiated chickpea starch. J. Int. J. Biol. Macromol, 97: 426-433.

[47]Luo, Z., Fu, X., He, X., Luo, F., Gao, Q., and Yu, S. 2008. Effect of ultrasonic treatment on the physicochemical properties of maize starches differing in amylose content. J. Starch-Strength, 60(11): 646-653.

[48]Kaur, H., and Gill, B.S. 2019. Effect of high-intensity ultrasound treatment on nutritional, rheological and structural properties of starches obtained from different cereals. J. Int. J. Biol. Macromol, 126: 367-375.

[49]Du, M., Cao, T., Yu, M., Zhang, C., and Xu, W. 2023. Effect of heat-moisture treatment on physicochemical properties of chickpea starch. J. Food Sci. Technol, 43.

[50]Din, Z.D., Xiong, H., and Fei, P. 2017. Physical and chemical modification of starches: A review. J. Crit Rev Food Sci Nutr, 57(12): 2691-2705.

[51]Chan, H.T., Bhat, R., and Karim, A.A. 2010. Effects of sodium dodecyl sulphate and sonication treatment on physicochemical properties of starch. J. Food Chem, 120(3): 703-709.

[52]Zuo, Y.Y.J., Hébraud, P., Hemar, Y., and Ashokkumar, M. 2012. Quantification of high-power ultrasound induced damage on potato starch granules using light microscopy. J. Ultrason Sonochem, 19(3): 421-426.

[53]Czechowska-Bishop , R. , Rokita , B. , Lotfy , S. , Ulanski , P. , and Rosiak , J.M. . 2005. Degradation of chitosan and starch by 360-kHz ultrasound. J. Carbohydr. Polym, 60(2): 175-184.

[54]Riesz, P., and Kondo, T. 1992. Free radical formation induced by ultrasound and its biological implications. J. Free Radic. Biol. Med, 13(3): 247-270.

[55]Szent-Györgyi, A. 1933. Chemical and biological effects of ultra-sonic radiation. J.Nature, 131(3304): 278-278.

[56]Peat, S. 1952. Evidence of multiple branching in waxy maize starch. J. chem, Soc.

[57]Bertoft, E., Piyachomkwan, K., Chatakanonda, P., and Sriroth, K. 2008. Internal unit chain composition in amylopectins. J. Carbohydr. Polym, 74(3): 527-543.

[58]Srichuwong, S., and Jane, J.I. 2007. Physicochemical properties of starch affected by molecular composition and structures: a review. J. Food Sci. Biotechnol, 16(5): 663-674.

[59]Su, C., Saleh, A.S., Zhang, B., Zhao, K., Ge, X., Zhang, Q., and Li, W. 2020. Changes in structural, physicochemical, and digestive properties of normal and waxy wheat starch during repeated and continuous annealing. J. Carbohydr. Polym, 247: 116675.

[60]Hanashiro, I., Abe, J.I., and Hizukuri, S. 1996. A periodic distribution of the chain length of amylopectin as revealed by high-performance anion-exchange chromatography. J. Carbohydr. Res, 283: 151-159.

[61]Zhu, F., Corke, H., and Bertoft, E. 2011. Amylopectin internal molecular structure in relation to physical properties of sweetpotato starch. J. Carbohydr. Polym, 84(3): 907-918.

[62]Biliaderis, C.G., Maurice, T.J., and Vose, J.R. 1980. Starch gelatinization phenomena studied by differential scanning calorimetry. J. Food Sci, 45(6): 1669-1674.

[63]Zheng, J., Li, Q., Hu, A., Yang, L., Lu, J., Zhang, X., and Lin, Q. 2013. Dual-frequency ultrasound effect on structure and properties of sweet potato starch. J. Starch-Strength, 65(7-8): 621-627.

[64]Sujka, M., and Jamroz, J. 2013. Ultrasound-treated starch: SEM and TEM imaging, and functional behaviour. J. Food Hydrocoll, 31(2): 413-419.

[65]Li, C., Liu, W., Gu, Z., Fang, D., Hong, Y., Cheng, L., and Li, Z. 2017. Ultrasonic pretreatment improves the high-temperature liquefaction of corn starch at high concentrations. J. Starch-Strength, 69(3-4): 1600002.

[66]Iida, Y., Tuziuti, T., Yasui, K., Towata, A., and Kozuka, T. 2008. Control of viscosity in starch and polysaccharide solutions with ultrasound after gelatinization. J. IFSET, 9(2): 140-146.

[67]Zuo, J.Y., Knoerzer, K., Mawson, R., Kentish, S., and Ashokkumar, M. 2009. The pasting properties of sonicated waxy rice starch suspensions. J. Ultrason Sonochem, 16(4): 462-468.

[68]Carmona-García, R., Bello-Pérez, L.A., Aguirre-Cruz, A., Aparicio-Saguilán, A., Hernández-Torres, J., and Alvarez-Ramirez, J. 2016. Effect of ultrasonic treatment on the morphological, physicochemical, functional, and rheological properties of starches with

different granule size. J. Starch-Strength, 68(9-10): 972-979.

[69]Bitik, A., Sumnu, G., and Oztop, M. 2019. Physicochemical and structural characterization of microfluidized and sonicated legume starches. J. Food Bioproc Tech, 12: 1144-1156.

[70] Grgić, I., Ačkar, Đ., Barišić, V., Vlainić, M., Knežević, N., and Medverec Knežević, Z. 2019. Nonthermal methods for starch modification—A review. J. Food Process. Preserv, 43(12): e14242.

[71]Shen, H., Guo, Y., Zhao, J., Zhao, J., Ge, X., Zhang, Q., and Yan, W. 2021. The multi-scale structure and physicochemical properties of mung bean starch modified by ultrasound combined with plasma treatment. J. Int. J. Biol. Macromol, 191: 821-831.

[72]Han, L., Cao, S., Yu, Y., Xu, X., Cao, X., and Chen, W. 2021. Modification in physicochemical, structural and digestive properties of pea starch during heat-moisture process assisted by pre-and post-treatment of ultrasound. J. Food Chem, 360: 129929.

[73]Gallant, D., Degrois, M., Sterling, C., and Guilbot, A. 1972. Microscopic effects of ultrasound on the structure of potato starch preliminary study. J. Starch-Strength, 24(4): 116-123.

[74]Majeed, T., Wani, I.A., Hamdani, A.M., and Bhat, N.A. 2018. Effect of sonication and γ-irradiation on the properties of pea (Pisum sativum) and vetch (Vicia villosa) starches: A comparative study. J. Int. J. Biol. Macromol, 114: 1144-1150.

[75]Hoover, R., and Ratnayake, W.S. 2002. Starch characteristics of black bean, chick pea, lentil, navy bean and pinto bean cultivars grown in Canada. J. Food Chem, 78(4): 489-498.

[76]Karaman, M., Tuncel, N.B., and Yılmaz Tuncel, N. 2017. The effect of ultrasound-assisted extraction on yield and properties of some pulse starches. J. Starch-Strength, 69(9-10): 1600307.

[77]Acevedo, B.A., Villanueva, M., Chaves, M.G., Avanza, M.V., and Ronda, F. 2022. Modification of structural and physicochemical properties of cowpea (Vigna unguiculata) starch by hydrothermal and ultrasound treatments. J. Food Hydrocoll, 124: 107266.

[78]Chen, Z., Schols, H.A., and Voragen, A.G.J. 2003. Physicochemical properties of starches obtained from three varieties of Chinese sweet potatoes. J. Food Sci, 68(2): 431-437.

[79]Zhu, T., Jackson, D.S., Wehling, R.L., and Geera, B. 2008. Comparison of amylose determination methods and the development of a dual wavelength iodine binding technique. J. Cereal Chem, 85(1): 51-58.

[80]Zhu, F., Yang, X., Cai, Y.Z., Bertoft, E., and Corke, H. 2011. Physicochemical properties of sweetpotato starch. J. Starch-Strength, 63(5): 249-259.

[81]Zhu, F., Bertoft, E., Kallman, A., Myers, A.M., and Seetharaman, K. 2013. Molecular structure of starches from maize mutants deficient in starch synthase III. J. Agric. Food Chem, 61(41): 9899-9907.

[82]Abegunde, O.K., Mu, T.H., Chen, J.W., and Deng, F.M. 2013. Physicochemical characterization of sweet potato starches popularly used in Chinese starch industry. J. Food Hydrocoll, 33(2): 169-177.

[83]Waramboi, J.G., Dennien, S., Gidley, M.J., and Sopade, P.A. 2011. Characterisation of sweetpotato from Papua New Guinea and Australia: Physicochemical, pasting and gelatinisation properties. J. Food Chem, 126(4): 1759-1770.

[84]Alcázar-Alay, S.C., and Meireles, M.A.A. 2015. Physicochemical properties, modifications and applications of starches from different botanical sources. J. Food Sci. Technol, 35: 215-236.

[85]Geddes, R., Greenwood, C.T., and Mackenzie, S. 1965. Studies on the biosynthesis of starch granules: Part III. The properties of the components of starches from the growing potato tuber. J. Carbohydr. Res, 1(1): 71-82.

[86]Li, G., Wang, S., and Zhu, F. 2016. Physicochemical properties of quinoa starch. J. Carbohydr. Polym, 137: 328-338.

[87]Cao, M., and Gao, Q. 2020. Effect of dual modification with ultrasonic and electric field on potato starch. J. Int. J. Biol. Macromol, 150: 637-643.

[88]Morrison, W.R., Milligan, T.P., and Azudin, M.N. 1984. A relationship between the amylose and lipid contents of starches from diploid cereals. J. Cereal Sci, 2(4): 257-271.

[89]Singh, N., Singh, J., Kaur, L., Sodhi, N.S., and Gill, B.S. 2003. Morphological, thermal and rheological properties of starches from different botanical sources. J. Food Chem, 81(2): 219-231.

[90]Bertoft, E. 2017. Understanding starch structure: Recent progress. J. Agron, 7(3): 56.

[91]Gernat, C., Radosta, S., Damaschun, G., and Schierbaum, F. 1990. Supramolecular structure of legume starches revealed by X-ray scattering. J. Starch-Strength, 42(5): 175-178.

[92]Hizukuri, S. 1985. Relationship between the distribution of the chain length of amylopectin and the crystalline structure of starch granules. J. Carbohydr. Res, 141(2): 295-306.

[93]Miao, M., Zhang, T., and Jiang, B. 2009. Characterisations of kabuli and desi chickpea starches cultivated in China. J. Food Chem, 113(4): 1025-1032.

[94]Zhu, J., Li, L., Chen, L., and Li, X. 2012. Study on supramolecular structural changes of ultrasonic treated potato starch granules. J. Food Hydrocoll, 29(1): 116-122.

[95]Huang, Q., Li, L., and Fu, X. 2007. Ultrasound effects on the structure and chemical reactivity of cornstarch granules. J. Starch-Strength, 59(8): 371-378.

[96]Wang, S., Hu, X., Wang, Z., Bao, Q., Zhou, B., Li, T., and Li, S. 2020. Preparation and characterization of highly lipophilic modified potato starch by ultrasound and freeze-thaw treatments. J. Ultrason Sonochem, 64: 105054.

[97]Karwasra, B.L., Kaur, M., and Gill, B.S. 2020. Impact of ultrasonication on functional and structural properties of Indian wheat (Triticum aestivum L.) cultivar starches. J. Int. J. Biol. Macromol, 164: 1858-1866.

[98]Genkina, N.K., Kozlov, S.S., Martirosyan, V.V., and Kiseleva, V.I. 2014. Thermal behavior of maize starches with different amylose/amylopectin ratio studied by DSC analysis. J. Starch-Strength, 66(7-8): 700-706.

[99]Vamadevan, V., and Bertoft, E. 2015. Structure-function relationships of starch components. J. Starch-Strength, 67(1-2): 55-68.

[100]Ai, Y., and Jane, J.L. 2015. Gelatinization and rheological properties of starch. J. Starch-Strength, 67(3-4): 213-224.

[101]Noda, T., Takahata, Y., Sato, T., Suda, I., Morishita, T., Ishiguro, K., and Yamakawa, O. 1998. Relationships between chain length distribution of amylopectin and gelatinization properties within the same botanical origin for sweet potato and buckwheat. J. Carbohydr. Polym, 37(2): 153-158.

[102]Yu, S., Zhang, Y., Ge, Y., Zhang, Y., Sun, T., Jiao, Y., and Zheng, X.Q. 2013. Effects of ultrasound processing on the thermal and retrogradation properties of nonwaxy rice starch. J. Food Process Eng, 36(6): 793-802.

[103]Yang, W., Kong, X., Zheng, Y., Sun, W., Chen, S., Liu, D., Zhang, H., Fang, H., Tian, J., and Ye, X. 2019. Controlled ultrasound treatments modify the morphology and physical properties of rice starch rather than the fine structure. J. Ultrason Sonochem, 59: 104709.

[104]Vela, A.J., Villanueva, M., Solaesa, Á.G., and Ronda, F. 2021. Impact of high-intensity ultrasound waves on structural, functional, thermal and rheological properties of rice flour and its biopolymers structural features. J. Food Hydrocoll, 113: 106480.

[105]Copeland, L., Blazek, J., Salman, H., and Tang, M.C. 2009. Form and functionality of starch. J. Food Hydrocoll, 23(6): 1527-1534.

[106]Hoover, R., and Sosulski, F.J.S.S. 1985. Studies on the functional characteristics and digestibility of starches from Phaseolus vulgaris biotypes. J. Starch-Strength, 37(6): 181-191.

[107]Sit, N., Misra, S., and Deka, S.C. 2014. Yield and functional properties of taro starch as affected by ultrasound. J. Food Bioproc Tech, 7: 1950-1958.

[108]Kim, Y.Y., Woo, K.S., and Chung, H.J. 2018. Starch characteristics of cowpea and mungbean cultivars grown in Korea. J. Food Chem, 263: 104-111.

[109]Zhong, Y., Xiang, X., Zhao, J., Wang, X., Chen, R., Xu, J., Luo, S., Wu, J., and Liu, C. 2020. Microwave pretreatment promotes the annealing modification of rice starch. J. Food Chem, 304: 125432.

[110]Schoch, T.J. 1968. Preparation and properties of various legume starches. J. Cereal Chem, 45: 564-573.

[111]Tolmasquim, E., Correa, A.M.N., and Tolmasqui, S.T. 1971. New starches. Properties of five varieties of cowpea starch. J. Cereal Chem.

[112]Tester, R.F., Morrison, W.R., and Schulman, A.H. 1993. Swelling and gelatinization of cereal starches. V. Risø mutants of Bomi and Carlsberg II barley cultivars. J. Cereal Sci, 17(1): 1-9.

[113]Tu, Z., Yin, Y., Wang, H., Liu, G., Chen, L., Zhang, P., Kou, Y., and Zhang, L. 2013. Effect of

dynamic high-pressure microfluidization on the morphology characteristics and physicochemical properties of maize amylose. J. Starch-Strength, 65(5-6): 390-397.

[114]Ding, Y., Luo, F., and Lin, Q. 2019. Insights into the relations between the molecular structures and digestion properties of retrograded starch after ultrasonic treatment. J. Food Chem, 294: 248-259.

[115]Majeed, T., Wani, I.A., and Hussain, P.R. 2017. Effect of dual modification of sonication and γ-irradiation on physicochemical and functional properties of lentil (Lens culinaris L.) starch. J. Int. J. Biol. Macromol, 101: 358-365.

[116]Hughes, T., Hoover, R., Liu, Q., Donner, E., Chibbar, R., and Jaiswal, S. 2009. Composition, morphology, molecular structure, and physicochemical properties of starches from newly released chickpea (Cicer arietinum L.) cultivars grown in Canada. J. Food Res. Int, 42(5-6): 627-635.

[117]Qi, X., and Tester, R.F. 2016. Effect of native starch granule size on susceptibility to amylase hydrolysis. J. Starch-Strength, 68(9-10): 807-810.

[118]Acevedo, B.A., Villanueva, M., Chaves, M.G., Avanza, M.V., and Ronda, F. 2020. Starch enzymatic hydrolysis, structural, thermal and rheological properties of pigeon pea (Cajanus cajan) and dolichos bean (Dolichos lab-lab) legume starches. J. Int. J. Food Sci. Technol, 55(2): 712-719.

[119]Kong, X., Kasapis, S., Bertoft, E., and Corke, H. 2010. Rheological properties of starches from grain amaranth and their relationship to starch structure. J. Starch-Strength, 62(6): 302-308.

[120]Zhu, F., Bertoft, E., and Li, G. 2016. Morphological, thermal, and rheological properties of starches from maize mutants deficient in starch synthase III. J. Agric. Food Chem, 64(34): 6539-6545.

[121]Wu, K., Dai, S., Gan, R., Corke, H., and Zhu, F. 2016. Thermal and rheological properties of mung bean starch blends with potato, sweet potato, rice, and sorghum starches. J. Food Bioproc Tech, 9: 1408-1421.

[122]Karunaratne, R., and Zhu, F. 2016. Physicochemical interactions of maize starch with ferulic acid. J. Food Chem, 199: 372-379.

[123]Chung, K.M., Moon, T.W., Kim, H., and Chun, J.K. 2002. Physicochemical properties of sonicated mung bean, potato, and rice starches. J. Cereal Chem, 79(5): 631-633.

[124]Awad, T. S., Moharram, H. A., Shaltout, O. E., Asker, D., and Youssef, M. M. 2012. Applications of ultrasound in analysis, processing and quality control of food: A review. J. Food Res. Int, 48: 410–427.

[125]Setyawati, Y. D., Ahsan, S. F., Ong, L. K., Soetaredjo, F. E., Ismadji, S., and Ju, Y. H. 2016. Production of glutinous rice flour from broken rice via ultrasonic assisted extraction of amylose. J. Food Chem, 203: 158–164.

[126]Bel Haaj, S., Magnin, A., Pétrier, C., and Boufi, S. 2013. Starch nanoparticles formation via high power ultrasonication. J. Carbohydr. Polym, 92:1625–1632.

[127]Gonçalves, P. M., Noreña, C. P. Z., da Silveira, N. P., and Brandelli, A. 2014. Characterization of starch nanoparticles obtained from Araucaria angustifolia seeds by acid hydrolysis and ultrasound. J. LWT-Food Sci Technol, 58: 21–27.

[128]Li, C., Liu, W., Gu, Z., Fang, D., Hong, Y., Cheng, L., and Li, Z. 2016. Ultrasonic pretreatment improves the high-temperature liquefaction of corn starch at high concentrations. J. Starch- Stärke, 68: 1–7.

[129]Nikolić, S., Mojović, L., Rakin, M., Pejin, D., and Pejin, J. 2010. Ultrasound-assisted production of bioethanol by simultaneous saccharification and fermentation of corn meal. J. Food Chem, 122: 216–222.

[130]Pejin, D. J., Mojović, L. V., Pejin, J. D., Grujić, O. S., Markov, S. L., Nikolić, S. B., and Marković, M. N. 2012. Increase in bioethanol production yield from triticale by simultaneous saccharification and fermentation with application of ultrasound. J. Chem. Technol. Biotechnol, 87: 170–176.

مجله علوم و صنایع غذایی ایران

سایت مجله: www.fsct.modares.ac.ir

مقاله علمی_پژوهشی

تأثیر تیمار فراصوت بر خواص فیزیکوشیمیایی، رئولوژیکی و ساختاری نشاسته‌های استخراج شده از حبوبات مختلف

محمدکاظم حیدریان[۱]، علیرضا حیدریان[۲]، سیدعلی مرتضوی[۳*]

۱-دانشجوی کارشناسی ارشد، گروه آموزشی علوم و مهندسی صنایع غذایی گرایش فناوری، دانشگاه فردوسی مشهد، مشهد، ایران

۲-دانشجوی کارشناسی ارشد، گروه آموزشی علوم و مهندسی صنایع غذایی گرایش زیست‌فناوری، دانشگاه فردوسی مشهد، مشهد، ایران

۳-استاد، گروه علوم و مهندسی صنایع غذایی، دانشکده کشاورزی، دانشگاه فردوسی مشهد، مشهد، ایران

اطلاعات مقاله

تاریخ های مقاله :

تاریخ دریافت: ۱۴۰۲/۲/۱۷

تاریخ پذیرش: ۱۴۰۲/۳/۲۳

کلمات کلیدی:

نشاسته حبوبات،

فراصوت،

اصلاح،

کاویتاسیون

DOI: 10.22034/FSCT.20.137.156

DOR:20.1001.1.20088787.1402.20.137.12.2

* مسئول مکاتبات:

morteza@um.ac.ir

چکیده

نشاسته فراوان‌ترین کربوهیدرات موجود در دانه حبوبات است. از طرف دیگر نشاسته حبوبات طبیعی به دلیل ماهیت غیر واکنشی و نامحلول بودن در آب سرد، کاربرد محدودی در صنایع غذایی دارد. نشاسته حبوبات طبیعی را می‌توان با روش‌های شیمیایی، فیزیکی و آنزیمی اصلاح کرد. نشاسته حبوبات اصلاح‌شده به دلیل خواص عملکردی بهبودیافته در صنایع غذایی اهمیت پیدا کردند. فراصوت یکی از روش‌های فیزیکی اصلاح نشاسته است که در این مقاله مورد بررسی قرار می‌گیرد. همچنین فراصوت به طور فزاینده‌ای برای اصلاح فیزیکوشیمیایی سیستم‌های غذایی به‌عنوان یک فناوری سبز استفاده می‌شود. هدف از این مطالعه بررسی اثر تیمار فراصوت (حمام - پروب) بر ویژگی‌های عملکردی، رئولوژیکی، حرارتی، مورفولوژی و ساختار کریستالی نمونه‌های نشاسته اصلاح‌شده می‌باشد. تغییر در خواص نشاسته اصلاح‌شده فراصوت عمدتاً به دلیل دپلیمریزاسیون زنجیره‌های آمیلوز و آمیلوپکتین است. پس از تیمار فراصوت، وزن مولکولی، ویسکوزیته و بلورینگی کاهش می‌یابد؛ بنابراین می‌توان نتیجه گرفت که فراصوت به‌عنوان فناوری جایگزین برای اصلاح خواص نشاسته حبوبات است.