Obtaining target dietary fats in the technology of step-by-step hydrogenation and their use

Obtención de grasas dietéticas objetivo mediante la tecnología de hidrogenación paso a paso y su uso

Karim Sattarov [1*].

Innovaciencia ISSN: 2346-075X

E- ISSN: 2346-075X
Innovaciencia 2023; 11(1); 1-13
http://dx.doi.org/10.15649/2346075X.3554

ORIGINAL RESEARCH

How to cite this paper:
Sattarov K., Obtaining target dietary fats in the technology of step-by-step hydrogenation and their use. Innovaciencia 2023; 11(1): 1-13.
http://dx.doi.org/10.15649/2346075X.3554

Received: 13 November 2023
Accepted: 30 November 2023
Published: 01 December 2023

Keywords:
Unsaturated fatty acids, Transisomers, Nickel catalyst, Fat and oil industry, Fat modification.

ABSTRACT

Introduction. Fats are an important component of a number of food products and affect their consistency, shelf life, taste, and nutritional qualities. Step-by-step hydrogenation is one of the main methods of modifying dietary fats, which allows for influencing their chemical structure and properties. The purpose of this study was to establish the main approaches to the step-by-step hydrogenation of dietary fats, the problems of the method, the main areas of use, and prospects for improving the technology. **Material and Methods.** A search to identify relevant papers was conducted for sources using open electronic databases, such as Google Scholar, Scopus, and Web of Science. **Results and Discussion.** During the study, the most common conditions of the hydrogenation reaction were established. The most important characteristics of the catalyst were determined by the activity, durability, selectivity, and stability of the formation of isomers. The formation of trans isomers of fatty acids, which reduces the quality of fat, has been identified as the main disadvantage of step-by-step hydrogenation. Factors contributing to the formation of trans isomers included high temperature, catalyst properties, and high content of unsaturated fatty acids in the feedstock. Step-by-step hydrogenation was identified to be the most characteristic of the soybean industry and for the production of confectionery and baking fats with specified properties. **Conclusion.** The results obtained indicate the potential of step-by-step hydrogenation to produce edible fats with a certain melting point and organoleptic characteristics after solving the cis/trans-isomerisation problem.

[1] Faculty of Production Technology, Gulistan State University, 120100, 4-microdistrict, Gulistan, Uzbekistan,
* Corresponding author: sattarovkarim178@gmail.com

INTRODUCTION

The primary trends in fat production for the margarine, bakery, and confectionery food industries revolve around the pursuit of a well-balanced fat composition with minimal transisomer content. To achieve this goal, a range of techniques is employed, including traditional methods like hydrogenation and fractionation, as well as innovative approaches such as the use of alternative, plant-based oils and non-thermal technologies. These efforts align with consumer preferences for healthier and more sustainable fat sources, reflecting the industry's commitment to providing functional and nutritionally sound products.

According to A.R. Patel et al. (1), in the field of food technology, the use of solid fats, usually of animal origin, is limited due to their low reproducibility, high saturation and melting temperatures. Consequently, the above-mentioned methods of modifying oils and fats are widely used. The conventional approach to the modification of vegetable fats also includes hydrogenation, in which the desired level of unsaturation is achieved (2). S.D. Bhandari et al. (3) stated that hydrogenated vegetable oils have been used since the beginning of the 20th century to expand the use of vegetable oils in food products. According to researchers, vegetable oils are the dominant type of edible oils, accounting for more than 70% of global consumption of edible oils. Hydrogenated fats give various widely consumed products a distinct taste, correct consistency, plasticity, and resistance to oxidation (4). On the other hand, the authors noted that the World Health Organization has called for the elimination of partially hydrogenated vegetable oils (PHVOs) from the global food supply and recommends their replacement with healthier alternatives.

J.H. Bruce (5) claims that hydrogenation allows changing the physical and chemical properties of fats, making them, among other things, more resistant to oxidative processes. This increases the shelf life of products and improves their texture and stability. A.R. Patel et al. (1) showed that the hydrogenation process can improve the organoleptic characteristics of fats, including taste, smell, and texture. This is especially useful for the production of oils, margarine, and other fatty products, where it is necessary to achieve the necessary qualities of the product. In the process of hydrogenation, a certain amount of unsaturated fatty acids is converted into trans fats (6, 7).

A.B. Oteng and S. Kersten (8) demonstrated that despite the fact that trans fats have a negative impact on health when consumed in large quantities, they have some advantages in the food industry. Trans fats can improve the structure and stability of products, provide a longer shelf life, and improve their functional properties. Hydrogenation allows increasing the content of a number of unsaturated fatty acids in dietary fats. According to I. Isabaev et al. (9), unsaturated fatty acids, such as omega-3 and omega-6, are essential for the normal functioning of the body and have a positive effect on the health of the heart and blood vessels. Thus, the enrichment of fats with unsaturated fatty acids allows offering consumers products with increased nutritional properties.

The purpose of this study was to analyse methods for obtaining technologically and physiologically functional baking and confectionery fats by combining non-selective and selective step-by-step hydrogenation and methods of their application. The objectives of the study included the analysis of general technological approaches to step-by-step hydrogenation, the role of catalysts and their selectivity in this process, the problems of the formation of trans isomers of fatty acids, and the possibilities of using targeted hydrogenated fats. This study identifies critical gaps in step-by-step hydrogenation technology, emphasizing the need for improved catalysts and the reduction of trans isomer formation. Solving the cis/trans isomerisation problem is essential to fully harness this technology's potential in producing dietary fats with specific properties.

MATERIALS AND METHODS

In this study, the preparation of target dietary fats using the method of step-by-step hydrogenation, and their potential use, was considered. In the course of the study, various aspects of the hydrogenation of dietary fats and their use were considered. This included investigating the hydrogenation process itself, the influence of various factors on the reaction results, determining the optimal conditions and properties of the obtained dietary fats. Data from open sources were used as materials, including studies, books, and publications related to the topic of hydrogenation of dietary fats. A search of sources was conducted using the electronic databases Google Scholar, Scopus, and Web of Science to identify relevant papers. The search strategy used a combination of keywords related to the topic, such as "targeted dietary fats", "step-by-step hydrogenation", and "application of dietary fats".

Studies were used for analysis if they met the following criteria: were aimed at obtaining target dietary fats using step-by-step hydrogenation technology; provided detailed information about the methodology used in step-by-step hydrogenation; reported on the use or application of these target dietary fats in food products. Studies were excluded if they were not written in English, Russian, or Uzbek, were meta-analyses themselves, or did not contain sufficient information about the methodology used for step-by-step hydrogenation or the use of targeted dietary fats.

The study was conducted on the basis of Gulistan State University. The initial review of the titles and abstracts of the identified studies was conducted by two reviewers to determine their eligibility for inclusion. Full-text papers of potentially relevant research were obtained and additionally evaluated for compliance with the requirements. The reviewers independently extracted the following information from each included study: authors, year of publication, study design, source of fats used, parameters of the hydrogenation process, and specific foods in which the target dietary fats were used. The methodological quality and risk of systematic error of the included studies were independently assessed by two reviewers using predefined criteria. Criteria included study design, clarity of reporting, and potential sources of systematic error. In the course of the study, nine sources were selected and analysed.

Initial edible fats, such as vegetable oils or animal fats, were used to describe the hydrogenation process. Information on the chemical composition of the starting materials was obtained from sources including data on the content of saturated and unsaturated fatty acids. The comparative analysis method used in the study included a comparison of various approaches to the hydrogenation of fats in such aspects as technological features (apparatus structure, reaction temperature, pressure, catalyst features), main disadvantages, and prospects for use. In this paper, using this method, the potential use of target dietary fats in the food industry is considered. To do this, an analysis of the results of previous studies and practical experience related to the use of similar dietary fats was conducted. The areas of the food industry on which the technology of step-by-step hydrogenation has the greatest impact were identified. Such possible applications of edible fats as the production of oils, margarine, dairy products, or pastries were considered.

RESULTS AND DISCUSSION

Technological features of the hydrogenation process

Step-by-step hydrogenation technology is a versatile chemical process employed primarily in the chemical and pharmaceutical industries. It entails selectively reducing or hydrogenating specific functional groups within organic compounds through a meticulously controlled series of steps [8, 9, 10]. Utilizing an appropriate catalyst and reaction conditions, hydrogen gas is gradually introduced into the reaction mixture to avoid over-reduction, thus enabling the precise modification of targeted functional groups while leaving others unaffected. This technology is instrumental in the production of specialty chemicals and pharmaceuticals, where the fine-tuned manipulation of molecular structures is essential for achieving desired properties and functions in the end products.

Hydrogenation is a process used to change the functional properties of liquid lipids. There are three types of hydrogenation:

- full hydrogenation is a chemical process that fully saturates double or triple bonds in organic compounds, often transforming unsaturated vegetable oils into solid, stable fats; however, it can result in the formation of unhealthy trans fats when used excessively;

- partial hydrogenation is a chemical process that saturates only some of the double or triple bonds in an organic compound, often utilized to create semi-solid or partially saturated fats found in processed snacks and baked goods. While these partially hydrogenated fats offer increased stability compared to unsaturated fats, they can still contain trans fats, which are associated with health concerns and are being gradually removed from various food products;

- partial hydrogenation without curing is a variation of the process where the hydrogenation is halted before full saturation, resulting in partially saturated fats with distinct properties, making them suitable for specialized industrial or culinary purposes, as they skip the curing step.

This process is aimed at converting oil into solid or semi-solid (plastic) fats. During hydrogenation, unsaturated fatty acids (FA) are converted into saturated fatty acids and trans isomers of fatty acids (TIFA), while increasing the oil's resistance to oxidation. The data obtained indicate that excessive oil moisture can negatively affect the process and lead to hydrolysis and the formation of free fatty acids. To mitigate such a negative effect, the researchers recommend drying the oils before or after being placed in an autoclave since these compounds can be saponified under hydrogenation conditions at high temperatures and using a nickel catalyst. The initial stage of the hydrogenation process involves heating the oil to 140℃, which is the initial temperature for the reaction indicated in all analysed studies. It was established that the specific reaction temperature can vary depending on the type of fat and the desired level of inhibition of the formation of trans fatty acids.

The analysis revealed that the most common definition of hydrogenation of oils is the saturation of double bonds in unsaturated fats using nickel as a catalyst. This process involves a complex set of reactions, in addition to direct saturation. The equipment for step-by-step hydrogenation has a relatively simple design. The main design features identified in all the analysed studies include a vessel capable of withstanding a manometric pressure of 35-40 kPa, a stirrer, a heating and cooling mechanism, an inlet for hydrogen, a pipeline, a pump for feeding raw materials, and a sampling pipe for monitoring the course of the reaction. This equipment allows controlling three main parameters: pressure, temperature, and mixing speed [11].

The hydrogen pressure in the reaction, according to the analysed data, is measured in the main space of the reactor and is regulated by an inlet valve. The free space can also be ventilated to remove gaseous impurities such as methane, nitrogen, carbon dioxide and carbon monoxide [12]. However, this ventilation process leads to some loss of hydrogen gas. M.A. Sánchez et al. [13] reported that ventilation increases the flow of hydrogen through the reaction mass, which leads to increased mixing. Mixing in the reactor is influenced by several factors. The main ones are the type and speed of the stirrer blades. In addition, the overall mixing effect is influenced by the design and number of heating and cooling coils, the presence of partitions and the speed at which hydrogen enters through a perforated distribution ring at the bottom of the reactor. Heating of the oil during periodic hydrogenation is usually achieved using high-pressure steam coils [14]. The analysed data showed that temperatures ranging from 140℃ to 225℃ were used for hydrogenation with a nickel catalyst. E.S. Jang et al. [15] report that it is possible to achieve higher temperatures by initiating the reaction at a standard starting temperature and providing exothermic heat of the reaction to increase it to the desired level.

The oil is pumped into the converter, while a vacuum is created in the free space to start the hydrogenation process, after which heating is conducted. Therewith, the catalyst is weighed and mixed in a catalyst mixture tank, forming a suspension with a small amount of oil. After reaching the desired gas formation temperature, the catalyst is pumped into the reactor and thoroughly mixed with oil. Hydrogen is then added to achieve the desired pressure. The reaction is initiated, and the temperature gradually rises to the working temperature. The reaction mass is cooled if necessary to maintain the desired temperature. The course of the reaction is monitored by observing changes in the refractive index. It was determined that most researchers point to the need for a preliminary step-by-step oil treatment before the hydrogenation process. Raw materials must be cleaned, bleached, and have a low content of soapy substances. According to R.R. Allen [16], the amount of soap substances in fat should be less than 25 mg/kg. In addition, the oil must be dry to ensure optimal hydrogenation results. As for the hydrogen used in the process, the gas must also be dry and have a low number of impurities. Modern hydrogen production plants using hydrocarbons can produce extremely pure hydrogen. On the other hand, older plants can produce hydrogen, which contains some methane, carbon dioxide, and potentially substantial amounts of nitrogen, if the source gas contained a high content of this gas. Some hydrogenation plants were designed to extract hydrogen from stored liquid hydrogen, which serves as a reliable backup gas source in case the gas plant is shut down [17, 18]. Following M. Žula et al. [19], liquid hydrogen has a high purity. In general, both oil and hydrogen used in the hydrogenation process must meet certain purity and dryness criteria to ensure the efficiency of the process.

It is also important to note that large-scale hydrogenation processes have a significant impact on the environment. When hydrogen is obtained from renewable methods such as electrolysis, these processes can substantially decrease greenhouse gas emissions and enhance air quality by producing cleaner-burning fuels and chemicals. Nevertheless, if the production of hydrogen is dependent on fossil fuels, it has the potential to contribute to the release of carbon emissions. Their environmental impact is exacerbated by the use of catalysts and chemicals that require a significant number of resources, high water consumption, waste production, and the need for infrastructure development. Essential measures to reduce these impacts include giving priority to renewable hydrogen sources, improving process efficiency, implementing carbon capture, adopting sustainable feedstocks, and practising responsible resource management.

The role of catalysts and selectivity of the hydrogenation process

Catalysts are essential in hydrogenation reactions, where they accelerate the conversion of unsaturated compounds to saturated ones by facilitating the addition of hydrogen atoms. Achieving selectivity in hydrogenation is paramount, as it allows control over which bonds are selectively hydrogenated, preventing over-hydrogenation and unwanted byproducts. Selectivity is influenced by factors such as catalyst structure, reaction conditions, and the nature of the unsaturated compound. Chemoselectivity ensures the preference of one functional group's hydrogenation over others, regioselectivity controls which carbon-carbon bonds are selectively hydrogenated within a molecule, and stereoselectivity governs the stereochemistry of newly formed bonds. Catalyst design and reaction optimization play crucial roles in tailoring this selectivity for desired outcomes in hydrogenation reactions.

According to M.A. Stoffels et al. [20], sulfur compounds, fatty acids, phosphatides, and other substances present in the oil are factors that can shorten the service life of the catalyst. In some cases, the catalyst can be used several times, however, a slight increase in its percentage may be required with each repeated use to compensate for the decrease in activity. Notably, the selectivity of the catalyst may also change with repeated use. The results obtained indicate the preference for the use of new catalysts for the production of critical base components and their reuse in the production of fully hydrogenated materials or solid materials, in cases where selectivity is not a critical factor.

It is necessary to examine the sequence of reactions occurring during this process to establish the selectivity of the catalyst or hydrogenation reactions. As the dienes in the fat are hydrogenated, they are reduced to monoene due to the hydrogenation of one double bond. Therewith, the monoene is additionally restored to a saturated or stearic form. In the case of linolenic acid containing three double bonds, the sequence involves the initial hydrogenation of the first double bond, which leads to the formation of linoleic and isololeic acids. These acids are then hydrogenated to form oleic or elaidic trans acids, which are subsequently hydrogenated to stearic acid.

Notably, with these reactions, there may be different paths and deviations. In the case of an acid with three double bonds, any of the three double bonds can be selectively hydrogenated, leaving the other two intact. The specific product formed depends on which double bond undergoes hydrogenation. In addition, some double bonds may be saturated, while others may undergo positional shifts or transition into a form with a higher melting point. Natural fats, such as soy and cottonseed oil, already contain a mixture of unsaturated fatty acids. Consequently, the hydrogenation of natural fats becomes more complicated, since not only the most unsaturated molecule undergoes hydrogenation but simultaneously all other unsaturated molecules present in the starting material.

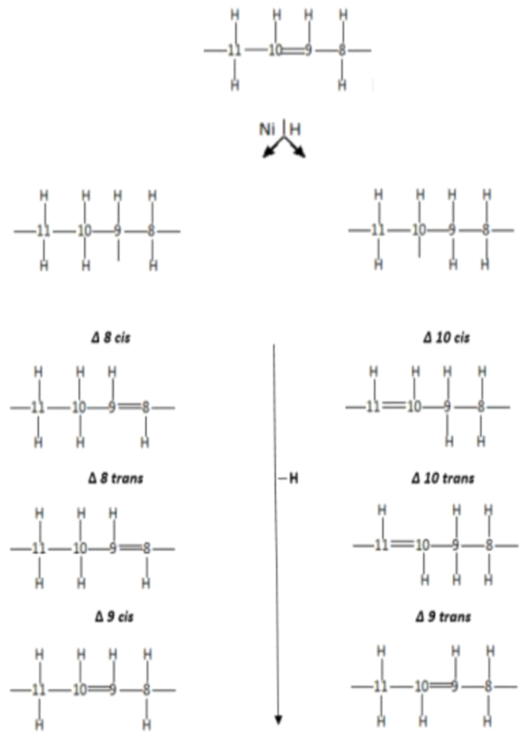
Reaction selectivity refers to the rate at which these various reactions occur. In earlier studies, the term “selectivity” was used by researchers to denote the desired characteristics of a hydrogenated product, such as achieving softness at a low iodine number or minimum melting, turbidity, or solidification temperature for the product, considering the iodine number. Thus, the definition of selectivity in this context remains a relative term. Descriptions of selectivity in the analysed studies were often subjective and inaccurate, using vague formulations. Consequently, a process that one group of researchers could define as highly selective, another could evaluate as not having a high value of this parameter. However, when selectivity is defined as the ratio of reaction rates, it is a more objective and absolute term.

Formation of trans isomers of fatty acids during hydrogenation

Notably, in the process of partial hydrogenation, a substantial amount of TIFA is formed. **(Figure 1)** illustrates the mechanism of TIFA formation, in particular for oleic acid. From one cis isomer (oleic acid – C18:1c), several geometric isomers are formed, primarily elaidic acid (C18:1t). According to the analysed data, the content of TIFA in partially hydrogenated oil depends on the process parameters, such as temperature, hydrogen pressure, reaction time, type of catalyst, and concentration of reagents.

On the other hand, the papers of A. Zbikowska [21], G. Van Duijn [22], and A.J. Dijkstra [23] showed that complete hydrogenation leads to complete saturation of unsaturated bonds, in particular, converting oleic acid into stearic acid.

Figure 1. Mechanisms of transisomer formation during hydrogenation



Source: (19)

It was established that the formation of trans isomers of fatty acids during hydrogenation is influenced by the degree of unsaturation of the oil and various process conditions. Table 1 provides an overview of how these factors affect the production of TIFA. Since hydrogen plays a crucial role in the trans-isomerisation process, it is important to supply a sufficient amount of it to the catalyst. This can be achieved by increasing the pressure or improving the mixing conditions. In addition, oils rich in unsaturated fatty acids require more hydrogen compared to highly saturated fats.

Table 1. Effect of process conditions and fat saturation on the hydrogenation process

Changing a parameter	Positive impact	
	Hydrogen concentration on a nickel catalyst	Formation of TIFA
Temperature increase	-	+
Intensification of mixing	+	-
Increase of the catalyst content	-	+
Increase in the activity of the catalyst	-	+
Pressure increase	+	-
Increased content of unsaturated fatty acids	-	+

Source: compiled by the author

According to G. Van Duijn [22] and also A.J. Dijkstra [23], when the amount of hydrogen on the catalyst surface increases during the cis/trans isomerisation process, the partially hydrogenated intermediate (as shown in Figure 1) reacts faster with the second hydrogen atom, which leads to the formation of TIFA. However, these chemical transformations, including saturation of unsaturated fatty acid bonds and geometric cis-trans isomerisation, lead to a decrease in the health benefits of the obtained lipids. In general, increased trans-fat consumption is associated with a range of serious health implications. Trans fats elevate LDL cholesterol levels, lower HDL cholesterol, and promote inflammation, leading to an increased risk of heart disease and stroke. They also contribute to weight gain and obesity, raise the risk of type 2 diabetes, and may negatively affect brain health. In addition, trans fats have been tentatively linked to an increased risk of certain cancers and adverse pregnancy outcomes. Their consumption can interfere with nutrient absorption and overall well-being. To mitigate these health risks, it's crucial to avoid products containing trans fats, prioritize a diet rich in unsaturated fats, and adhere to regulations and recommendations aimed at reducing trans-fat content in foods.

A. Zbikowska et al. [24] showed that the biological activity of unsaturated fatty acids is disrupted during hydrogenation. This process allows obtaining products with a variety of physical and chemical characteristics and high technological value. However, due to the low nutritional value and the increased content of harmful TIFA in partially hydrogenated fats, it becomes necessary to examine alternative modification methods to replace partial hydrogenation. An increase in the level of trans-unsaturation also leads to an increase in the melting point of the hydrogenated fat product. Since trans isomers of fatty acids are inevitably formed during hydrogenation, it becomes important to regulate the reaction parameters to achieve the desired TIFA content. Notably, the selectivity attributes of the catalyst do not depend on its ability to generate trans-unsaturation. Catalysts can exhibit both low and high selectivity, however H. Iida et al. [25] showed that the most widely used nickel catalysts produce a constant amount of TIFA under identical conditions.

Obtaining target dietary fats by hydrogenation

The production of specialised fats for the bakery and confectionery industry using highly solid hydrogenated, transesterified raw materials, such as palm stearin and animal fats, faces limitations due to various factors. These include the complexity and high cost of technological modification processes, limited availability of transesterification catalysts, and dependence on imported palm stearin. As a result, the widespread production and use of such fats in the bakery and confectionery industry has not become widespread in many regions. The use of dispersed selective catalysts in hydrogenation technology is fraught with difficulties, primarily from the point of view of separating the catalyst from the final product and the associated filtration costs [26]. In addition, there is concern about the relatively high content of transisomerised fatty acids in hydrogenated fats, which may affect their nutritional profile and overall quality. These factors together contribute to the limited distribution and introduction of highly solid hydrogenated transesterified fats in the bakery and confectionery industry in many regions. Further research and advances in technology may be needed to address these limitations and ensure the wider use of these fats.

Obtaining edible fats with the desired properties by hydrogenation of fats on stationary catalysts can be difficult for a number of reasons. The process of obtaining liquid fats with a certain ratio of solid and liquid phases by partial hydrogenation on stationary catalysts can be more effective. This is especially true for baking, where the simultaneous presence of solid and liquid glycerides in non-selectively hydrogenated fats is desirable, unlike margarine and solid confectionery fats, which require selective hydrogenation for uniformity. To solve this problem, I. Isabaev et al. [9] developed a two-stage continuous technology for the hydrogenation of cottonseed oil. The process includes a series of column-type reactors that use a stationary nickel-copper-rhodium-aluminium catalyst. According to the authors of the study, this technology allows for non-selective partial hydrogenation, as a result of which it becomes possible to obtain fats with a given ratio of solid and liquid fractions. The development of such technologies is driven by technological considerations (such as the desired fat composition), economic factors (such as productivity), and social aspects (such as reducing the content of trans-isomers of fatty acids). The results obtained indicate that the use of such a two-stage saturation process, including non-selective hydrogenation on multifunctional catalysts of an active alloy, allows achieving the desired technological, economic, and social results in the production of edible fats from cottonseed oil [27, 28].

The desired ratio of polyunsaturated fatty acids (PUFA) of the groups ω-6: ω-3 is an important aspect in determining the functionality of fat products. However, according to I. Isabaev et al. [9], hydrogenated fats, which serve as the basis for many dietary fats, usually do not contain PUFA from the group ω-3. Special-purpose edible fats are used to solve this problem, which include vegetable oils rich in omega-3 PUFA, such as linseed, soy, and wheat seed oil. Although the addition of these omega-3-rich oils can improve the nutritional profile of fat products, certain problems arise in their production. For example, when using linseed oil, there are difficulties in protecting against oxidative changes due to their high susceptibility to oxidation. On the other hand, the use of wheat grain oil is characterised by problems in the extraction process, especially when using pressing methods since wheat grains are raw materials with a low oil content [29, 30, 31]. These problems emphasise the need for careful consideration and appropriate methods of production of dietary fats containing oils rich in omega-3 PUFA. Strategies to overcome these difficulties may include the introduction of effective antioxidant protection of susceptible oils or the use of alternative extraction methods to overcome the limitations associated with raw materials with low oil content, such as wheat germ. By solving these problems, it becomes possible to include oils rich in ω-3 in fatty foods, providing the desired PUFA ratio and increasing their nutritional value [32].

The use of hydrogenated fats

Hydrogenation has a rich history dating back to the beginning of the 20th century, when Wilhelm Norman successfully conducted the hydrogenation of fats for the first time, which became an important stage of development for the fat and oil industry. Subsequently, he patented his discovery in 1903, and the technique was also used in the soap industry [33, 34]. Since then, hydrogenation has become the main chemical process in this industry. It had a profound impact on the entire oilseed industry, as it allowed the processing of by-oils obtained during seed extraction. T.C. Jenkins and B.F. Jenny [35] showed that this reduces the cost of the protein component used in animal feed. According to S.D. Bhandari et al. [3], the growth of the soybean industry, in particular, is closely related to the expansion of hydrogenation in the edible oil sector. Hydrogenation of fats serves two main purposes. Firstly, this process reduces the number of double bonds in the molecules, thereby reducing the likelihood of oxidation and increasing the stability of taste qualities. Secondly, the physical characteristics of the oil change, which makes it more versatile for various applications. The main advantage of using targeted dietary fats in the technology of step-by-step hydrogenation is the possibility of creating fats with certain physical and chemical properties that can be adapted for specific applications in the food industry [36]. B.K. Pradhan et al. [37] demonstrated that by changing the structure of fat, it becomes possible to obtain a product with a given melting point or with a better ability to preserve its texture and structure during storage and cooking. In all the studies analysed, hydrogenated fats had a higher melting point, which potentially makes them ideal for achieving the desired texture in various foods. According to A. Al-Jawaldeh et al. [38], partially hydrogenated fats are most commonly used in margarine, frying oil, and food products such as confectionery and pastries. In the one hand, hydrogenated fats are used in the manufacture of various foods to increase the fat's resistance to oxidation and to raise its melting point. For example, coconut and sunflower oils are hydrogenated to make ice cream, confectionery, margarine, salamis, spreads and other products. However, hydrogenation leads to the formation of fatty acid trans-isomers, which can be harmful to human health. Such fats are found in fast food, fried foods and confectionery. Their consumption can lead to an increased risk of cardiovascular disease and cancer. On the other hand, the hydrogenated fats, derived from vegetable oils, have diverse non-food applications. They're used in cosmetics, pharmaceuticals, lubricants, candles, textiles, inks, plastics, and more for properties like stability, texture, and lubrication. While their use has declined due to health and environmental concerns, hydrogenated fats still contribute to various industries, with a growing focus on sustainable alternatives [39, 40].

Excessive consumption of hydrogenated fats can be regarded as a novel peril to humanity. Originally designed to prolong the durability of food items and enhance their consistency, the process of hydrogenation generates trans fats, which have been associated with a range of health problems, such as heart disease and elevated levels of cholesterol. Overconsumption of trans fats can indeed present substantial health hazards, necessitating the need to restrict their consumption. Nevertheless, it is important to note that not all hydrogenated fats are detrimental, as certain ones undergo partial hydrogenation, leading to a reduced presence of trans fats. Individuals and policymakers must prioritise the promotion of healthier dietary choices and regulations that reduce the consumption of harmful hydrogenated fats, while also encouraging the adoption of alternatives that prioritise human health and well-being.

CONCLUSIONS

In the course of the study, the main approaches to obtaining target fats using the technology of step-by-step hydrogenation were analysed, and methods of their application were also considered. The most widespread technological features of the process of stepwise hydrogenation of fats, the requirements for hydrogen, and the catalyst used during the reaction were established. It is shown that hydrogenation is most often conducted at temperatures ranging from 140 °C to 225 °C. The most commonly used hydrogen is obtained from a liquid form and nickel as a catalyst. In the course of the study, it was determined that the most important characteristics of the catalyst for the hydrogenation of fats are its activity, durability, selectivity, and stability of the formation of isomers. It was established that the selectivity of the catalyst is a key factor for obtaining target dietary fats by step-by-step hydrogenation. It was noted that different researchers use different definitions of this term. The most successful definition of selectivity is the rate of various reactions during hydrogenation. The study demonstrated that repeated use of the catalyst can lead to a decrease in selectivity. Thus, to obtain the most important components, its reuse should be avoided. The problem of the formation of trans isomers of fatty acids that reduce the nutritional qualities of fats has been identified as one of the main disadvantages of the technology of step-by-step hydrogenation. The main factors that contribute to the formation of trans isomers of fatty acids were determined by the high temperature, the specificity of the catalyst, and the use of raw materials with a high amount of unsaturated fatty acids.

It was shown that one of the main needs in the industry is the development of catalysts that can efficiently convert dienes and trienes into monoenes without creating trans-unsaturation. This will allow the use of a substrate with a high content of unsaturated fatty acids to create stable dietary fats, eliminating the need for additional processing to remove refractory glycerides. Despite the substantial progress made in hydrogenation studies, these problems require further research. It was determined that the technology of step-by-step hydrogenation is most actively used in the soybean industry and for the production of confectionery and baking fats with specified characteristics.

The study on step-by-step hydrogenation of dietary fats holds significant scientific and practical value. It deepens understanding of the complex chemical processes involved in modifying dietary fats, particularly in terms of catalyst properties and the formation of trans isomers. This knowledge provides a foundation for improving fat quality and consistency in the food industry. By addressing the cis/trans isomerization problem, the study hints at market expansion opportunities, making it relevant for both researchers and industry professionals seeking to enhance the nutritional and organoleptic properties of food products.

This study is limited by measurements of selectivity in the hydrogenation process, insufficient exploration of alternative methods to replace partial hydrogenation, a focus on technological properties rather than nutritional quality and health effects. Further investigations can encompass the development of quantitative measures for hydrogenation selectivity, exploration of viable alternatives to partial hydrogenation, and nutritional assessments of specialized fats. Additionally, researches may focus on extraction methods for omega-3 rich oils from unconventional sources and the engineering of structured catalysts to enhance selectivity in hydrogenation processes.

REFERENCES

1. **Patel AR, Nicholson RA, Marangoni AG**. Applications of fat mimetics for the replacement of saturated and hydrogenated fat in food products. Curr Opin Food Sci. 2020;33:61-68. https://doi.org/10.1016/j.cofs.2019.12.008

2. **Abzhanova SA, Bulambayeva AA, Dzhetpisbaeva BS, Kozhakhiyeva MO, Matibaeva AI, Serikkyzy MS, Rskeldiyev BA**. Research of the impact of a vegetable protein composition on the functional and technological properties of national meat products. Asian J. Microbiol. Biotechnol. Environ. Sci. 2018;20(4):1071-1080.

3. **Bhandari SD, Delmonte P, Honigfort M, Yan W, Dionisi F, Fleith M, Iassonova D, Bergeson LL.** Regulatory changes affecting the production and use of fats and oils: Focus on partially hydrogenated oils. J Am Oil Chemists Soc. 2020;97(8):797-815. https://doi.org/10.1002/aocs.12366

4. **Bahatska O, Melnyk V, Snarovkina O.** Assessment of drought resistance in plants of the genus Aristolochia L. Ukr. J. For. Wood Sci. 2023;14(3):8-20. https://doi.org/10.31548/forest/3.2023.08

5. **Bruce JH.** The technological challenges of reducing the saturated fat content of foods. Nutr Bull. 2020;45(3):315-320. https://doi.org/10.1111/nbu.12452

6. **Shukesheva SE, Uzakov YaM, Chernukha IM, Nabiyeva ZS, Kozybayev A.** On the role of controlling systems in the quality of food products. J. Adv. Res. Dyn. Control Syst. 2018;10(13):642-648.

7. **Honchar V, Iakubchak O, Shevchenko L, Midyk S, Korniyenko V, Kondratiuk V, Rozbytska T, Melnik V, Kryzhova Y.** The effect of astaxanthin and lycopene on the content of fatty acids in the yolks of chicken eggs under different storage regimes. Potravinarstvo Slovak J. Food Sci. 2022;16:473-489.

8. **Oteng AB, Kersten S.** Mechanisms of action of trans fatty acids. Adv Nutr;2020;11(3): 697-708. https://doi.org/10.1093/advances/nmz125

9. **Isabaev I, Khudaykulov A, Dzhuraeva, N, Ashurova Z, Tursunova U.** Obtaining technologically and physiologically functional special-purposes of fat products. In: IOP Conference Series: Earth and Environmental Science (pp. 1-7). Bristol: IOP Publishing; 2021.

10. **Sargsyan G, Gukasyan P, Sargsyan H, Poveda R.** Diffusion flames and a semi-empirical method for estimating the distribution of hydrogen molecules in propane flames. Sci. Herald Uzhhorod Univ. Series "Physics". 2023;(53):42-52. https://doi.org/10.54919/physics/53.2023.42

11. **Shukesheva SE, Uzakov YM, Chernukha IM, Nurmukhanbetova DE, Nabiyeva ZS, Nurtaeva AB.** Research to improve the quality of food products. News of the National Academy of Sci. of the Republic of Kazakhstan, Series of Geology Tech. Sci. 2018;3(430):37-45.

12. **Lukashchuk H, Onufriv Ia, Tupis S.** Green space and planning structure optimisation ways in parks and monuments of landscape architecture. Archit. Stud. 2023;9(1):23-35. https://doi.org/10.56318/as/1.2023.23

13. **Sánchez MA, Torres GC, Mazzieri VA, Pieck CL.** Selective hydrogenation of fatty acids and methyl esters of fatty acids to obtain fatty alcohols – A review. J Chem Technol Biotech. 2017;92(1):27-42. https://doi.org/10.1002/jctb.5039

14. **Bandura V, Fialkovska L.** Quality indicators of extracted sunflower and rapeseed oil obtained with hexane and ethyl alcohol solvents. Anim. Sci. Food Tech. 2023;14(1):9-25. https://doi.org/10.31548/animal.1.2023.9

15. **Jang ES, Jung MY, Min DB.** Hydrogenation for low trans and high conjugated fatty acids. Compr Rev Food Sci Food Saf. 2005;4(1):22-30. https://doi.org/10.1111/j.1541-4337.2005.tb00069.x

16. **Allen RR.** 1978. Principles and catalysts for hydrogenation of fats and oils. J the Am Oil Chemists Soc. 1978;55(11):792-795. https://doi.org/10.1007/BF02682650

17. **Nazarova VD, Salikova NS, Bektemissova AU, Begenova BE, Aubakirova GB.** Isolation of miricetine-containing fractions from linosyris villosa plant and their application as antianemic agent. Periodico tche quimica. 2020;17(35):998-1012.

18. **Chornobrov O, Melnyk O, Karpuk A, Vasylyshyn R.** Peculiarities of plant adaptation of interspecific hybrid Betula ex vitro. Sci. Horiz. 2023;26(11):49-57. https://doi.org/10.48077/scihor11.2023.49

19. **Žula M, Grilc M, Likozar B.** Hydrocracking, hydrogenation and hydro-deoxygenation of fatty acids, esters and glycerides: Mechanisms, kinetics and transport phenomena. Chem Eng J. 2022;444:136564. https://doi.org/10.1016/j.cej.2022.136564

20. **Stoffels MA, Klauck FJ, Hamadi T, Glorius F, Leker J.** Technology trends of catalysts in hydrogenation reactions: A patent landscape analysis. Adv Synth Catalysis 2020;362(6):1258-1274. https://doi.org/10.1002/adsc.201901292

21. **Zbikowska A.** Formation and properties of trans fatty acids – A review. Pol J Food Nutr Sci. 2010;60(2):107-114.

22. **Van Duijn G.** Technical aspects of trans reduction in modified fats. Oilseeds Fats Crops Lipids. 2005;12(5-6):422-426. https://doi.org/10.1051/ocl.2005.0422

23. **Dijkstra AJ.** Kinetics and mechanism of the hydrogenation process – The state of the art. Eur J Lipid Sci Technol. 2012;114(9):985-998. https://doi.org/10.1002/ejlt.201100405

24. **Zbikowska A, Onacik-Gür S, Kowalska M, Zbikowska K, Feszterová M.** Trends in fat modifications enabling alternative partially hydrogenated fat products proposed for advanced application. Gels. 2023;9(6):453. https://doi.org/10.3390/gels9060453

25. **Iida H, Takahashi K, Yanagisawa A, Hashimoto H, Igarashi A.** Reduction of trans fatty acids in hydrogenated soybean oil using Ni/TiO_2 catalysts. Food Chem. 2021;340:127927. https://doi.org/10.1016/j.foodchem.2020.127927

26. **Kryzhova Y, Slobodianiuk N, Moskalenko I.** Application of modern technologies to improve the quality of sausage products. Anim. Sci. Food Tech. 2023;14(1):49-64. https://doi.org/10.31548/animal.1.2023.49

27. **Ospanov AA, Muslimov NZH, Timurbekova AK, Mamayeva LA, Jumabekova GB.** The effect of various dosages of poly-cereal raw materials on the drying speed and quality of cooked pasta during storage. Current Res. Nutr. Food Sci. 2020;8(2):462-470. http://dx.doi.org/10.12944/CRNFSJ.8.2.11

28. **Iskakova AN, Abitayeva GK, Abeev AB, Sarmurzina ZS.** Meta-analysis data of the accuracy of tests for meat adulteration by real-time PCR. Data in Brief. 2022;41:107972. http://dx.doi.org/10.1016/j.dib.2022.107972

29. **Pavliuk L.** Electron modelling in conjunction witch vacuum modelling. Sci. Herald Uzhhorod Univ. Series "Physics". 2022;(52):27-35. https://doi.org/10.54919/2415-8038.2022.52.27-35

30. **Asangalieva Z, Iztaev AI, Shaimerdenova DA, Abzhanova SA.** Kazakhstan wheat as raw material for deep processing. Res. J. Pharm., Biol. Chem. Sci. 2015;6(6):931-934.

31. **Palamarchuk I, Tsurkan O, Sevin S, Palamarchuk V, Vasyliv V.** Analysis of energy characteristics of vibration mixing of multicomponent mixtures of agricultural raw materials. Anim. Sci. Food Tech. 2023;14(1):65-79. https://doi.org/ 10.31548/animal.1.2023.65

32. **Uzakov YM, Ospanova DA.** Study of the morphological structure and nutritional value of lamb. World Appl. Sci. J. 2013;27(4):479-482. https://doi.org/10.5829/idosi.wasj.2013.27.04.13659

33. **Balji Yu.** Preliminary assessment of the safety of genetically modified food products. Anim. Sci. Food Tech. 2023;14(3):9-19. https://doi.org/10.31548/animal.3.2023.9

34. **Bulhakova A.** Mass spectrometric studies of valine molecules by electron shock in the gas phase. Sci. Herald Uzhhorod Univ. Series "Physics". 2022;(51):9-17. https://doi.org/10.54919/2415-8038.2022.51.9-17

35. **Jenkins TC, Jenny BF.** Effect of hydrogenated fat on feed intake, nutrient digestion, and lactation performance of dairy cows. J Dairy Sci. 1989;72(9):2316-2324. https://doi.org/10.3168/jds.S0022-0302(89)79363-2

36. **Mukhametov A, Dautkanova D, Kazhymurat A, Yerbulekova M, Aitkhozhayeva G.** The Effects of Heat Treatment on the Oxidation Resistance and Fatty Acid Composition of the Vegetable Oil Blend. J. Oleo Sci. 2023;72(6):597-604. https://doi.org/10.5650/jos.ess23010

37. **Pradhan BK, Saigiri S, Bharti D, Kim D, Pal K.** Natural wax-based oleogels for food application. In: Fat Mimetics for Food Applications (pp. 21-37). Hoboken: John Wiley & Sons; 2023.

38. **Al-Jawaldeh A, Taktouk M, Chatila A, Naalbandian S, Abdollahi Z, Ajlan BA, Hamad NA, Alkhalaf MM, Almamary S, Alobaid R, Alyafei SA, Azizi MH, Baqadir NM, Barham R, Binsunaid FF, Ammari LE, Ati JE, Hoteit M, Massad H, Nejad MS, Nasreddine L.** A systematic review of trans fat reduction initiatives in the Eastern Mediterranean region. Front Nutr. 2021;8:771492. https://doi.org/10.3389/fnut.2021.771492

39. **Sun X, Guo C, Zhang Y, Wang Q, Yang Z, Wang Z, Wang W, Cao Z, Niu M, Li S.** Effect of diets enriched in n-6 or n-3 fatty acids on dry matter intake, energy balance, oxidative stress, and milk fat profile of transition cows. J Dairy Sci. 2021;106(8):5416-5432. https://doi.org/10.3168/jds.2022-22540

40. **Al-Rawi W, Hamad A, Muslih R, Al-Kenany N, Hamash M., Abid F., Hamada A.** Variations in some biochemical parameters in a group of patients with primary brain tumours: A review of four studies. Innovac. 2018;6(2):1-15. http://dx.doi.org/10.15649/2346075X.457