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# POTENTIAL NATURAL SOURCES OF TOCOPHEROLS AND TOCOTRIENOLS AND POSSIBILITIES THEIR USE IN THE FOOD INDUSTRY®

## Potencjalne naturalne źródła tokoferoli i tokotrienoli oraz możliwości ich zastosowania w przemyśle spożywczym®

*Tocopherols and tocotrienols are natural compounds found in oil plants. Their antioxidant properties make them interesting for food producers and consumers looking for healthy food. The aim of this study is to present the potential natural sources of tocopherols and tocotrienols, which as antioxidants are increasingly used as food additives to extend itheir durability, and additionally enrich the product with vitamin E. The work shows their chemical structure, methods of obtaining and legal regulations allowing tocopherols and tocotrienols for use in food processing. The current ways of using them in food production were discussed.*

**Key words:** vitamin E, tocopherols, tocotrienols, antioxidant, food stability, food quality.

**Abbreviations:** α – alpha
β – beta
γ – gamma
δ – delta

*Tokoferole i tokotrienole to naturalne związkami występujące w roślinach oleistych. Ich właściwości przeciwutleniające sprawiają, że są interesujące dla producentów żywności i konsumentów poszukujących zdrowej żywności. Celem artykułu jest omówienie potencjalnych naturalnych źródeł tokoferoli i tokotrienoli, które jako substancje przeciwutleniające są coraz częściej wykorzystywane jako dodatki do żywności w celu przedłużenia jej trwałości, a dodatkowo wzbogacają produkt w witaminę E. W artkule przedstawiono ich strukturę chemiczną, sposoby pozyskiwania oraz regulacje prawne dopuszczające tokoferole i tokotrienole do wykorzystania w przetwórstwie żywności. Omówiono dotychchczasowe sposoby ich wykorzystania w produkcji żywności.*

**Słowa kluczowe:** witamina E, tokoferole, tokotrienole, antyoksydant, stabilność, jakość.

## INTRODUCTION

The content of bioactive ingredients with documented and beneficial effects on health as well as high quality and nutritional value of foods are now becoming the main determinant of the choice of food products [29]. Consumers are looking for foods, which can improve their health and prevent diseases. Food producers focus on research into, among others, new, natural substances, which increase the nutritional value of products, extend the shelf life of foods, including natural antioxidants, which effectiveness are comparable with synthetic counterparts [35]. Thermal processing of food raw materials, time and method of storage of raw materials or finished products, type of packaging determine the durability of the product and its final quality. One of the most important mechanisms leading to lowering the nutritional value and quality of foods, shortening the shelf life of products containing fat in their composition is the process of lipid oxidation, which causes undesirable changes in the final products. This process leads to the formation of an unpleasant taste and smell, a decrease in the nutritional quality and the safety of food products [20,22].The main initiators of lipid oxidation are free radicals, i.e., molecules having at least one unpaired electron on the outer shell, and therefore having a high affinity, e.g. to lipids. Prevention of oxidation depends primarily on eliminating free radicals as they form and inhibit the propagation process. One of the most effective and convenient strategies for delaying or preventing lipid oxidation is the addition of antioxidants, including vitamin E [43]. Vitamin E encompasses a group of eight fat-soluble compounds – four tocopherols (α, β, γ, δ) and four tocotrienols (α, β, γ, δ) (Fig. 1.), of which the highest biological activity is shown by α-tocopherol. Biochemically, α –tocopherol acts as an antioxidant by breaking chain reaction and interfering with reactive oxygen species formed by scavenging lipid peroxyl

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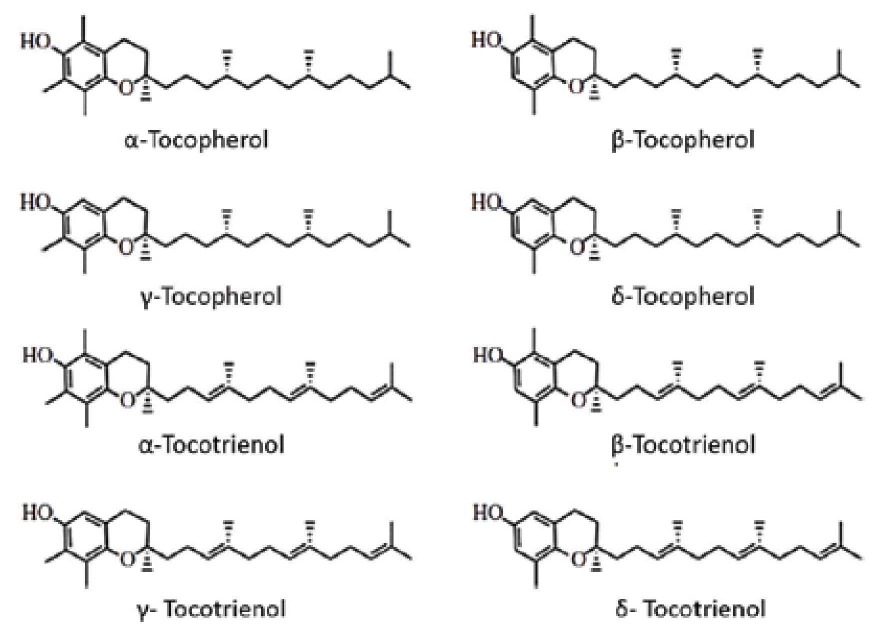


**Fig. 1. Structural formulas of tocopherols and tocotrienols.**
**Rys.1. Wzory strukturalne tokoferoli i tokotrienoli.**

**Source:** [37]

**Źródło:** [31]

radicals. During the chain-breaking reaction, α-tocopherol forms a free radical that can reacts quickly with another peroxide radical, thus ending two peroxidation chains [7].

## VITAMIN E AS A CHEMICAL AND BIOACTIVE COMPOUND

Vitamin E was first described by Evans and Bishop in 1922, characterized as a dietary factor necessary for reproduction. Soon, vitamin E was identified as an antioxidant for polyunsaturated lipids. Subsequent studies have shown that tocochromanoles – a common name for tocopherols and tocotrienols, act as signal molecules which regulate gene expression, signal transduction and modulate cell function, regardless of antioxidant properties [14,33]. Tocopherols and tocotrienols are amphipathic molecules containing a 6-chromanol (6-hydroxychromanol) ring and a side chain made of 3 isoprene units. In tocopherols, it is linked to the phytyl chain and in the case of tocotrienols, it is linked to the isoprenoid chain [9]. They differ in the number and location of methyl groups in chemical structures and the presence of three trans double bonds at the 3’, 7’, and 11’ positions in the side chain of tocotrienols, which is responsible for their unsaturated nature as compared with tocopherols. Structural interrelationships are presented in Table 1 [27, 33, 41].

Tocopherols and tocotrienols are homologs to each other. α-homologs contain three methyl groups, β- and γ-homologues are mutual isomers with two methyl groups, and α-tocopherols and δ-tocotrienols are monomethyl. Synthetic α-tocopherol (all-rac-α-T) is a racemic mixture of individual stereoisomers. Therefore, each of the tocopherols has eight optical isomers. For α-tocopherol, these are RRR-, RSR-, RRS-, RSS-, SRR-, SSR-, SRS-, SSS-. Only RRR-tocopherols occur in nature [41].

Vitamin E is an essential nutrient, it has antioxidant properties, hence it can play an important role in maintaining good health, reducing the risk of diseases in which reactive oxygen species participate in the pathogenesis [29,38]. Deficiencies of vitamin E can cause anemia, impaired immune response, retinopathy, and neuromuscular and neurological problems. Research also points to the numerous health benefits of taking tocochromanols, including the prevention of certain types of cancer, heart disease, and other conditions, and therefore it is suggested that daily vitamin E intake may be significantly higher than the presently established adequate daily intake [33].

**Table 1. Structural relationship between tocopherols and tocotrienols**
**Tabela 1. Powiązania strukturalne między tokoferolami i tokotrienolami**

| Common name | Chemical name | Short | Position of the ring | | |
|---|---|---|---|---|---|
| | | | R1 | R2 | R3 |
| tocol | 2-methyl-2-(4′,8′,12′-trimethyltridecyle)-chroman-6-ol | - | H | H | H |
| α-tocopherol | 5,7,8-trimethyltocol | α-T | $CH_3$ | $CH_3$ | $CH_3$ |
| β-tocopherol | 5,8-dimethyltocol | β-T | $CH_3$ | H | $CH_3$ |
| γ-tocopherol | 7,8-dimethyltocol | γ-T | H | $CH_3$ | $CH_3$ |
| δ-tocopherol | 8-methyltocol | δ-T | H | H | $CH_3$ |
| tocotrienol | 2-methyl-2-(4′,8′,12′- trimethyltrideca-3′,7′,11′-trienyl) chroman-6-ol | - | H | H | H |
| α-tocotrienol | 5,7,8-trimethyltocotrienol | α-T3 | $CH_3$ | $CH_3$ | $CH_3$ |
| β-tocotrienol | 5,8-dimethyltocotrienol | β-T3 | $CH_3$ | H | $CH_3$ |
| γ-tocotrienol | 7,8-dimethyltocotrienol | γ-T3 | H | $CH_3$ | $CH_3$ |
| δ-tocotrienol | 8-methyltocotrienol | δ-T3 | H | H | $CH_3$ |

**Source:** [41]

**Źródło:** [41]

Vitamin E is widely distributed in nature, but can only be synthesized by photosynthetic eukaryotes and other photosynthetic organisms such as cyanobacteria. Plants accumulate tocochromanols available in seeds, fruits or young tissues undergoing active cell division [2]. Due to their amphipathic properties, they join in the phospholipid bilayer of cell membranes, with a chromanol ring directed towards the water compartment, with a side chain embedded in non-polar space [6]. In this way, vitamin E protects membrane lipids, photosynthesis apparatus and plant seeds against oxidative stress [24]. Vitamin E in plant products occurs mainly in non-esterified form. Its content varies depending on the species, variety, stage of ripeness, season, time and method of harvesting as well as processing and storage time [31].

Tocopherols and tocotrienols occur naturally in vegetable oils, sprouts and cereals, nuts and almonds. Tocopherol is found in almond, walnut, sunflower, rapeseed, and olive oil. The best sources of tocotrienols are palm oil and rice bran oil; other sources are grape seed oil, hazelnuts, oats, corn, olive oil, sea buckthorn berries, rye, linseed, and sunflower oil (Tab. 2.). Research indicates that one of the best sources of both tocopherols and tocotrienols are palm fruits, rice grains and annatto seeds from the fruit of the Achiote tree (Bixa orellana) [29,33].

## USE OF VITAMIN E IN THE FOOD INDUSTRY

Vitamin E in fortified foods, but also in dietary supplements, is often the esterified form of α-tocopherol, the most common esters being acetate and succinate. Esterified forms of vitamin E are more resistant to oxidation as they have a longer shelf life. A small number of studies focus on other esters, such as α-tocopheryl nicotinate, which is an ester of vitamin E and niacin and is not yet well understood [7]. Some studies suggest that the potency of antioxidants may vary between natural or synthetic sources of tocochromanols [2]. Due to their antioxidant activity, tocochromanols play a major role in protecting mono- and polyunsaturated fatty acids (PUFAs) from oxidation [33]. Natural tocopherols (E306) and synthetic α-, γ- and δ-tocopherols (E307, E308 and E309, respectively) are used as antioxidants in food to inhibit lipid peroxidation. They are used individually or in combination, according to Regulation (EC) No 1333/2008 on food additives and subsequent amendments according to Regulation (EU) 2018/1497. So far, no Acceptable Daily Intake (ADI) has been established, but the Upper Intake Level (UL) is set at 300 mg vitamin E per day according to EFSA or 1000 mg according to the Institute of Medicine. However, the ADI for α-tocopherol established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) was determined to be 0.15-2.0 mg α-tocopherol/kg body weight/day [9,12,32]. No oral toxicity was observed in tocopherols. Additionally, EFSA has approved the health claim for vitamin E. Food industry may use the "vitamin E sources" claim on their products when the food contains 1.8 mg of vitamin E per 100 g or 100 ml or a single serving of food or drink [22]. The Food and Drug Administration (FDA) in the United States has granted the status of tocopherols and tocotrienols generally recognized as safe (GRAS), with an approved dose of 40 mg tocopherol per 1 kg food [10]. The Supplements Working Group of Main Sanitary Inspectorate in Poland had established maximum acceptable level of vitamin E in supplements at 250 mg /day [17].

## METHODS OF EXTRATIONS OF VITAMIN E

Initially, the main commercial sources of vitamin E used as a food additive were vegetable oils, however soybean oil and wheat germ oil contain too little of it. Soon, vitamin E extraction from fatty acid distillates from vegetable oils began, which proved to be cheaper and with higher content of vitamin E. Currently, almost all producers obtain vitamin E from distillates, although new raw materials appeared, from which they tried to obtain it – palm leaves, bananas, pineapples, sugar cane, rice, wheat, barley, corn, rye, rice bran [31].

**Table 2. Total tocopherols (T) and tocotrienols (T3) content in selected food oils (mg/100g)**

**Tabela 2. Całkowita zawartość tokoferoli (T) i tokotrienoli (T3) w wybranych olejach spożywczych (mg / 100 g)**

| Products | α-T | β-T | γ-T | δ-T | α-T3 | β-T3 | γ-T3 | δ-T3 |
|---|---|---|---|---|---|---|---|---|
| Barley | 14.2-20.1 | 0.6-1.9 | 3.5-15.1 | 0.9-4.6 | 46.5-76.1 | nd-12.4 | 8.5-18.6 | 0.5-2.6 |
| Coconut | 0.2-1.8 | tr-0.25 | tr-0.12 | nd-0.39 | 1.1-3.0 | nd-0.17 | 0.33-0.64 | nd-0.1 |
| Corn | 18.0-25.7 | 0.5-1.1 | 44.0-75.2 | 2.20-3.25 | 0.94-1.50 | nd | 1.30-2.00 | nd-0.26 |
| Cottonseed | 30.5-57.3 | 0.04-0.30 | 10.5-31.7 | tr | nr | nr | nr | nr |
| Olive | 11.9-17.0 | nd-0.27 | 0.89-1.34 | nd-tr | nd-tr | nd | nd | nd-tr |
| Palm | 6.05-42.0 | nd-0.42 | tr-0.02 | nd-0.02 | 5.70-26.0 | nr-0.82 | 11.3-36.0 | 3.33-8.00 |
| Peanut | 8.86-30.4 | nd-0.38 | 3.50-19.2 | 0.85-3.10 | nd | nd | nd | nd |
| Sunflower | 32.7-59.0 | tr–2.40 | 1.40-4.50 | 0.27-0.50 | 0.11 | nd | tr | tr |
| Rapeseed | 18.9-24.0 | nd–tr | 37.0-51.0 | 0.98-1.90 | nd | nd | nd | nd |
| Soybean | 9.53-12.0 | 1.00-1.31 | 61.0-69.9 | 23.9-26.0 | nd | nd | nd | nd |
| Wheat germ | 15.1-19.2 | 31.2-65.0 | tr-52.3 | nd-0.55 | 2.5-3.6 | nd-8.2 | nd-1.85 | nd-0.24 |

nd: not detected; nr: not reported; tr: trace; T: tocopherols, T3: tocotrienols

**Source:** Own study based on [33]

**Źródło:** Opracowanie własne na podstawie [33]

The distillate is a mixture of acylglycerols, free fatty acids, tocopherols and stanols, hydrocarbons and other substances that affect the organoleptic characteristics of vegetable oils. It is produced as waste from the deodorization process, i.e. the removal of undesirable substances from the raw material. The content of vitamin E in distillates is dependent on oil, from which it has been produced; most content is observed, among others, in oil from corn, sunflower, peanuts, rapeseed and cottonseed [1, 31, 36].

Many researchers have developed various methods and techniques for extracting, analyzing, identifying, purifying and quantifying tocochromanols from various sources. However, scientists are still looking for a method of obtaining vitamin E which would be efficient, economical, and would lead to obtaining vitamin E concentrate, or individual isoforms, with the desired degree of purity and in the largest amount possible. Determination of tocochromanols in plant products combines classical techniques with physico-chemical methods and is based on such processes as esterification, saponification, liquid-liquid extraction, crystallization, distillation, enzymatic methods, ion exchange, chromatographic methods and their combinations (Fig. 2.) [7,25]. Due to the low concentration of vitamin E isoforms in food, an effective method of pre-treatment of samples is extremely important [25]. Sample preparation protocols vary at homogenization and extraction stages. Most methods include the saponification of samples [21]. However, studies have shown that the process of saponification of samples reduced the content of individual forms of vitamin E, which leads to a decrease in the content of overall vitamin E [7]. Similarly, the method of mechanical pressing, frequently used during extraction, have been shown to reduce the overall content of vitamin E in the tested samples compared to extraction with organic solvents [20]. Direct extraction methods are also widely used, differing in the choice of solvents, e.g. hexane, petroleum ether, pentane and in extraction procedures [29,31]. Other methods involve liquid-liquid extraction without saponification or solvent extraction after saponification. High-performance liquid chromatography (HPLC) is used in various combinations, using both the normal and reverse phases. HPLC uses UV (ultraviolet) diode, fluorescence, ELSD (evaporative light scattering detection), electrochemical and amperometric detection. In some studies [13], normal phase adsorption chromatography shows an advantage over other methods because they indicate that there is a complete separation of isomers. The use of fluorescence is described as more sensitive and selective than UV, and ELSD (evaporative light scattering detector) is used to analyze several compounds simultaneously [9,40]. Lu and Yang [25] proposed ultrasonic dispersion micro-extraction in the solid phase using multi-walled carbon nanotubes - the authors recommended the method as fast and simple, reproducible, and with lower usage of organic solvents. Rapid progress in vitamin E extraction and homologation separation technologies may lead to the development of the most cost-effective method for producing vitamin E of the highest quality and biological activity for producers, which will be used in food processing and other industries [31].

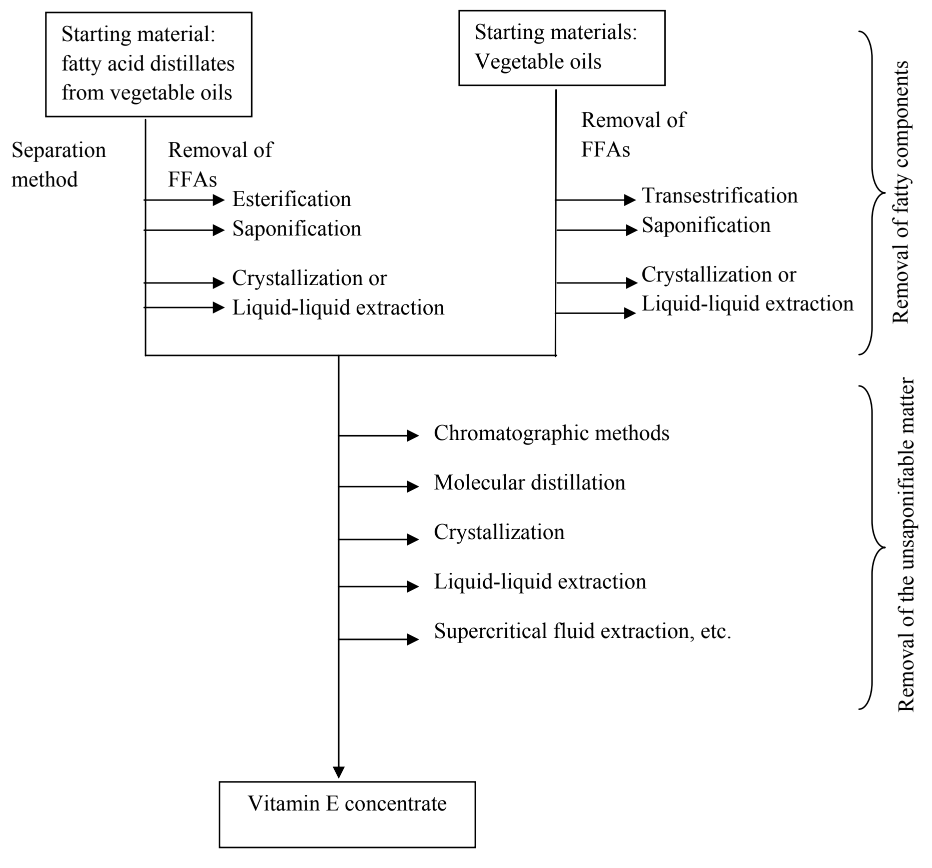


**Fig. 2. Sample procedures for obtaining vitamin E.**
**Rys. 2. Przykładowe metody uzyskiwania witaminy E.**
**Source:** [31]
**Źródło:** [31]

## PRACTICAL USE OF VITAMIN E IN FOOD PROCESSING

The most common and easiest way to use vitamin E is to add it to food products as an antioxidant, in order to increase the stability of fatty acids, reduce food biochemical changes, e.g. a mixture of tocopherols obtained from soybean oil processing is often used to stabilize oxidation-sensitive lipid dietary supplements, such as fish oil. Also, oils rich in tocopherols, such as from oat, barley or wheat germ, can be mixed with other oils to stabilize them [42].

Tocopherols as antioxidants are also used to extend the shelf life of confectionery fat, lard, margarine, mixtures, drinks and infant formulas, which at the same time enriches these products with vitamin E [19, 39, 43]. Economos and co-workers [8] proposed fortifying orange juice with, among others, vitamin E, which could be a new source of fat-soluble vitamins in populations with insufficient consumption of this vitamin.

An example of a food which can be fortified with vitamin E is food consumed by the crew during missions on a spacecraft. Sirmons and co-workers [34] evaluated the stability and content of vitamins, sensory acceptance and color variation of fortified space food over the course of two years. It was noted that enriching food with antioxidant vitamins reduces the rate of color degradation of stored products. Vitamin E proved to be stable at different storage temperatures and did not affect the organoleptic quality.

Since tocochromanols have an antioxidant effect on lipid compounds, they are at the same time most frequently used in products which are most exposed to such reactions, i.e. in meat and meat products [16]. Bolger and his team [4] evaluated the effect of increasing the tocopherol content on physical and sensory quality in poultry sausages. They studied the stability of α-tocopherol during storage, cooking, frying, and grilling. α-tocopherol was added at a concentration of 200 mg/kg of product (the amount considered necessary to reduce lipid oxidation and exceeding the amount needed to meet the requirements of the EFSA health claim). It has been found that it is possible to produce sausages enriched with sufficient α-tocopherol to meet EFSA's nutritional and health requirements without adversely affecting the quality or shelf life of the sausages. During storage or thermal treatment of the product, no significant loss of α-tocopherol was observed. Similarly, the addition of tocopherols to fish, poultry, and red meat lowered the oxidation level of fat contained in meat [33].

It turns out that the stage of breeding is important for the content of vitamin E in a meat product. Research proves that the way animals are fed and the use of feed with higher vitamin E content affect later meat quality [23]. The meat of rabbits, which were fed with different contents of vitamin E during breeding was examined. The content of vitamin E in meat increased with the increase of vitamin addition in feeding. During storage, a slower meat lipid oxidation rate was noted. Additionally, lower cholesterol content was found in the meat of rabbits that received 100 mg of vitamin E / kg feed compared to animals fed with a lower content of vitamin E. The assessment of individual sensory quality characteristics of meat (smell, taste, juiciness, tenderness) varied depending on the amount of vitamin E administered in the feed [23].

In recent years, the antioxidant properties of tocopherols have also been used in the production of "active" food packaging. Antioxidant films, packaging made of several layers, i.e. high-density layers and low-density layers, containing α-tocopherol as a natural antioxidant, are becoming popular [30]. It was found that the addition of an industrial mixture of natural antioxidants containing the highest concentration of tocopherols (90.2%) to the packaging was the most effective in extending the shelf life of salmon and reduced the lipid oxidation in meat to 70%. This suggests that it is possible to use active antioxidant films to extend the shelf life of high-fat products [3,5,15]. The Otero-Pazos and co-workers' study [28] evaluated the possibility of using biodegradable films for coating food with the addition of α-tocopherol as an active antioxidant in food packaging. Those films maintained antioxidant activity for over 20 days. Similarly, biodegradable polyester-based films containing α-tocopherol showed antioxidant activity [26]. Other raw materials for producing "new" packaging are biopolymers - biodegradable, releasing natural α-tocopherol. In other studies, α-tocopherol was encapsulated in three different matrices (whey protein isolate WPI, soy protein isolate SPI and zein), which were then used as a food packaging on a thermoplastic wheat gluten film to form a double layer film. α-tocopherol was comparably stable in all films produced [11]. The new trend is called "active packaging" or "active package" [18].

## SUMMARY

Tocopherols and tocotrienols are substances widely disseminated in nature. They exhibit antioxidant activity by eliminating free radicals. They can easily be obtained from available plant tissues and oil plants are their main source. Tocopherols and tocotrienols are generally recognized as safe and can be applied in food processing. Moreover, manufacturers can use health claims on the labels of products, which are vitamin E sources. Recently, food producers have become interested in new, natural ways to extend the shelf life of food products. As a result of this interest, many concepts arise for the use of vitamin E in animal breeding, in the processing of food raw materials, and in packaging materials used for food storage. These techniques are designed to preserve the flavor and odor sought by the consumer, adequate nutritional quality and food safety. Besides the use of natural vitamin E as a food additive, innovative packaging, called "active packaging" or biodegradable films for coating food products with the addition of antioxidants that release vitamin E into foods and prevent food quality changes, are created.

## PODSUMOWANIE

Tokoferole i tokotrienole są substancjami szeroko rozpowszechnionymi w przyrodzie. Wykazują aktywność przeciwutleniającą poprzez eliminację wolnych rodników. Można je łatwo uzyskać z dostępnych tkanek roślinnych, a rośliny oleiste są ich głównym źródłem. Tokoferole i tokotrienole są ogólnie uznawane za bezpieczne i mogą być stosowane w przetwórstwie spożywczym. Ponadto producenci mogą stosować oświadczenia zdrowotne na etykietach produktów, które są źródłami witaminy E. Niedawno producenci żywności zainteresowali się nowymi, naturalnymi sposobami przedłużenia okresu przydatności produktów spożywczych. W wyniku tego zainteresowania powstaje wiele koncepcji zastosowania witaminy E w hodowli zwierząt, w przetwarzaniu surowców żywnościowych oraz w materiałach opakowaniowych używanych do przechowywania żywności. Techniki te zostały zaprojektowane w celu zachowania smaku i zapachu poszukiwanego przez konsumenta, odpowiedniej jakości odżywczej i bezpieczeństwa żywności. Oprócz zastosowania naturalnej witaminy E jako dodatku do żywności, powstają innowacyjne opakowania, zwane „aktywnymi opakowaniami" lub biodegradowalne folie do powlekania produktów spożywczych z dodatkiem przeciwutleniaczy, które uwalniają witaminę E do żywności i zapobiegają zmianom jakości żywności.

## REFERENCES


[1] **AH NGAN M., Y. BASIRON, C. YUEN MAY, H. LAU LIK NANG. 2004.** "Extraction of vitamin E, phytosterols and squalene from palm oil". European Patent Office – Bulletin 2004/10.

[2] **AHSAN H., A. AHAD, W.A. SIDDIQUI. 2015.** "A review of characterization of tocotrienols from plant oils and foods". Journal of Chemical Biology 8(2): 45–59.

[3] **BARBOSA-PEREIRA L., J.M. CRUZ, R. SENDÓN, A. RODRÍGUEZ BERNALDO DE QUIRÓS, A. ARES, M. CASTRO-LÓPEZ, M.J. ABAD, J. MAROTO, P. PASEIRO-LOSADA. 2013.** "Development of antioxidant active films containing tocopherols to extend the shelf life of fish". Food Control 31(1): 236–243.

[4] **BOLGER Z., N.P. BRUNTON, J.G. LYNG, F.J. MONAHAN. 2016.** "Quality attributes and retention of vitamin E in reduced salt chicken sausages fortified with vitamin E". Journal of Food Science and Technology 53(11): 3948–3959.

[5] **CHEN X., D.S. LEE, X. ZHU, K.L. YAM. 2012.** "Release kinetics of tocopherol and quercetin from binary antioxidant controlled-release packaging films". Journal of Agricultural and Food Chemistry 60(13): 3492–3497.

[6] **DÖRMANN P. 2007.** "Functional diversity of tocochromanols in plants". Planta 225(2): 269–276.

[7] **DUNCAN K., Y. SUZUKI. 2017.** "Vitamin E Nicotinate". Antioxidants 6(1): 20.

[8] **ECONOMOS C.D., C.E. MOORE, R.R. HYATT, J. KUDER, T. CHEN, S.N. MEYDANI, M. MEYDANI, E. KLEIN, R.M. BIANCUZZO, M.F. HOLICK. 2014.** "Multinutrient-fortified juices improve vitamin D and vitamin E status in children: A randomized controlled trial". Journal of the Academy of Nutrition and Dietetics 114(5): 709–717.

[9] **EFSA ANS Panel (EFSA Panel on Food Additives and Nutrient Sources added to Food), 2015.** "Scientific Opinion on the re-evaluation of tocopherol-rich extract (E 306), α-tocopherol (E 307), γ-tocopherol (E 308) and δ-tocopherol (E 309) as food additives". EFSA Journal 13(9): 4247.

[10] **EFSA Authority, 2008.** "Scientific Opinion of the Panel on Food Additives, Flavourings, Processing Aids and Materials in Contact with Food on a request from the Commission on mixed tocopherols, tocotrienol tocopherol and tocotrienols as sources for vitamin E". The EFSA Journal 604: 1–34.

[11] **FABRA M.J., A. LÓPEZ–RUBIO, J.M. LAGARO. 2016.** "Use of the electrohydrodynamic process to develop active/bioactive bilayer films for food packaging applications". Food Hydrocolloids 55: 11–18.



## REFERENCES

[1] **AH NGAN M., Y. BASIRON, C. YUEN MAY, H. LAU LIK NANG. 2004.** "Extraction of vitamin E, phytosterols and squalene from palm oil". European Patent Office – Bulletin 2004/10.

[2] **AHSAN H., A. AHAD, W.A. SIDDIQUI. 2015.** "A review of characterization of tocotrienols from plant oils and foods". Journal of Chemical Biology 8(2): 45–59.

[3] **BARBOSA-PEREIRA L., J.M. CRUZ, R. SENDON, A. RODRIGUEZ BERNALDO DE QUIROS, A. ARES, M. CASTRO-LOPEZ, M.J. ABAD, J. MAROTO, P. PASEIRO-LOSADA. 2013.** "Development of antioxidant active films containing tocopherols to extend the shelf life of fish". Food Control 31(1): 236–243.

[4] **BOLGER Z., N.P. BRUNTON, J.G. LYNG, F.J. MONAHAN. 2016.** "Quality attributes and retention of vitamin E in reduced salt chicken sausages fortified with vitamin E". Journal of Food Science and Technology 53(11): 3948–3959.

[5] **CHEN X., D.S. LEE, X. ZHU, K.L. YAM. 2012.** "Release kinetics of tocopherol and quercetin from binary antioxidant controlled-release packaging films". Journal of Agricultural and Food Chemistry 60(13): 3492–3497.

[6] **DORMANN P. 2007.** "Functional diversity of tocochromanols in plants". Planta 225(2): 269–276.

[7] **DUNCAN K., Y. SUZUKI. 2017.** "Vitamin E Nicotinate". Antioxidants 6(1): 20.

[8] **ECONOMOS C.D., C.E. MOORE, R.R. HYATT, J. KUDER, T. CHEN, S.N. MEYDANI, M. MEYDANI, E. KLEIN, R.M. BIANCUZZO, M.F. HOLICK. 2014.** "Multinutrient-fortified juices improve vitamin D and vitamin E status in children: A randomized controlled trial". Journal of the Academy of Nutrition and Dietetics 114(5): 709–717.

[9] **EFSA ANS Panel (EFSA Panel on Food Additives and Nutrient Sources added to Food), 2015.** "Scientific Opinion on the re-evaluation of tocopherol-rich extract (E 306), α-tocopherol (E 307), γ-tocopherol (E 308) and δ-tocopherol (E 309) as food additives". EFSA Journal 13(9): 4247.

[10] **EFSA Authority, 2008.** "Scientific Opinion of the Panel on Food Additives, Flavourings, Processing Aids and Materials in Contact with Food on a request from the Commission on mixed tocopherols, tocotrienol tocopherol and tocotrienols as sources for vitamin E". The EFSA Journal 604: 1–34.

[11] **FABRA M.J., A. LOPEZ–RUBIO, J.M. LAGARO. 2016.** "Use of the electrohydrodynamic process to develop active/bioactive bilayer films for food packaging applications". Food Hydrocolloids 55: 11–18.

[12] **Food and Nutrition Board Institute of Medicine, 2000.** "A Report of the Panel on Dietary Antioxidants and Related Compounds, Subcommittees on Upper Reference Levels of Nutrients and Interpretation and Uses of Dietary Reference Intakes, and the Standing Committee on the Scientific Evaluation of Dietary Referenc". NATIONAL ACADEMY PRESS Washington, D.C.

[13] **FRANKE A.A., S.P. MURPHY, R. LACEY, L.J. CUSTER. 2007.** "Tocopherol and tocotrienol levels of Foods Consumed in Hawaii". Journal of Agricultural and Food Chemistry 55: 769–778,

[14] **GALLI F., A. AZZI, M. BIRRINGER, J.M. COOK -MILLS, M. EGGERSDORFER, J. FRANK, G. CRUCIANI, S. LORKOWSKI, N.K. ÖZER. 2017.** "Vitamin E: Emerging aspects and new directions". Free Radical Biology and Medicine 102(September 2016): 16–36.

[15] **GALUS S., A. LENART. 2019.** "Wpływ powlekania na stabilność żywności". Postępy Techniki Przetwórstwa Spożywczego 2: 106–114.

[16] **GANTNER M., A. STOKOWSKA. 2015.** "Nie tylko przyprawy przedłużają trwałość mięsa". Postępy Techniki Przetwórstwa Spożywczego 1: 86–90.

[17] **Główny Inspektorat Sanitarny. Uchwała nr 1/2020 Zespołu do spraw Suplementów Diety z dnia 7 lutego 2020 r.** w sprawie wyrażenia opinii dotyczącej maksymalnej dawki witaminy E w zalecanej dziennej porcji w suplementach diety.

[18] https://www.researchgate.net/publication/267037548_The_antioxidant_role_of_tocopherol_in_food_packaging. Accessed March 6, 2020.

[19] **ILONA R., D. WICHROWSKA. 2011.** "Najpopularniejsze dodatki utrwalające stosowane w nowoczesnej technologii żywności". Inżynieria i Aparatura Chemiczna 50(2): 19–21.

[20] **IRÍAS-MATA A., W. STUETZ, N. SUS, S. HAMMANN, K. GRALLA, A. CORDERO-SOLANO, W. VETTER, J. FRANK. 2017.** "Tocopherols, Tocomonoenols, and Tocotrienols in Oils of Costa Rican Palm Fruits: A Comparison between Six Varieties and Chemical versus Mechanical Extraction". Journal of Agricultural and Food Chemistry 65(34): 7476–7482.

[21] **KNECHT K., K. SANDFUCHS, S.E. KULLING, D. BUNZEL. 2015.** "Tocopherol and tocotrienol analysis in raw and cooked vegetables: A validated method with emphasis on sample preparation". Food Chemistry 169: 20–27.

[22] **Rozporządzenie Komisji (UE) nr 432/2012 z dnia 16 maja 2012 r.** ustanawiające wykaz dopuszczonych oświadczeń zdrowotnych dotyczących żywności, innych niż oświadczenia odnoszące się do zmniejszenia ryzyka choroby oraz rozwoju i zdrowia dzieci.

[12] **Food and Nutrition Board Institute of Medicine, 2000.** "A Report of the Panel on Dietary Antioxidants and Related Compounds, Subcommittees on Upper Reference Levels of Nutrients and Interpretation and Uses of Dietary Reference Intakes, and the Standing Committee on the Scientific Evaluation of Dietary Referenc". NATIONAL ACADEMY PRESS Washington, D.C.

[13] **FRANKE A.A., S.P. MURPHY, R. LACEY, L.J. CUSTER. 2007.** "Tocopherol and tocotrienol levels of Foods Consumed in Hawaii". Journal of Agricultural and Food Chemistry 55: 769–778,

[14] **GALLI F., A. AZZI, M. BIRRINGER, J.M. COOK -MILLS, M. EGGERSDORFER, J. FRANK, G. CRUCIANI, S. LORKOWSKI, N.K. OZER. 2017.** "Vitamin E: Emerging aspects and new directions". Free Radical Biology and Medicine 102(September 2016): 16–36.

[15] **GALUS S., A. LENART. 2019.** "Wplyw powlekania na stabilnosc zywnosci". Postepy Techniki Przetworstwa Spozywczego 2: 106–114.

[16] **GANTNER M., A. STOKOWSKA. 2015.** "Nie tylko przyprawy przedluzaja trwalosc miesa". Postepy Techniki Przetworstwa Spozywczego 1: 86–90.

[17] **Glowny Inspektorat Sanitarny. Uchwala nr 1/2020 Zespolu do spraw Suplementow Diety z dnia 7 lutego 2020 r.** w sprawie wyrazenia opinii dotyczacej maksymalnej dawki witaminy E w zalecanej dziennej porcji w suplementach diety.

[18] https://www.researchgate.net/publication/267037548_The_antioxidant_role_of_tocopherol_in_food_packaging. Accessed March 6, 2020.

[19] **ILONA R., D. WICHROWSKA. 2011.** "Najpopularniejsze dodatki utrwalajace stosowane w nowoczesnej technologii zywnosci". Inzynieria i Aparatura Chemiczna 50(2): 19–21.

[20] **IRIAS-MATA A., W. STUETZ, N. SUS, S. HAMMANN, K. GRALLA, A. CORDERO-SOLANO, W. VETTER, J. FRANK. 2017.** "Tocopherols, Tocomonoenols, and Tocotrienols in Oils of Costa Rican Palm Fruits: A Comparison between Six Varieties and Chemical versus Mechanical Extraction". Journal of Agricultural and Food Chemistry 65(34): 7476–7482.

[21] **KNECHT K., K. SANDFUCHS, S.E. KULLING, D. BUNZEL. 2015.** "Tocopherol and tocotrienol analysis in raw and cooked vegetables: A validated method with emphasis on sample preparation". Food Chemistry 169: 20–27.

[22] **Rozporzadzenie Komisji (UE) nr 432/2012 z dnia 16 maja 2012 r.** ustanawiajace wykaz dopuszczonych oswiadczen zdrowotnych dotyczacych zywnosci, innych niz oswiadczenia odnoszace sie do zmniejszenia ryzyka choroby oraz rozwoju i zdrowia dzieci.

[23] **KOWALSKA D., A. GUGOLEK, P. KOBYLARZ. 2015.** "Wpływ metody pakowania i przechowywania na właściwości fizykochemiczne mięsa królików żywionych mieszankami paszowymi – wzbogaconymi olejem rybnym i witaminą E". Żywność. Nauka. Technologia. Jakość 1(98): 58–74.

[24] **KRAUß S., V. DARWISCH, W. VETTER. 2018.** "Occurrence of tocopheryl fatty acid esters in vegetables and their non-digestibility by artificial digestion juices". Scientific Reports 8: 7657.

[25] **LU D., Y. YANG, C. SUN, S. WANG. 2019.** "Determination of tocopherols and tocotrienols in cereals and nuts by dispersive solid-phase microextraction-gas chromatography-mass spectrometry". Analytical Methods 11(42): 5439–5446.

[26] **MARCOS B., C. SÁRRAGA, M. CASTELLARI, F. KAPPEN, G. SCHENNINK, J. ARNAU. 2014.** "Development of biodegradable films with antioxidant properties based on polyesters containing α-tocopherol and olive leaf extract for food packaging applications". Food Packaging and Shelf Life 1(2): 140–150.

[27] **NOGALA-KAŁUCKA M., A. SIGER. 2011.** Tokochromanole – bioaktywne związki roślin oleistych. Od biosyntezy do biomarkerów., Rośliny Oleiste – Oilseed Crops 32: 9–28.

[28] **OTERO-PAZOS P., R. SENDÓN, B. BLANCO-FERNANDEZ, S. BLANCO-DORADO, C. ALVAREZ-LORENZO, A. CONCHEIRO, I. ANGULO, P. PASEIRO-LOSADA, A. RODRÍGUEZ-BERNALDO DE QUIRÓS. 2016.** "Preparation of antioxidant active films based on chitosan: diffusivity study of α-tocopherol into food simulants". Journal of Food Science and Technology 53(6): 2817–2826.

[29] **PANDYA J.K., M. DEBONEE, M.G. CORRADINI, M.E. CAMIRE, D.J. MCCLEMENTS, A.J. KINCHLA. 2019.** "Development of vitamin E-enriched functional foods: stability of tocotrienols in food systems". International Journal of Food Science and Technology 54(12): 3196–3204.

[30] **POPOWICZ R., T. LESIÓW. 2014.** "Zasada działania innowacyjnych opakowań aktywnych w przemyśle żywnościowym. Artykuł przeglądowy". Nauki Inżynierskie i Technologie 1(12): 82–101.

[31] **QUEK S., B. CHU, B.S. BAHARIN. 2007.** "Commercial Extraction of Vitamin E from Food Sources", The Encyclopedia of Vitamin E: 140–152.

[32] **Rozporządzenie Komisji (UE) 2018/1497 z dnia 8 października 2018 r.** zmieniające załącznik II do rozporządzenia Parlamentu Europejskiego i Rady (WE) nr 1333/2008 w odniesieniu do kategorii żywności 17 i stosowania dodatków do żywności w suplementach diety.

[33] **SHAHIDI F., A.C. DE CAMARGO. 2016.** "Tocopherols and tocotrienols in common and emerging dietary sources: Occurrence, applications, and health benefits". International Journal of Molecular Sciences 17(10): 1745.

[23] **KOWALSKA D., A. GUGOLEK, P. KOBYLARZ. 2015.** "Wplyw metody pakowania i przechowywania na wlasciwosci fizykochemiczne miesa krolikow zywionych mieszankami paszowymi – wzbogaconymi olejem rybnym i witamina E". Zywnosc. Nauka. Technologia. Jakosc 1(98): 58–74.

[24] **KRAUß S., V. DARWISCH, W. VETTER. 2018.** "Occurrence of tocopheryl fatty acid esters in vegetables and their non-digestibility by artificial digestion juices". Scientific Reports 8: 7657.

[25] **LU D., Y. YANG, C. SUN, S. WANG. 2019.** "Determination of tocopherols and tocotrienols in cereals and nuts by dispersive solid-phase microextraction-gas chromatography-mass spectrometry". Analytical Methods 11(42): 5439–5446.

[26] **MARCOS B., C. SARRAGA, M. CASTELLARI, F. KAPPEN, G. SCHENNINK, J. ARNAU. 2014.** "Development of biodegradable films with antioxidant properties based on polyesters containing α-tocopherol and olive leaf extract for food packaging applications". Food Packaging and Shelf Life 1(2): 140–150.

[27] **NOGALA-KALUCKA M., A. SIGER. 2011.** Tokochromanole – bioaktywne zwiazki roslin oleistych. Od biosyntezy do biomarkerow., Rosliny Oleiste – Oilseed Crops 32: 9–28.

[28] **OTERO-PAZOS P., R. SENDON, B. BLANCO-FERNANDEZ, S. BLANCO-DORADO, C. ALVAREZ-LORENZO, A. CONCHEIRO, I. ANGULO, P. PASEIRO-LOSADA, A. RODRIGUEZ-BERNALDO DE QUIROS. 2016.** "Preparation of antioxidant active films based on chitosan: diffusivity study of α-tocopherol into food simulants". Journal of Food Science and Technology 53(6): 2817–2826.

[29] **PANDYA J.K., M. DEBONEE, M.G. CORRADINI, M.E. CAMIRE, D.J. MCCLEMENTS, A.J. KINCHLA. 2019.** "Development of vitamin E-enriched functional foods: stability of tocotrienols in food systems". International Journal of Food Science and Technology 54(12): 3196–3204.

[30] **POPOWICZ R., T. LESIOW. 2014.** "Zasada dzialania innowacyjnych opakowan aktywnych w przemysle zywnosciowym. Artykul przegladowy". Nauki Inzynierskie i Technologie 1(12): 82–101.

[31] **QUEK S., B. CHU, B.S. BAHARIN. 2007.** "Commercial Extraction of Vitamin E from Food Sources", The Encyclopedia of Vitamin E: 140–152.

[32] **Rozporzadzenie Komisji (UE) 2018/1497 z dnia 8 pazdziernika 2018 r.** zmieniajace zalacznik II do rozporzadzenia Parlamentu Europejskiego i Rady (WE) nr 1333/2008 w odniesieniu do kategorii zywnosci 17 i stosowania dodatkow do zywnosci w suplementach diety.

[33] **SHAHIDI F., A.C. DE CAMARGO. 2016.** "Tocopherols and tocotrienols in common and emerging dietary sources: Occurrence, applications, and health benefits". International Journal of Molecular Sciences 17(10): 1745.

[34] **SIRMONS T.A., M.R. COOPER, G.L. DOUGLAS. 2017.** “Food Fortification Stability Study”. NASA Technical Reports Server, Report nr JSC-CN-38387.

[35] **STRATULAT I., M. BRITTEN, S. SALMIERI, P. FUSTIER, D. ST-GELAIS, C.P. CHAMPAGNE, M. LACROIX. 2014.** “Enrichment of cheese with bioactive lipophilic compounds”. Journal of Functional Foods 6(1): 48–59.

[36] **SUMNER C.E., J.D. MONCIER, J.S. KANEL, M.K. FOSTER. 2001.** United States Patent – Methods for separating a tocotrienols from a tocol-containing mixture and compositions thereof (Patent No.:US 6,224,717 B1).

[37] **TORQUATO P., R. MARINELLI, D. BARTOLINI, F. GALLI. 2020.** “Vitamin E: nutritional aspects”. In: Molecular Nutrition 447–485.

[38] **TRELA A., R. SZYMAŃSKA. 2018.** W profilaktyce zdrowotnej. Kraków: (1): 60–68.

[39] **VAN HET HOF K.H., L.B.M. TIJBURG, H.S.M. DE BOER, S.A. WISEMAN, J.A. WESTSTRATE. 1998.** “Antioxidant fortified margarine increases the antioxidant status”. European Journal of Clinical Nutrition 52(4): 292–299.

[40] **ZHIDONG X., K.A. HARVEY, T.M. PAVLINA, G.P. ZALOGA, RA. SIDDIQUI. 2015.** „Tocopherols and tocotrienols homologs in parenteral lipid emulsions”. European Journal of Lipid Science and Technology 117: 15–22.

[41] **ZIELIŃSKA A., I. NOWAK. 2014.** “Tokoferole i tokotrienole jako witamina E”. Chemik 68(7): 585–591.

[42] **ZOU L., C.C. AKOH. 2015.** “Antioxidant activities of annatto and palm tocotrienol-rich fractions in fish oil and structured lipid-based infant formula emulsion”. Food Chemistry 168: 504–511.

[43] **ZOU L., C.C. AKOH. 2015.** “Oxidative stability of structured lipid-based infant formula emulsion: Effect of antioxidants”. Food Chemistry 178: 1–9.

[34] **SIRMONS T.A., M.R. COOPER, G.L. DOUGLAS. 2017.** “Food Fortification Stability Study”. NASA Technical Reports Server, Report nr JSC-CN-38387.

[35] **STRATULAT I., M. BRITTEN, S. SALMIERI, P. FUSTIER, D. ST-GELAIS, C.P. CHAMPAGNE, M. LACROIX. 2014.** “Enrichment of cheese with bioactive lipophilic compounds”. Journal of Functional Foods 6(1): 48–59.

[36] **SUMNER C.E., J.D. MONCIER, J.S. KANEL, M.K. FOSTER. 2001.** United States Patent – Methods for separating a tocotrienols from a tocol-containing mixture and compositions thereof (Patent No.:US 6,224,717 B1).

[37] **TORQUATO P., R. MARINELLI, D. BARTOLINI, F. GALLI. 2020.** “Vitamin E: nutritional aspects”. In: Molecular Nutrition 447–485.

[38] **TRELA A., R. SZYMANSKA. 2018.** W profilaktyce zdrowotnej. Krakow: (1): 60–68.

[39] **VAN HET HOF K.H., L.B.M. TIJBURG, H.S.M. DE BOER, S.A. WISEMAN, J.A. WESTSTRATE. 1998.** “Antioxidant fortified margarine increases the antioxidant status”. European Journal of Clinical Nutrition 52(4): 292–299.

[40] **ZHIDONG X., K.A. HARVEY, T.M. PAVLINA, G.P. ZALOGA, RA. SIDDIQUI. 2015.** „Tocopherols and tocotrienols homologs in parenteral lipid emulsions”. European Journal of Lipid Science and Technology 117: 15–22.

[41] **ZIELINSKA A., I. NOWAK. 2014.** “Tokoferole i tokotrienole jako witamina E”. Chemik 68(7): 585–591.

[42] **ZOU L., C.C. AKOH. 2015.** “Antioxidant activities of annatto and palm tocotrienol-rich fractions in fish oil and structured lipid-based infant formula emulsion”. Food Chemistry 168: 504–511.

[43] **ZOU L., C.C. AKOH. 2015.** “Oxidative stability of structured lipid-based infant formula emulsion: Effect of antioxidants”. Food Chemistry 178: 1–9.