



Usage of Natural Colour Indicators in Packaging Materials for Monitorization of Meat Freshness

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ARTICLE INFO	ABSTRACT
<p><i>Review Article</i></p> <p>Received : 10/05/2021 Accepted : 06/07/2021</p> <p>Keywords: Colour indicators Intelligent packaging Meat freshness Natural pigments Visual monitorization</p>	<p>Food packaging has an important role in protecting food against physical, chemical, and biological hazards during storage and distribution and in informing the consumer about the product. The packaging of foods that susceptible to chemical / microbiological spoilage especially such as meat, hence limited storage time, is even more important than other foods. In addition, the tendency of health-conscious consumers to be a part of real-time controls and monitoring food safety has led to the widening of this packaging perception. Hence, there have been innovative studies in recent years, especially aiming real time monitorization of freshness indicators. The focus of these studies is "colour indicators" used in the production of intelligent indicator films and colorimetric sensors within specific matrices to be integrated into packaging materials. The colour indicators change colour in the presence of certain metabolites released in food spoilage, which allows freshness to be determined. Colour substances used for this purpose can be natural or synthetic. Hence, natural pigments such as anthocyanin, curcumin, etc. have been more preferable since being harmless to the health as well as increasing tendency of consumers to utilization from natural resources. In this review, information about natural colour indicators and studies in which these indicators are used to determine the freshness of meat in real time and visually are given.</p>

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Ette Tazeliğin İzlenmesine Yönelik Olarak Ambalaj Materyallerinde Doğal Renk İndikatörlerinin Kullanımı

MAKALE BİLGİSİ	ÖZ
<p><i>Derleme Makale</i></p> <p>Geliş : 10/05/2021 Kabul : 06/07/2021</p> <p>Anahtar Kelimeler: Renk indikatörleri Akıllı ambalajlama Ette tazelik Doğal pigmentler Görsel izleme</p>	<p>Gıda ambalajları, gıdanın depolama ve dağıtım sırasında fiziksel, kimyasal ve biyolojik tehlikelere karşı korunmasında ve tüketicinin ürün hakkında bilgilendirilmesinde önemli bir role sahiptir. Özellikle et gibi kimyasal / mikrobiyolojik bozulmaya duyarlı, dolayısıyla saklama süresi sınırlı olan gıdaların ambalajlanması diğer gıdalara göre daha önemlidir. Bir de sağlık bilincine sahip tüketicilerin gıda güvenliğini izlemek ve gerçek zamanlı kontrollerin bir parçası olmak istemesi bu ambalaj algısının kapsamının genişlemesine yol açmıştır. Bu nedenle, son yıllarda özellikle tazelik indikatörlerinin gerçek zamanlı izlenmesini amaçlayan yenilikçi çalışmalar yapılmıştır. Bu çalışmaların odak noktası, ambalaj malzemelerine entegre edilecek belirli matrisler içerisinde, akıllı indikatör filmlerin ve kolorimetrik sensörlerin üretiminde kullanılan "renk indikatörleri" dir. Renk indikatörleri, gıdanın bozulmasında açığa çıkan belirli metabolitlerin varlığında renk değiştirmekte ve bu da tazeliğin belirlenebilmesine olanak vermektedir. Bu amaçla kullanılan renk maddeleri doğal veya sentetik olabilir. Antosiyanin, kurkumin gibi doğal renk maddeleri, sağlık açısından zararsız olmaları ve tüketicilerin doğal kaynaklardan yararlanma eğilimi nedeniyle öne çıkmaktadır. Bu derlemede doğal renk indikatörleri ve bu indikatörlerin etin tazeliğinin gerçek zamanlı ve görsel olarak belirlenmesi amacıyla kullanıldığı çalışmalar ile ilgili bilgiler verilmiştir.</p>

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Introduction

Meat is known to be a vulnerable food material against to microbiological spoilage which may cause poisonings and economical losses. There is an increasing demand for a nutritious and high-quality food which has a parallel tendency with increasing diet and health awareness and income of individuals especially in developed countries (Özkaya and Kayaardı, 2018). Recently, further satisfaction of consumer expectations is also considered and new technologies are emerging in order to enable real time visual monitorization of meat freshness. Major starting point of related researches is chemical, microbiological and pH changes in meat which tends to lose freshness as the time passes. Hence, freshness criteria come into view by evaluation of these changes.

Major freshness criteria of meat can be aligned as total volatile basic nitrogen (TVB-N), hypoxanthine/xanthine, hydrogen sulphure (H₂S), ammonia (NH₃) level, pH and microbiological parameters (total mesophilic aerobic, coliform and yeast and mould counts) (Fu et al., 2019). Due to release of these substances or concentration increase and even pH change, there occurs a colour change within susceptible packaging material which can be recognized by naked eye. Therefore, consumer-based freshness detection becomes possible. In this frame, intelligent packaging system and its basic ingredient within special films, -indicators- (Dudnyk et al., 2018; Zhai et al., 2019; Mohammadlinejad et al., 2020), have been used in many researches. Especially, there are successful indicator films which are integrated into fresh meat packages that make possible real time freshness control of the product. This review aims to evaluate natural colour indicators which are being used for packaging many kinds of meat.

Natural Colour Indicators and Their Usage for Intelligent Packaging

Colour indicators are defined as qualitative and semi-quantitative detection tools that reflects the present status of the product via colour changes (Zhai et al., 2019). They are integrated into packaging materials and hence, meat freshness can be detected.

Natural or synthetic substances can be obtained from several kinds of sources and fixed into suitable materials to be used within packages for expected functions. Due to formation of several metabolites such as CO₂, SO₂, NH₃, colour of the synthetic indicators, including xylene blue, bromcresole blue, cresole, phenol phytalein, etc. may change (Çelik and Tümer, 2016). However, possible toxic and carcinogenic features of those synthetic colour indicators have resulted in a considerable interest towards natural sources (Roy and Rhim, 2020). For instance, natural colour substances such as curcumin, betalain, anthocyanins, carotenoids and chlorophyll which are derived from plants and root vegetables have been considered as ideal pH-sensitive indicators for this purpose. Moreover, these natural colour indicators are used within biodegradable films containing chitosan, starch, polylactide, polyhydroxybutyrate, etc. (Latos-Brozio and Masek, 2020). On the other hand, methods of film production also have several alternatives that integration of indicator substances into the packaging materials can be

performed by solution casting method (Roy and Rhim, 2020), lamination technique (Lee et al., 2020), extrusion method (Zhai et al., 2020) or electrospinning (Aghaei et al., 2020). Therefore, usage of natural colorants in intelligent packaging concept is evaluated for several kinds of meat and meat products including seafood for easy and real time visual detection of freshness.

Anthocyanins

Anthocyanins are defined as one category of phenolic compounds that can be derived from several sources such as purple sweet potato (Jiang et al., 2020; Li et al., 2021), red cabbage, (Dudnyk et al., 2018), mulberry (Zeng et al., 2019), etc. and mentioned as excellent antioxidant, antimicrobial and pH-sensitive water-soluble natural colorants. Anthocyanins contain a huge group of molecules with a plenty of biological functions including anti-inflammatory, anti-proliferative and anti-carcinogenic activities and take an important place in the group of bioactive compounds because of these functional properties. Anthocyanins exist within the group of polyphenols which has also been the most abundant group in nature together with flavonoids, flavones, flavanones, isoflavones, catechins, phenolic acids, and tannins phytoestrogens, stilbenes, and curcuminoids (Filho et al., 2021). Since the name, -anthocyanins-, refers to a chemical group, there has not been a single substance with a unique colour, there have been hundreds of identified anthocyanin molecules up to now and they are separated into six groups (pelargonidin, cyanidin, delphinidin, peonidin, petunidin and malvidin) according to their basic structures. There exist some colour variations depending on the source of anthocyanin molecule and pH which include a wide colour spectrum from light pink to dark purple/blue and brownish tones (Yong and Liu, 2020). This colour changing character of anthocyanins is attributed to different groups attached at each position of the molecule and the acids attached to them, resulting in the formation of a pH dependent visible colour (Filho et al., 2021). Thus, an aqueous solution of an anthocyanin extract can demonstrate a colorimetric change from red or pink at pH < 7, purple at pH ≈ 7, green-yellow at pH > 7, and colorless in a highly alkaline medium. They are also nontoxic as they are a constituent in a variety of plants and have been used as a coloring additive in foodstuffs. Moreover, they demonstrated biological activities, such as anticancer, as well as antioxidant due to their ability to quench active oxygen species (Yong and Liu, 2020).

As it is mentioned that anthocyanins have a good potential to utilize in intelligent packaging applications, which are considered as safe to be used and abundant in the nature as well as their good colorimetric indicator properties. So, anthocyanins are considered as effective molecules for detection of meat freshness via intelligent packaging because of their sensitive nature to the substances which are released from meat during spoilage since the research of Huang et al. (2014) showed it with a comparative study. In the present study, reddish (*Raphanus sativus L.*) and black rice (*Oryza sativa L. indica*) extract anthocyanins were used in addition to carotene and chlorophyll natural pigments of spinach (*Spinacia*

oleracea) and winter jasmine (*Jasminum nudiflorum*) to detect the presence of biogenic amines in pork meat. The most sensitive pigment to biogenic amines was found to be black rice anthocyanins. This performance was attributed to the interaction between hydroxyl and carbonyl groups of anthocyanin molecule and the analytes. It can also be seen that, there have been many different anthocyanin molecules resulting in variations in performance between each other within this chemical group. Thus, anthocyanin molecules of reddish and black rice anthocyanins acted differently that the latter's performance was superior. Actually, there have been a wide variety of examples related to anthocyanin-based intelligent packages. Dudnyk et al. (2018) succeeded to manufacture an edible sensor film which was containing red cabbage anthocyanins. The film was also advantageous to be appropriate for several product groups such as beef, chicken, fish, shrimp. Colour of the film was turning from purple to yellow due to formation of amines as a result of spoilage, which was possible to recognize easily. As another example, Kürek et al. (2019) produced an intelligent packaging film from blueberry and red grape skin pomace extracts that were immobilized on chitosan and carboxymethyl cellulose polymer matrices to determine chicken meat freshness. When pH changes due to spoilage, colour of the films turned to green and orange according to containing

blueberry and red grape skin pomace extract anthocyanins, respectively. Jiang et al. (2020) also used a similar polymer matrix but another source of anthocyanin to manufacture an intelligent package. It was including carboxy methyl cellulose/starch and sweet purple potato anthocyanins to determine fish freshness. The film was especially sensible to ammonia and colour of the film (initially red) turned to blue-green as its concentration increased within the pack. On the other hand, flowers are also considered as a good source for natural pigments that, Zhang et al. (2021) produced a multi-layered packaging film, in which hydrophobic polyvinylidene fluoride film was a moisture prevent-layer and the sensor layer was provided based on polyvinyl alcohol/sodium alginate and roselle anthocyanins. Freshness change of griskin, a kind of meat product manufactured from pork, was determined with colour change from pinky tones to yellow/brownish colours pH change caused by TVB-N formation.

Sources of anthocyanins and appropriate matrices to be integrated have a wide variety of alternatives in addition to being abundant in the nature that, indicated properties of anthocyanins have encouraged many researchers to manufacture new natural-based colorimetric films for meat packaging and also consumer-based freshness monitoring. These researches are shown on Table 1 for meat and poultry and seafood.

Table 1. Anthocyanin-based packaging films according to different types of meat and seafood.

Package film content	Product	Function mechanism	Colour	Reference
Edible sensor from red cabbage anthocyanins with pectin	Beef, chicken, fish, shrimp	Amines	From purple to yellow	Dudnyk et al., 2018
Chitosan/Starch/ PVA and Roselle calyx anthocyanins	Pork	pH (TVB-N)	Red- Green- Yellow	Zhang et al., 2019
Gelatine/poly viny alcohol and black berry extract anthocyanins	Fish	TVB-N	From bright red to dark green	Zeng et al., 2019
Bacterial cellulose nanofibers and black carrot anthocyanins	Fish	pH (TVB-N)	From charm pink color to jellybean blue and khaki colors	Moradi et al., 2019
Blueberry and red grape skin pomace extracts immobilized on chitosan and carboxymethyl cellulose polymer matrices	Chicken meat	pH	Towards green in blueberry-based film and towards orange in grape seed extract-based film	Kürek et al., 2019
Polyvinyl alcohol/okra mucilage polysaccharide incorporated with rose anthocyanins	Shrimp	pH (Volatile ammonia)	Towards dark green (purple →blue →dark-green → yellow)	Kang et al., 2019
Starch/PVA and sweet purple potato and red cabbage anthocyanins	Shrimp	pH (TVB-N)	Light Purple-Bright Red- Blue- Green	Zhang et al., 2020
Jambolan fruit anthocyanins and agarose Solution	Chicken	pH (TVB-N)	Pink to yellow	Talukder et al., 2020
Bacterial cellulose and <i>Echium amoenum</i> anthocyanins	Shrimp	pH	From violet to yellow	Mohammadalinejad et al., 2020
Methylcellulose/chitosan nanofiber and barberry anthocyanins	Meat and seafood	NH ₃ /VBN formation-pH	From pink to green and finally yellow	Alizadeh-Sani et al., 2020
Halochromic nanocellulose label (containing grape anthocyanins)	Meat	pH (TVB-N)	From bright red to purplish red	Taherkhani et al., 2020.
Hydrophobic Polyvinylidene Fluoride film as a moisture prevent-layer and the sensor layer was provided based on polyvinyl alcohol/sodium alginate and roselle anthocyanins	Griskin	pH (TVB-N)	From pinky tones to yellow/brownish colors	Zhang et al., 2021

Curcumin

Curcumin is obtained from turmeric and it is used as a kind of spice and a natural colour pigment. It is produced from *Curcuma longa* (*Zingiberaceae*) tropical plant which is cultivated in several Asian countries such as India, China, Indonesia and has a bitterish taste similar to ginger. Curcumin is defined as a low-molecular weight polyphenolic compound. But demethoxycurcumin and bisdemethoxycurcumin also exist other than curcumin (diferulylmethane) that, these three are called as curcuminoids together (Er, 2016). Curcuminoids are commonly used which also considered as a kind of alternative treatment for several health problems including asthma, sinusitis, hepatic disorders, rheumatism, diabetic wounds, etc. Moreover, curcumin has been considered as a cure for poisoning, snakebites or a treatment of some parasites. It is also listed in the international numbering system for food additives. Because, curcumin is accepted as a safe coloring agent which gives a sharp yellow colour after addition to the food (Katmer, 2015). In addition, anti-inflammation, anticancer and antiviral characteristics of curcumin are also mentioned in literature. But similar to the anthocyanins, curcumin is also a pH-sensitive pigment and its colour changes from yellow to orange/reddish tones because of phenoxide anion formation (Yıldız et al., 2021). This property has recently drawn more attention for colorimetric indicator studies and intelligent packaging of foodstuff. So, there has been another area of utilization, in addition to present functions of curcumin. Therefore, it has become much more popular compared to the past (Chen et al., 2020). For instance, Liu et al. (2018) produced a packaging film with curcumin and κ -carrageenan for packaging shrimp and pork and successfully monitored freshness change due to TVB-N formation resulting in pH change of the packaging environment. For fish and beef, Zhai et al. (2020) manufactured a hydrophobic ammonia sensor (extruded low-density polyethylene-curcumin film) which was sensitive to NH_3 and other volatile amines. In this research, integration technique of the pigment was based on extrusion which also shows that there might be different methods in production of pigment containing packaging films. Hence, electrospinning is another alternative that, Yıldız et al. (2021) obtained electrospin nanofibers from curcumin loaded chitosan and polyethylene oxide nanofibers. Sensitivity of the nanofibers to TVB-N enabled visual determination of chicken meat freshness.

Natural pigments can also be used together. There has been recent research in which starch, polyvinyl alcohol (SPVA) and glycerol-based film was used with anthocyanin and curcumin. Three different colour formations could be achieved, representing freshness, medium freshness and spoilage of fish in SPVA/Glycerol film (curcumin and anthocyanin ratio was 2:8 (v/v)) (Chen et al., 2020). In another research, konjac glucomannan/ camellia oil and carrageenan/anthocyanin/curcumin-based pH-responsive double-layer indicator films had been manufactured and successfully enabled visual detection of meat freshness. It was shown that combined usage of curcumin and anthocyanin gave more obvious colour change and provided sensitivity increase (Zhou et al., 2021). Nevertheless, curcumin has been going on to be used alone in this field and some researches based on producing curcumin containing indicator or sensor films for meat packaging and visualizing change in freshness are shown on Table 2.

Other Natural Colour Indicators

Researchers have also benefited from several other natural pigments and reproduced alternatives to manufacture intelligent packages. Alizarin is one of them as a multifunctional natural pigment which is mainly used in pharmaceutical and food industries. Plant roots are its natural sources that, it is also called as Turkey Red. Production of indicators from alizarin is performed by ionisation and deprotonation of hydroxyl groups within phenolic compounds of that pigment (Ezati et al., 2020). Cellulose/chitosan-based film of alizarin was used for intelligent packaging of minced beef which had reversible colour changes from yellow to purple between pH 2-12 (Ezati et al., 2019). Aghaei et al. (2018) also manufactured a real time fish spoilage indicator to be used as on-packaging sensor whose colour changes because of TVB-N formation and pH increment caused by alizarin containing cellulose acetate nanofibers of the halochromic sensor. Aghaei et al. (2020) manufactured another sensor that was designed by electrospin zein nanofibers with alizarin content as indicator dye for detection of rainbow trout fillets. The fillets were preserved at 4°C for 12 days that, the sensor was colorless for 4 days while it turned to light purple later and finally it got magenta by the 10.-12. days of cold storage due to TVB-N and TVC formation.

Table 2. Curcumin-based packaging films according to different types of meat and seafood.

Package content	Product	Function mechanism	Reference
Curcumin from turmeric and κ -carrageenan	Shrimp and pork	pH (TVB-N)	Liu et al., 2018
Curcumin + chitosan/ chitosan oxide film	Fish and seafood	pH	Wu et al., 2019
Irradiated sodium alginat (NaAlg)/ acrylamide (AAm) mix	Chicken meat	pH	Demirel, 2019
Electrospun nanofibers from Curcumin + poly vinyl prolydon and ethyl cellulose/polyethylen oxide	Fish and seafood	Volatile amines	Luo et al., 2020
Hydrophobic ammonnia sensor (Extruded low-density polyethylene-curcumin film)	Silver carp (fish) and beef	NH_3 and other volatile amines	Zhai et al., 2020
Curcumin + sulphure nanoparticles with pectin-based film	Shrimp	pH	Ezati and Rhim, 2020
Curcumin + agar and polyvinyl alcohol	Freshwater shrimp (<i>Macrobrachium rosenbergii</i>)	NH_3	Zhang et al., 2021
Electrospun nanofibers from curcumin loaded chitosan and polyethylene oxide nanofibers	Chicken meat	TVB-N	Yıldız et al., 2021

It was concluded that the alizarin containing sensor was a good alternative for indication of fish spoilage

Shikonin is another alternative which is derived from the root of gromwell (*Lithospermum erythrorhizon*). It is exactly defined as a red naphthoquinone which is used for a cure for burns and inflammations, other than its colorant character. Recently, it has been used for an intelligent packaging system as a pH-sensitive colour indicator for monitoring the freshness of fish and pork. Colour of the film turned to blue while it was initially red, due to pH change. It was also reported that the packaging material had gained some other advantageous properties; water resistance and heat stability of the packaging material increased, and antioxidant activity improved. Therefore, shikonin reported to be a good alternative in this field (Ezati et al., 2021). Dong et al. (2020) also studied on colorimetric sensing film for real time monitoring the freshness of shrimp and pork. They used biodegradable cellulose and naphthoquinone dyes extracted from *Arnebia euchroma* (AENDs) which have alkannin and shikonin as the main pigments to be used as biogenic amines indicator. It was claimed that, use of this material within the packaging film provided a better mechanical strength, colorimeter properties, thermal stability and some other advantages.

On the other hand, betalains are another group of bioactive compounds, which contains water soluble pigments that replace anthocyanins in *Caryophyllales* plant family that, Kanatt (2020) benefited from the advantages of *Amaranthus* leaf extract (ALE) which is rich in phenolic compounds and betalain for packaging of fish and chicken. Shelf-life extension during chilled storage could also be succeeded due to antioxidant, antibacterial activity of the package content. It is reported that ALE changed colour from red to yellow under basic conditions due to betalain presence and increase in TVBN concentration had caused it. Finally, it was concluded that incorporation of ALE into PVA-gelatin films have provided an active/intelligent packaging film.

Natural sources can further be varied. In the research of Ian et al. (2020), a colorimetric sensor was designed with genipin which naturally exists in fruit extracts. Genipin was immobilized to edible Ca-alginate and used for chicken packaging, since it is known to interact with biogenic amines (cadaverine, putrescine, tyramine, histamine). The colour of the sensor had turned to dark blue due to spoilage.

Other natural pigments such as caroten, chlorophyll and lutein have also been in the scope of innovative packaging systems especially together with environmentally friendly biodegradable polymers for food industry, not only for meat packaging (Latos-Brozio and Masek, 2020). Moreover, sources and kind of natural pigments have been extending in time. For instance, a new natural source, *Spirulina* is defined as a microalgae with its characteristic blue-green colour and rich in pH-sensitive natural pigments such as β -carotene, tocopherols, phycocyanin, phycoerythrin and chlorophylls while it has also legally been on the market as a food supplement due to its composition (rich in high quality proteins and lipids), bioactives (bioactive peptides, PUFAs, vitamins, carotenoids) and

functional (anti-hypertensive, anti-obesity, anti-diabetes, anti-oxidant) properties (Lafarga et al., 2020).

Moreira et al. (2018), could successfully use the intense blue coloured pigment phycocyanin from *Spirulina* within poly lactic acid (PLA) / poly ethylene oxide (PEO) ultrafine nanofibers by electrospinning, while encapsulation of its biomass in polymer nanofibers is also considered as a promising application for developing a colorimetric pH indicator as also performed by Kuntzler et al. (2020). Usage of *Spirulina* within intelligent packaging has been going on that, recent research by Terra et al. (2021) was performed for visual estimation of pH changes depending on quality loss. Time-pH indicator nanofibers were manufactured to monitor the quality of foods by using curcumin and quercetin obtained from vegetable plants and phycocyanin from *Spirulina*. They concluded that polycaprolactone (PCL)/ (PEO) nanofibers containing 2% (w v⁻¹) of phycocyanin can be a good alternative to detect quality loss of perishable foods such as meat.

These researches obviously show that there exist a wide variety of natural pigments and sources to be utilized within the scope of intelligent and active packaging concept.

Common Challenges and Obstacles

Stability of these substances are quite important for their expected functions. However, each material is affected by extrinsic factors differently. For instance, curcumin is sensible to light, while betanin and anthocyanins are heat sensitive (Etxabide et al., 2021). Significant information about chemical nature and behaviour and general properties of them is also needed, since they ought to be integrated into appropriate matrices and to be well attached where the main purpose is getting the best performance. In details, anthocyanins are negatively affected by heat, light, metal ions and pH, while it is claimed that stability is mostly affected by its molecular structure. For example, stability decreases as the count of hydroxyl groups existing in the B-ring of the anthocyanidin increases; however, stability increases as the level of methylation increases. There has been another claim that acylation can promote stability increase which had been found with research on blueberry anthocyanins that was treated with maleic acid. It was concluded that, anthocyanins which had been processed with acid treatment can be a good colour indicator for packaging materials (Fei et al., 2021).

It is concluded that production of natural colorimetric packaging materials is a promising field of intelligent packaging applications especially for vulnerable foods such as meat (Takma and Nadeem, 2019). Although they have not been widely used or commercialized, it seems to be succeeded in the future with progressive studies.

Conclusion

Meat has been an important food material and also an economic value since the ancient times but open to intrinsic and extrinsic threats, especially chemical and microbiological factors. So, detection of its freshness is required to be as possible as easy, accurate and fast. It is

quite important for prediction/prevention of possible economical loss and/or foodborne diseases as well as meeting health-conscious consumers' expectations for fresh and nutritious food. In this context, freshness criteria of meat should be known first of all. So, formation of biogenic amines, TVBN, hypoxanthine and xanthine, sulphur compounds and pH changes are determinant other than microbiological parameters. At this point, principle of intelligent packaging to check product freshness is based on selection of a particular substance which is called as "freshness indicator" due to being sensible to the changes caused by spoilage and integration of that indicator into packaging film within a compatible matrix. On the other hand, selected indicator substance can be obtained from natural sources or it can be synthetic. Natural indicator substances are originated from several kinds of plants and fruits and vegetables and regarded as safe to be used in that field. Moreover, they have extra advantages for product protection and health due to their bioactive nature (antioxidant, antimicrobial, anticarcinogenic, anti-inflammatory, etc.) while synthetic ones are claimed to be opposite, unhealthy, and have not recently been recommended to use. That's why, main focus of this review was on natural indicators such as anthocyanins, curcumin, alizarin, etc. pigments and related intelligent or active packaging researches instead of the ones with synthetic indicators such as methyl red, bromocresol green, etc. However, the main purpose of those researches is independent from the origin of indicator, since the aim is enabling real time visual monitorization of spoilage via colour changes of special packaging films. Hence, meat freshness can be checked at any time with naked eyes, even by the consumers at the time of purchasing the product or consumption step. Nevertheless, it should be mentioned that, application of this type of packaging have not gained a commercial dimension worldwide. Promising results are taken by academic studies while practical applications sometimes fail due to some obstacles, especially stability problems of natural pigments, but researchers focus on progressive studies and trying to enhance the present status. Moreover, biodegradable polymers and manufacturing eco-friendly packaging materials can be considered as future trends in addition to the usage of natural indicator pigments. Therefore, we conclude that intelligent packaging of meat is quite open to improvement with new researches.

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