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The Important of Beta Carotene on Poultry Nutrition

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ABSTRACT

Beta carotene, the primary source of vitamin A in poultry rations, is one of the most important carotenoids. Under the influence of enzymes, Beta carotene (BC) is converted to vitamin A. The BC molecule is a double retinal structure and theoretically gives 2 molecules retinal. Its biological activity is only half of retinal. Conversion of carotenoids to retinol is rarely 100%. Thus the vitamins of various foods are expressed in terms of the potential retinol equivalence (RE).

BC is absorbed from the duodenum and if there is oil in the intestinal tract, it is absorbed faster. Oxidatively converting BC into vitamin A is mainly carried out in the intestinal brush border membrane, organs such as the liver, kidney and lungs. BC egg yolk is transported to and stored in immune organs and similar tissues. The BC content of the egg of the poultry varies. BC contents of hen eggs are low, while BC contents of eggs of wild birds are between 25-30%. Despite depletion of BC in the liver it's transfer to the egg continues.

Since poultry can not synthesize BC, it must be taken from outside. Products such as yellow corn, marigold and alfalfa are very rich sources of beta-carotene. BC is abundant in egg yolks.

BC is effective in the pigmentation of skin and egg yolks of hens. Due to BC's antioxidant properties prevents deterioration of egg and meat. It has also been shown that BC has important effects on the immunity and endocrine system. BC, strengthens see function, reduces the risk of cardiovascular disease, prevents inflammation and some types of cancer. Studies have shown that BC enhances the immune system by raising antibody response in poultries and prevents acute respiratory tract infections.

In this review article, the introduction of BC, its functions, effects on poultry nutrition were investigated.

1. Introduction

It has been observed that the nutrient profile (fatty acids, minerals, vitamins, etc.) of the egg, which is considered to be a highly nutritious food among nutritional sources, can be significantly improved by diet manipulation. For this reason, intensive research is carried out on the passage of some nutrients that can affect human health positively to eggs (Bean and Leeson, 2003; Khan et al., 2012).

It is stated that the enrichment of egg in terms of carotenoids will be beneficial for human health (Skřivan et al., 2015). One of the carotenoids suitable for this purpose is BC (Stahl and Sies, 2005), a provitamin A (Olson, 1996). In recent years, due to the increase in demand for safe animal products, it has become more important to prefer natural resources for coloring the egg yolk (Calislar and Uygur, 2010). The nutrient profile of the eggs can be improved by diet manipulation. In the researches, it has been seen that some nutrient components that have important benefits for health can be transferred to the egg yolks via feed (Bean and Leeson, 2003; Khan et al., 2012).

Since poultry are exposed to stress conditions in a significant proportion of their lives, it is extremely important that their immune system is strong. One of the most suitable sources for this is the BC, which has a high antioxidant content. In the researches, it has been emphasized that BC enhances the survival of poultry by strengthening the immune system and positively affects the efficiency parameters.

BC is the primary source of vitamin A. Vitamin A is necessary for healthy development of bone, skin and mucosa, especially in eyesight (Thomas, 2006). Therefore, it is seen that BC has a combined effect in poultry. Particularly due to its antioxidant properties, it is thought that BC will contribute positively to the gen-

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eral immune system and performance of poultry which are exposed to diseases and effects of mycotoxins. It is also clear that as an egg component, it will have a positive impact on human health.

BC is used as a colorant and antioxidant agent in the food, cosmetics, pharmaceutical, animal feed industry (Martelli, et al., 1990; Astorg, 1997). BC gives color to products such as eggs and meat. However, it is known that most of the BC, which is used as colorant in various production industries, is synthetic. Recently, the use of natural BC has started to become widespread in line with consumer demands. By-products obtained from fruit juice production (carrot, grapefruit, apricot pulp, etc.) have low prices. Therefore, these products are used as natural BC source in chicken feeds (Sikder et. al., 1998; Mascarell et al., 2012). It has been reported that the recommended amount of BC in the feed of laying hens should be at the maximum feed rate of 30 mg / kg feed (EFSA, 2012).

It is considered that there is a small number of studies on poultry feed in relation to BC, which has important contributions to both poultry and human health, and it will be useful to focus on new research in this area.

2. Beta Carotene Resources

BC is a yellow-orange pigment. BC is found in the structure of fruits, grains, vegetables (carrots, green plants, pumpkin, spinach) and oils (Liu, 2013) with maize, green fodder, moss, marigold, stinging nettle and similar products (Table 1) (Kljak et al., 2012).

Plants such as sweet potatoes, carrots, cabbage, spinach, lettuce, fresh thyme, gourd, turnip, melon, green cabbage and broccoli are rich in BC (Groff et al., 1995). BC is more common in the leaves of plants and the amount decreases as the plant ages (Ballet et al., 2000). Egg yolks, milk, butter and liver are also animal sources containing BC. Because of its low amount and unstable structure, BC deficiency is sometimes observed in animals.

BC is also produced by algae (Dunaliella bardawil and Murielopsis sp) (Goodwin, 1992), fungi (Blakeslea trispora) (Mantzouridou and Tsimidou, 2008) and yeasts (*Rhodotorula glutinis*; Park et al., 2005). Among microbial sources, Rhodotorula glutinis, which is rich in protein, lipid and vitamins, has been reported to be suitable for producing BC (Bhosale and Gadre, 2001). In order to meet the BC needs of poultry, non-toxic Rhodotorula cells are used in rations (Kushwaha et al., 2014). The major carotenoid in the Western diet is BC (Stahl and Sies, 2005).

Table 1
Some sources of beta carotene and beta carotene contents

Source of BC	BC content	Literatur
Corn, yellow (mg/100g)	0.051	Yılmaz, 2010
Corn, sweet, yellow (mg/100g)	0.033	Lee et al., 1981
Daucus carrota (mg/100 g fresh weight)	3.2-6.1	Yılmaz, 2010
Carrots, raw (mg/100g)	4.65	Bushway, 1986
Red pepper, dry (mg/100g)	2.20	Yılmaz, 2010
Peppers, sweet, red, raw (mg/100g)	0.059	Philip and Chen, 1988
Alfa alfa, green (mg/kg crude matter)	97.5	Descalzo et al., 2012
Alfa alfa, dry (mg/kg crude matter)	5.5	Descalzo et al., 2012
Soybean meal, expeller (mg/kg crude matter)	0.30	Descalzo et al., 2012
Sunflower, expeller (mg/kg crude matter)	nd	Descalzo et al., 2012
Naturel meadow grass, green (mg/kg crude matter)	63.8	Kalac, 2012
Blakeslea trispora (mg/L)	173	Wang, et al., 2014
Rhodotorula glutinis (mg/L)	6.54	Kushwaha et al., 2014

Since vitamin A cannot be synthesized by poultry, it should be taken as BC or vitamin A with feeds (Theodosiou et al., 2010). Besides carotenoids from plants, some carotenoid derivatives in the European Union have also been approved for use as an additive. These; capsantin (C40 carotenoid), P-cryptoxanthine (C40), lutein (C40), zeaxanthin (C40), P-apo-8-carotenal (C30), P-apo-8'-carotenoic acid ethyl ester (C30), xanthaxanthin (C40) and sitranaxanthin (C33) (Nimalaratne et al., 2013). The bioavailability of BC (crystal form) found in carrot juice in the feeding of wild poppies was about 30% (White et al., 1993).

Carotenoids are tetraterpenoid (C40) pigments synthesized from eight isoprene units found only in plants (Wagner and Elmadfa, 2003). They are divided into two groups according to their chemical structure: carotenes (hydrocarbon class) and xanthophylls (oxygen class) (Shete and Quadro, 2013; Von Lintig, 2012). Carotenes consist of alpha, beta and gamma carotene. The most important of carotene is the BC, which is the source of vitamin A (Taylor, 1996). BC is a fat-soluble provitamin A (Valko et al., 2007).

The BC was first isolated by Wachenroder in 1831 (Davies, 1976). The name BC was taken from carrot (Daucus carota) (Deming and Erdman, 1999). BC is almost always associated with chlorophyll in plants (Merck Index, 2006). The 1-carotene absorption spectrum is between 400-500 nm and is green-blue (Isler and Solms, 1971). Therefore, the BC molecule absorbs green-blue light and gives red-yellow colors.

BC is insoluble in water, acids, alkalis, but soluble in carbon disulfide and chloroform. Insoluble in methanol and ethanol BC, ether, hexane and oils (FCC, 2011) slightly soluble. The diluted solution was yellow. Absorbs oxygen, which leads to inactive, colorless oxidation products (Merck Index, 2006). Pure BC is a rather dark reddish-orange color, while oxidized or melted BC is slightly yellowish orange and gray. BC, like vitamin A does not dissolve in water, it is only soluble in fat (Tek et al., 2002).

BC melts between 176-182 °C. BC, which is in the cis- and trans-isomeric forms, has a melting point of 184.50 ^{0} C (Olson, 1996). The molecular weight is 536.87 g/mol (Merck Index, 2006; FCC, 2011).

Although many carotenoids commonly have asymmetric carbon atoms, BC does not contain asymmetric carbon atoms (Woollard, 2012). The BC in the non-polar hydro-carbon group has two ion rings and theoretically this retinal structure is converted into two molecules of retinol. The conversion of carotenoids to retinole is rarely 100%. Therefore, vitamin A power of various foods is expressed as retinol equivalence (RE). Accordingly, 1 RE; 1 mg of retinol is equal to 6 mg of BC and 12 mg with other provitamin A carotenoids (Maynard et al., 1979). Vitamin A requirement of poultry is expressed as international unit (IU). It has been reported that 1 IU vitamin A activity is equivalent to 0.6 microgram BC activity or 1 mg BC is equivalent to 1.667 IU vitamin A (Blair, 2018). 1 mg of BC is equivalent to 400 IU of retinole in broiler chicks (Johannsen et al., 1998), 1200 IU in old geese and only 60 IU in young geese (Jamroz et al., 2002).

There is no proven information that the carotenoids have been transformed into another carotenoid. However, β-apo-8'-carotenal and β-apo-8' carotenoic acid ethyl esters of the BC degradation products have been shown to have coloring potential in poultry (El-Boushy and Raterink, 1992; Erdman et al., 1993). BC gives yellow-orange color to egg yolk (Dufossé, 2009).

Feed carotenoids are present in the natural compounds in about 60 to 90% trans and 10 to 30% cis form. Trans form is a more effective pigment due to its red color tone and greater stability. Chickens have the ability to convert some of the trans form of BC into the cis form and this transformation takes place in egg yolk (Hencken, 1992).

Most commercialized beta carotenes are the chemical synthesis of β-ionone (Raja et al., 2007; Ribeiro et al., 2011). The β-ionone is originally synthesized from natural sources, such as lemon grass oil or pine turpentine. However, in recent years it has been produced from β-ionone, acetone or butadiene. BC is synthesized by saponification of vitamin A acetate. Fungal and microalgae are very promising sources for the industrial production of carotenoids (Echavarri-Erasun and Johnson, 2002). Some strains of Blakeslea trispora fungus, a host of tropical plants, are high BC producing sources (Dufossé, 2006).

3. Functions of Beta Carotene

Provitamin A and thus BC are required to perform visual functions (Von Lintig, 2012). BC has been shown to inhibit certain types of cancer with arthrosclerosis, cataract, and multiple sclerosis due to the antioxidant properties and provitaminase activity (Terao, 1989).

BC prevents oxidative damage to cellular lipids, proteins and DNA. BC, which shows anti-inflammatory properties, protects the skin against premature aging, photodermatitis and cancers against the harmful effects of UV light (Stahl and Sies, 2007; Cazzonelli, 2011). It has been reported that carotenoids have a significant effect on skin, egg and meat quality (Liufa et al., 1997). Carotenoids have a great effect on the color of the hens' skin and egg yolk, egg and meat quality (Sirri et al., 2007; Hien et al., 2013).

The annual total carotenoid production in nature is estimated to be around 100 thousand tons. Carotenoids play an important antioxidant function by activating singlet oxygen, an oxidant formed during photosynthesis in plants (Halliwell and Gutteridge, 1999). BC is an active molecule that has properties that inactivate some reactive oxygen species in relation to its antioxidant potency. Epidemiological findings have shown that BC can prevent cancers of various organs such as lung, stomach, cervix, pancreas, colon, rectum, breast, prostate and ovary due to its antioxidant activity (Jayappriyan et al., 2013).

Carotenoids with provitamin A and antioxidant effect have cellular differentiation, growth, reproduction, gene expression, immune function, and adipocyte functions (Tourniaire et al., 2009).

According to the BC free group, cock fed with BC containing rations, has been reported to produce higher antibody titer against newcastle disease (McWhinney et al., 1989). They reported that BC used in combination with vitamin E provided more protection against the infection of Escherichia coli in chickens (Tengerdy et al., 1990).

According to other organs, the concentration of BC in the corpus luteum was highest but no effect on reproduction was determined (Thomas, 2006).

4. Metabolism of Beta Carotene

Vitamin A is required for the survival of all vertebrate animals. BC is one of the important sources of vitamin A requirement. Absorption of BC from intestines, transformation into vitamin A, transport, accumulation and metabolism of tissues vary according to animal species.

The conversion of BC to vitamin A generally occurs in intestinal mucosa cells and liver (Coultate, 1996). Since the BC molecule consists of a pair of retinas, two molecules of retinal formation occur when this structure is separated from the middle. However, the biological activity of BC is only about half of the retinal. The enzyme responsible for the conversion of BC to retinale is known as BC-15, 15 monooxygenase or 15.15 si dioxigenase (Wyss et al., 2000; Dela Seña et al., 2014). Retinol and retinoic acid are also produced from the retinal (Taylor, 1996; Arikan and Muğlalı, 1999).

Absorption of BC occurs in the duodenum of the small intestine. The absorption of BC can last for several days. Absorption is faster and more effective if there is an oil in the environment. Sometimes the BC is absorbed into the intestinal wall and is quickly converted to vitamin A in there. The rest of BC is transported in the blood as very low density lipoprotein cholesterol (Nnaji et al., 2013).

Approximately 40%-45% of total carotene content is found in egg yolk (Surai and Speake 1998; Surai et al., 1999). However, compared to other carotenoids, the amount of BC stored in the egg yolk is very low. Because BC is used as a provitamin A by poultry, it is very poor to accumulate in egg yolks or other tissues (Hammershoj et al., 2010).

Poultry predominantly accumulate oxycarotenoids in their body tissues or eggs (Goodwin 1986; Hencken 1992). The deposition rate of lutein and zeaxanthin in the egg yolk was 25%, while the accumulated amount of BC was only 0.5% (Jiang et al., 1994; Hammershoj et al., 2010).

The main storage site of BC in poultry is liver. Only 0.16% to 0.66% of the total carotenoids stored in the egg yolk of poultry cultivated under intense and semi-intensive conditions were reported as BC. It was found that the amount of BC accumulated in the duck egg yolk was 1.62% (Khan et al., 2017).

The total amount of carotenoid in the egg yolk of poultry has been reported to vary between 17.33% and 37.90%, while the amount of BC varies between 1.07% and 2.12% (Kotrbáček et al., 2013). Astaxanthin in egg yolk is stored at 14%, zeaxanthin 25% and canthaxanthin at 30-40% (Hencken, 1992).

The transfer of BC to egg yolk is 0.6% while the rate of conversion to vitamin A (5-6%) is relatively high. In a study in which chickens were given sweet potato and silage, the absorption rate of xanthophylline was 93-94% and the carotene was absorbed between 55-63% (Yamada et al., 1958). Poultry animals absorb carotenes less than xanthophylls (Surai et al., 2001). BC increase in egg yolk is only 2.1% of total carotenoids (Török et al., 2007).

The number of studies on the effects of egg yolk changes in BC content is insufficient. In previous some studies, it has been reported that the amount of BC in the egg yolk decreases due to increased storage time regardless of source (Rock et al., 1996; Thomas, 2006).

The amount of BC in the eggs of different poultry breeds varies. The amount of BC on the first day of storage white leghorn hens egg yolk has found to be 0.060 mg / g, in the first week 0.047 mg / g, in the second week 0.027 mg / g and in the third week 0.004 mg / g (Okonkwo, 2009).

5. Accumulation of Beta Carotene

Feed carotenoids can undergo numerous transformations in the metabolism of animals. Some of these compounds have vitamin A activity. Usually only monohydroxy and mono-cetocarotenoids are converted into vitamin A. Carotenoids, which have high vitamin A activity, generally have very low coloring properties (Hencken, 1992).

In a feeding study with a weight of 8000 IU vitamin A in laying hens, 80% of vitamin A was transferred to egg yolk (Squires et al., 1993). In another study, it was reported that only 85.11 micrograms of vitamin A in dietary 120 micrograms could be transferred to egg yolk (Surai et al., 1998).

The amount of BC stored in egg yolk was reported to be very low (1%) (Hammershoj et al., 2010; Xue et al., 2013). In a recent study, it was determined that 8.85% of the BC in different hybrid maize was deposited in the egg yolk of laying hens (Kristina et al., 2018).

Laying hens store vitamin A in egg yolks for incubation and embryo development during the first stages of life (Bardos, 1989). Most of the vitamin A stored in the egg yolk is retinol and a small portion is retinyl esters (Joshi et al., 1973).

Adding up to 70 g of carrots per day to the rations during the feeding of laying hens has been shown to increase the egg yolk color value, especially lutein, alpha carotene and BC content effectively (Hammershoj et al., 2010). Xanthophylls (lutein, zeaxanthin) have been found to be better absorbed than hydrocarbons carotenoids (alpha-carotene, BC) (Dumbrava et al., 2006).

The addition of lutein to the ration (100 mg / kg) increased the yolk color and redness value. Compared with the control group, lutein containing diets increased the amount of BC in egg yolks by 66%, lutein 97% and zeaxanthin by 94%. However, because it is expensive, lutein is not routinely added to rations (Englmaierová and Skininivan, 2013).

BC has an accumulation rate of less than 1% in egg yolk. It has been reported that there is a linear increase in the amount of egg yolk retinol due to the increase in the amount of BC in the diet (Jiang et al., 1994). In some previous studies, it has been reported that the amount of BC in egg yolk is 1.07-2.12 (µg / kg; Kotrbáček et al., 2013) and 0.16-1.62 (mg / kg-1; Khan et al., 2017).

Very few of the BC given with the ration passes to the yolk and the rest is converted to retinol and stored in the egg. Egg yolk color is mainly affected by fat-soluble carotenes, xanthophylls and BC. A decrease in the color of the egg yolk in line with the increase in vitamin A of the rations occurred. It has been stated that high vitamin A can cause absorption of fat-soluble pigments (Mendonça et al., 2002).

In bird species, carotenoids tend to accumulate in their immune organs. When carotenoids were included in the breeding diet, it was shown that there was a significant accumulation in the thymus and bursa fabricus of chickens. Furthermore, carotenoids from the chicken diet were still detected 4 weeks after hatching in carotenoid consuming diets fed from chickens (Koutsos et al., 2003).

Carotenoids can be exposed to oxidative effects due to storage time, room temperature and illumination (photochemical) due to the large number of double bonds in their structure. The enzymatic degradation of BC requires oxygen and the destruction at high temperatures is highest. Destruction stops after complete dehydration. Therefore, both enzymatic and photochemical effects which cause the destruction of BC during storage must be controlled (Geoffrey, 1998). Losses occur during storage of BC. It was reported that the loss in the waiting period of 25 ^{0} C for one month was 10% and the loss after three months was 29% of the initial value (EFSA, 2012).

6. Conclusion and Suggestion

Some nutrients in feeds can be transferred to eggs and functional eggs can be produced. It is thought that one of the nutrients that may contribute to functional production due to increasing the amount of egg that is passed to the egg and which is stored here may be BC. However, more information is needed about the transition of BC into eggs. It is thought that it is necessary to focus more intensely on BC, which is thought to have an important contribution to the realization of an organic and sustainable animal production suitable for human health in a century when organic egg and meat production is gaining momentum.

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