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Review Article

Dietary enrichment of broiler chicken with omega-3 fatty acids and beneficial role in human cardiovascular health: A Review

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ABSTRACT

Broiler meat consumptionin the world increases annually with the development of modern diet pattern. Saturated fatty acid content of the meat causes high risk of cardiovascular disease in human. Fish is an important source of omega-3 fatty acids, which reduce the risk of cardiovascular disease in human. However, access to food fish, which are rich in omega-3 fatty acids, is questionable for many people in the world. Fortunately, studies revealed that the dietary enrichment of broiler chicken ration with omega-3 fatty acids enriched the broiler chicken meat with omega-3 fatty acids. Hence, consumption of such broiler chicken meat may supplement the scarcity of consumption of omega-3 fatty acids rich foods viz. fish. Moreover, dietary enrichment of omega-3 fatty acids improves carcass by reducing the abdominal fat deposition in broilers. However, shelf-life of broiler chicken meat that is enriched with omega-3 fatty acids low due to high levels of lipid oxidation. However, usage of antioxidants improves the shelf-life of omega-3 fatty acid enriched broiler chicken meat.

Introduction

Animal source foods are complete and nutrient-dense, and provide high quality protein and bio-available micronutrients *viz.* iron, zinc vitamin A, vitamin B_{12} and calcium, particularly for children and pregnant and lactating mothers (FAO, 2011). In particular, consumption of meats prevents anaemia and enhances iron absorption from plant based foods(Walker *et al.*, 2005). Hence, different communities in the world regard meat as a desirable food with high nutritive value (FAO, 1992; Michael and Bambrick, 2005). Irrespective of cultural taboos for the consumption of meats, poultry meat is accepted in many cultures (FAO, 2011), particularly broiler chicken meat (Chashnidel *et al.*, 2010). In developing countries, a great rise in the production of poultry has been observed (Fig. 1) and expected to continue in future (Speedy, 2003).

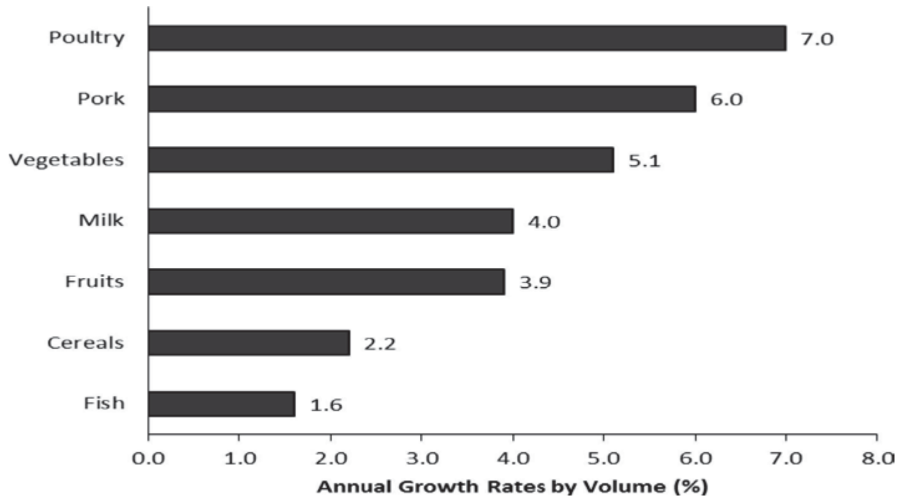

Fig 1. Growth in production of agricultural products in developing countries (1975–2005)
Source: FAO (2008).

Compare to pigmeat, bovine meat, and ovine meat, world poultry meat production has grown at a higher rate for last ten years (Fig. 2), and it is expected to rise by 1.5% in 2015 (FAO, 2015). According to FAO (2011), growth in world poultry meat consumption will be 225% by2050 (Fig. 3).In particular, developing countries have shown a higher growth in broiler production(Chang, 2007). Globally, poultry meat contributes around 35% of all meats (FAO, 2015), whereas in Sri Lanka 75% of the per capita meat consumption is contributed by poultry meat (Department of Animal Production and Health, 2011), mainly by the chicken (De Silva *et al.*, 2010).

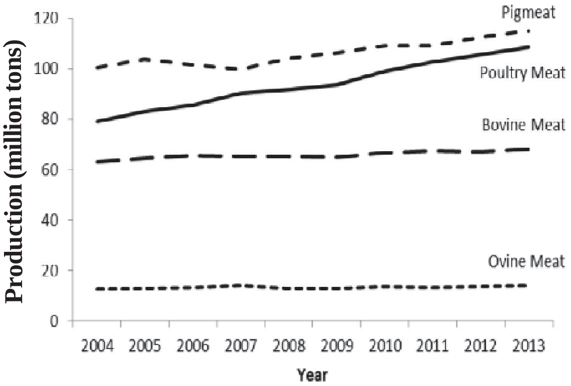

Fig. 2 World meat production trends in past ten years
Source: FAO Food Outlook (2006-2015).

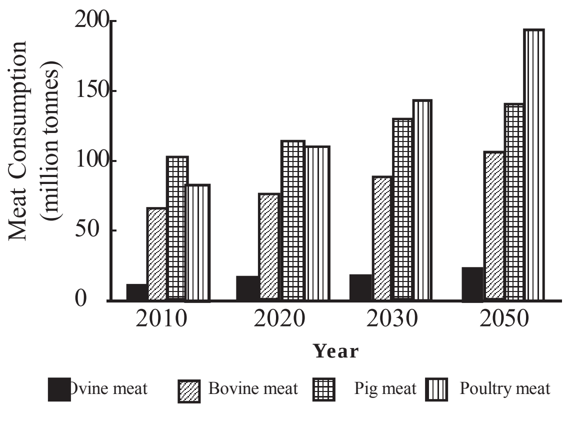

Fig 3. Projected growth in world meat consumption
Source: FAO (2011).

On the contrary, meats are the primary source of saturated fats, which are responsible for high risk of cardiovascular disease, diabetes mellitus and cancers in human (McMichael and Bambrick, 2005). Moreover, modern agribusiness and food processing industries change the nutrient content and structure of many food items. For example, hydrogenation of foods changes the double bonds of fatty acid from *cis* to *trans* and result with increased *trans* fatty acids in processed foods. This structural change increases the risk of coronary heart disease (CHD) in human (Simopoulos, 1999). Furthermore, modern diets have high saturated fatty acids (SFAs) and low mono-unsaturated fatty acids (MUFAs) and poly-unsaturated fatty acids (PUFAs) (de Witt *et al.*, 2009). Myristic and palmitic acids are the principal dietary SFAs that increase the blood cholesterol level (**Bender, 1992**).Arterial plaques, which lead to partial blockage of the blood vessels, are caused by oxidized (rancid) form of cholesterol (Farrell, 2010).

In these contexts, there are growing interests in the world in modifying the cholesterol content and fatty acid compositions of poultry products (Hargis and Van Elswyk, 1993; Sacks, 2002; Salma *et al.*, 2007) to produce superior health quality food. Recent researches also deal with reducing fat, cholesterol, and SFA contents of poultry meat by dietary supplementation of garlic, copper, α-tocopherol acetate and omega-3 fatty acid (Salma *et al.*, 2007). The latter has utmost importance due to its human health benefits. However, consumption of omega-3 fatty acid by human is rare. Hence, there are several studies have been carried out in the world to enrich the favourite human foods *viz.* poultry meat with omega-3 fatty acids so as to provide health benefits to the human.

This article is intended to review the studies related to dietary enrichment of broiler chicken with omega-3 fatty acids and their impacts on productive parameters of broiler chicken and health condition of broiler chicken meat consumers.

Omega-3 fatty acids

Dietary fat consists of both SFA and unsaturated fatty acids (UFA). The latter further divided into MUFA and PUFA. Based on the chemical nature, PUFAs are further classified into omega-3 fatty acids (also called as ω-3 fatty acidsor n-3 fatty acids) and omega-6 fatty acids (Din *et al.*, 2004). Thus, omega-3 fatty acids areone of two families of essential PUFAs. The term omega-3 (also ω”3 or *n*”3) indicates the first double bond exists as the third carbon-carbon bond from the terminal methyl end of the carbon chain. Eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and alpha-linolenic acid (ALA) are the major omega-3 fatty acids useful for humans.EPA (C20:5 n-3) and DHA (C22:6 n-3) are rich in marine sources *viz.* fish and shellfish while ALA (C18:3 n-3) is rich in plant sources *viz.* flaxseed (linseed), soybean, walnut, canola and rapeseed oils (Stone, 1996; Mellor, 2005).

Importance of omega-3 fatty acids in human health

Consumption of long chain omega-3 fatty acids *viz.* EPA and DHA reduces risk of cardiovascular diseases (CVD) in human by lowering the blood pressure and heart beat rate (Kromhout *et al.*, 1995; Connor, 2000; Kris-Etherton *et al.*, 2002; AHRQ, 2004; Din *et al.*, 2004; Grashorn, 2005; Mellor, 2005; Hooper *et al.*, 2006; Schacky and Harris, 2007; Betti *et al.*,2009; Mirghelenj *et al.*, 2009). Moreover, the long chain omega-3 fatty acids reduce serum triglycerides, thrombotic tendency, inflammation, and arrhythmias and improves endothelial function, insulin sensitivity, paraoxonase concentrations, and plaque stability in human (Geelen *et al.*, 2004).

Nevertheless, true essential fatty acids (EFAs) *viz.* linoleic acid (C18:2 n-6) and ALA (Mellor, 2005) should be converted into EPA and DHA to be effective in human body (Gerster, 1998; Brenna, 2002; AHRQ, 2004). However, the rate of conversion is only around 2% (Mellor, 2005) to 5% (Brenna, 2002) as humans lack the necessary enzymes to convert omega-6 fatty acids to omega-3 fatty acids (Din *et al.*, 2004). Hence, it is very important to have dietary EPA and DHA through meat based diet such as poultry meat, marine and freshwater fish, *etc.* to get advantages of omega-3 PUFAs.

Fish as a rich dietary source of EPA and DHA

Vegetable oils are rich in ALA, whereas fish and fish oils are rich in EPA and DHA (Sargent, 1997; Din *et al.*, 2004; Mirghelenj *et al.*, 2009). However, amount of EPA and DHA varies among fish species (Table 1) and environmental factors. WHO and NATO recommended 0.3 to 0.5 g/d of EPA+DHA and 0.8 to 1.1 g/d of ALA as a dietary inclusion level of omega-3 fatty acids for a healthy person (Kris-Etherton *et al.*, 2002). Furthermore, American Heart Association (AHA) recommended 1 g/d of EPA+DHA for CHD patients (Kris-Etherton *et al.*, 2002; Schacky and Harris, 2007). Although this level of EPA and DHA could be obtained through fish consumption, the required intake may be difficult to achieve and sustain in long term (Kris-Etherton *et al.*, 2002) due to seasonal availability, affordability and consumer preference of fish (Hargis and Van Elswyk 1993). Hence, supply of these PUFAs is easier if they are incorporated with widely consumed food items *viz.* meats. In this context, broiler chicken meat is ideal for the enrichment with essential fatty acids.

In poultry, lipid digestion takes place in the small intestine, where the pancreatic lipase breakdowns the triacylglycerols into 2-monoacylglycerols and free fatty acids (Nietoand Ros, 2012). These products are formed into micelles when linked to the conjugated bile salts. Monoglycerides and long-chain unsaturated fatty acids have higher ability to form the micelles with bile salts than saturated fatty acids due to their characteristic low polarity (Baião and Lara,2005). Because of pancreatic lipase, the mixed micelles are absorbed without any alteration in the composition of fatty acids. Hence, the dietary lipid sources have a direct effect on the fatty acid composition of poultry products (Baião and Lara,2005; Nietoand Ros, 2012).

As the tissues of poultry could simply be enriched with unsaturated fatty acids by increasing their proportion in the diet (Nieto and Ros, 2012), enrichment of broiler chicken meat with omega-3 fatty acids could be an alternative source for fish (Hargis and Van Elswyk 1993).

Table 1. Long chain omega-3 fatty acid contents of selected fin-fish and shellfish species

	EPA+DHA content (g/100g of edible portion of fish)	Fish required to provide 1 g of EPA+DHA(g)
Fin-fish		
Catfish	0.18	556
Cod	0.28	357
Tuna (fresh)	0.28 - 1.51	66 - 357
Tuna (canned)	0.31	323
Mackerel	0.4 - 1.85	54 - 250
Halibut	0.47 - 1.18	85 - 213
Rainbow trout	1.15	87
Sardines	1.15 - 2	50 - 87
Atlantic salmon	1.28 - 2.15	42.5 - 70.9
Atlantic herring	2.01	50
Shellfish		
Scallop	0.2	500
Shrimp	0.32	313
Oyster	0.44	227

Source: Din *et al.* (2004).

Dietary enrichment of broiler chicken meat with omega-3 fatty acids

Chickens modify their lipid profile within a week of feeding a new diet enriched with lipid sources (Lopez-Ferrer *et al*., 2001). Dietary fatty acids could be absorbed and deposited in the body tissue of broiler chickens without any modific-ations.Thus, lipid composition of broiler chicken meat could be altered according to the fatty acid profile of the dietary lipid sources (de Witt *et al.*, 2009; Hugo *et al*., 2009b). This ensures the potential to increase the consumption of omega-3 PUFAs through broiler chicken meat (Coetzee and Hoffman, 2002).

Unfortunately, high growth rate of modern broiler chicken breeds has been associated with increased fat deposition. Lipids in broiler chicken are mainly deposited as abdominal fat (20%) and subcutaneous fat (18%), and skeleton fat (15%), fats on liver and feather (2.5%), and fats on carcass (40%) as intermuscular fat, intramuscular fat and subcutaneous fat. Abdominal and subcutaneous fats are the main sources of waste in the slaughterhouse (Tůmová and Teimouri, 2010). However, a minimum quantity of intramuscular fat is necessary for an optimal sensory quality because of its positive influence on succulence, tenderness and flavour (Guo-Bin *et al.*, 2010;Tůmová and Teimouri, 2010; Pegg and Shahidi, 2012).

Dietary enrichment of broiler chicken meat with unsaturated fatty acids positively improved the intramuscular fat deposition. Baião and Lara (2005) reported that the broiler chicken fed with a diet containing sunflower oil (unsaturated fat) and bovine/swine fat (saturated fat) caused higher accumulation of intramuscular fat and abdominal fat. However, broilers fed with a diet containing 8% sunflower oil had significantly less amount of abdominal fat deposits than those fed with a diet containing 8% beef tallow (saturated fat). Thus, the location of fat deposition in broiler chicken depends on the kind of fatty acid added to the diet.

Past studies revealed that incorporation of omega-3 PUFA rich sources *viz.* fish oil (Lo´pez-Ferrer *et al.*, 2001; Basmacıoğlu *et al*., 2003; Mirghelenj *et al.*, 2009) into broiler chicken diet enriched the chicken meat with omega-3 PUFAs (Hargis and Van Elswyk, 1993; Leskanich and Noble, 1997; Moghadasian, 2008; Zuidhof *et al*., 2009; Zduńczyk and Jankowski, 2013).Table 2 shows that different sources of long-chain (LC) *n-3* PUFAs used in the broiler chicken ration have the impact on the fat deposition of the broiler chicken meat (Zduńczyk and Jankowski, 2013).

In addition to fish oil, marine algae (Basmacıoğlu *et al*., 2009) or precursors of omega-3 PUFAs *viz.* ALA through canola oil (Shahriar *et al.*, 2007; Salamatdoustnobar *et al.*, 2008), linseeds, flaxseed or similar oils (López-Ferrer *et al*., 1999), also used for dietary manipulation of broiler chicken.

Table 2. Fatty acid composition of diets with different sources of PUFAs and whole-body concentration of PUFAs in chickens

Fatty acid composition (%)	Sources of LC *n-3* PUFAs			
	Palm oil	Soybean oil	Linseed	Fish oil
In the diet				
n-6 PUFAs	14.7	24.11	14.5	12.4
n-3 PUFAs	0.9	2.4	14.1	9.8
n-6/n-3	16.7	10.0	1.0	1.3
In the body of chicken				
n-6 PUFAs	11.9	22.7	14.4	10.5
n-3 PUFAs	0.7	2.2	13.4	6.9
n-6/n-3	17.0	10.3	1.1	1.5
Accumulation (% of net intake)				
n-6 PUFAs	73.1	74.7	85.2	73.0
n-3 PUFAs	63.9	64.3	65.3	58.4

Source: Zduńczyk and Jankowski (2013).

Dietary omega-3 PUFA on bodyweight gain of broiler chickens

Dietary omega-3 PUFA alters bodyweight (BW) of broiler chickens. Studies showed that 1% dietary conjugated LA (CLA) increased bodyweight gain (BWG) of broiler chickens (Lypez-Ferrer *et al.*, 2001; Aydin, 2007). Similarly, dietary omega-3 PUFA supplemented with vitamin E and organic Se improved BW of broiler chickens (Malayoğlu *et al.*, 2009). According to Haug *et al.* (2007), a high level of dietary organics increased the concentration of EPA and DHA in the broiler chicken muscle tissues. However, enrichment of omega-3 PUFA may increase energy content of the diet, thereby excess energy could be deposited as fat. In contrast, Salamatdoustnobar *et al.* (2008) and Szymczyk *et al.* (2001) observed that the dietary omega-3 PUFA reduced the abdominal fat content of broiler chickens.

Broiler chicken gets fat deposition by means of exogenous (from the diet) or endogenous (synthesized in the liver) or from skeleton. Absorbed dietary fat is packed into portomicrons and non-esterified fatty acids which pass directly into the hepatic portal blood supply, whereas fat synthesized in the liver is transported to other tissues in the form of triglyceride-rich very low density lipoprotein(Tůmová and Teimouri, 2010).Since dietary omega-3 PUFA lowers the low-density lipoprotein (LDL) levels in blood stream of broiler chickens, fat deposition may be reduced. Because LDL transfers cholesterol from liver to tissues, thereby it increases the tissue fat deposition. Moreover, there is an effect of genotype on the dressing percentage and growth of breast muscle of broiler chickens enriched with omega-3 PUFA (de Witt *et al.* 2009).

Dietary omega-3 PUFA on lipid oxidative stability of broiler chicken meat

Lipid oxidation in muscle and fat tissues affects the shelf-life of meat and meat products thereby deteriorate quality of meat products. Membrane lipids (phospholipids) in the meat have a greater share of PUFAs, which are most prone to oxidation(Pegg and Shahidi, 2012). However, dietary enrichment of broiler chicken meat with PUFAs has become as a popular practice in the world due to human health concerns. Hence, the chance of lipid oxidation in broiler chicken meat is high. Studies revealed that the lipid oxidative stability is low in omega-3 PUFA enriched broiler chicken (Hugo *et al.*, 2009b) especially, colour, flavorand shelf life of meat are affected (Smet *et al.*, 2008; Betti *et al.*, 2009). Although, dietary fish oil in broiler chicken ration causes "fishy taint" in broiler chicken meat through the oxidation of omega-3 PUFA which in turn reduce the feed intake of birds (Chashnidel *et al.*, 2010) and consumer preference of chicken meat (Hugo *et al.*, 2009a).

More than 2% fish oil in the broiler chicken ration reduces consumer preference of chicken meat fed with that ration due to fishy smell in cooked meat (Mirghelenj *et al.*, 2009). Moreover, oxidation of highly PUFA enriched meat may harm human health (Lypez-Ferrer *et al.*, 2001).

Improving meat quality

Favourable enrichment of meats with omega-3 PUFAs depends on the dose of fish oil or other omega-3 rich PUFA sources (Leskanich and Noble, 1997; Bou *et al.*, 2004). In this context, chicken diet should be enriched with less than 15-20 g fish oil per kg feed or less than 120 g fish meal per kg feed to minimise unpleasant aromas and flavours (Hargis and Van Elswyk, 1993; Leskanich and Noble, 1997; Howe *et al*. 2002). However, combining fish oils and vegetable oils and/or seeds could favourably increase the omega-3 PUFAs in chicken meat (Bou*et al.* 2005). Moreover, usage of quality fish oil and addition of antioxidants *viz.* vitamin E in the broiler chicken diets could improve oxidative stability of such meat.

Summary

Biologically important omega-3 PUFAs are EPA, DHA and ALA. The latter is abundant in plant sources while, others are rich in fish. Enrichment of broiler chicken meat with omega-3 PUFA is possible through dietary treatment. Dietary enrichment of omega-3 PUFA improves body weight gain in broiler chickens whereas consumption of omega-3 PUFA enriched broiler chicken meat prevents risk of cardiovascular disease in human.

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