"The dairy cow is built to handle large quantities of roughage. She has a rumen or paunch that holds 2 or 3 bushels of ingested material and acts much like a fermentation vat in digesting the fibrous parts and other constituents of forage crops. She is highly efficient therefore in converting them into products that humans eat." – L.A. Moore, in Stefferud, Grass: The 1948 Yearbook of Agriculture, p. 120.

In Grass: The 1948 Yearbook of Agriculture (Steffrud, 1948), grasslands were clearly valued as a source of forage for livestock that also conserved soil. The first page of the introduction quotes Deuteronomy 11:15—"And I will send grass in thy fields for thy cattle that thou mayest eat and be full." In the chapter on dairy forage, L.A. Moore also recognized that green and leafy forages were highest in carotene, and were better sources of vitamin A and D than grain crops. He explained that "the vitamin A content of milk usually drops to 50% of the amount present in milk during the pasture season." (Moore, 1948, p. 120). He recommended that efforts be made to produce forages that preserve vitamin contents, and he explained that grass silage was usually a better source of carotene than the best-quality hay.

Grasslands are still valued for livestock production and providing ecosystem services, and today we also have an improved understanding of the influence of grasslands on livestock product quality and human health. Our understanding has been facilitated by human health research that has advanced our knowledge of the connection between human diet and disease. This chapter reviews recent agricultural and human health research indicating that animals that graze grasslands or consume primarily forages produce foods that are often better for human health than do livestock bunker fed concentrates and conserved forages (Dewhurst et al., 2006; Clancy, 2006; Scollan et al., 2006). Specifically, meat, milk, and eggs from livestock that graze pastures frequently have less fat and higher concentrations of vitamins and healthful fats.

"YOU ARE WHAT YOU EAT"

Meat from grass-fed livestock often has less fat and higher concentrations of omega-3 fatty acids (FA), conjugated linoleic acid (CLA), and vitamin E than meat from animals fed diets with grains (Turner et al., 2002; Poulson et al., 2004; Scollan et al., 2006). Similarly, in various studies, dairy cattle that grazed pastures and consumed
FATTY ACID COMPOSITION OF SOME FEEDS

From Khanal et al. (2008), Livestock Science; used by permission of Elsevier.

DAILY CHANGES IN FATTY ACID COMPOSITION OF MILK FROM COWS

In an experiment by Khanal et al. (2008), cows were fed a total mixed ration of 50% conserved forage and 50% grain for the first two days. On Day 3 (first arrow) the cows were turned out on pasture; the second arrow (Day 29) indicates when the cows were withdrawn from pasture and fed a total mixed ration diet again. C18:3 is an omega-3 fatty acid. (Y axis = % of reported fat.)

From Khanal et al. (2008), Livestock Science; used by permission of Elsevier.
diets high in forages produced milk that had 1.3 to 3.8 higher concentrations of omega-3 FA (Dewhurst et al., 2006), and 2 to 3 times higher CLA concentrations (Elgersma et al., 2006) than those fed concentrate and conserved forages. Further, chickens that foraged on pasture produced eggs with almost threefold greater omega-3 FA and significantly more fat-soluble vitamins than poultry fed typical grain-based diets (Lopez-Bote et al., 1998).

These differences appear to be due to the nutritional qualities of the livestock diets. In ruminants, grain-based diets, typically high in carbohydrates, provide a substrate for microbial populations to transform unsaturated fatty acids to saturated fatty acids. These saturated fats become incorporated into products of the host. By contrast, grazing and forage-fed animals consume a diet that is higher in the polyunsaturated, omega-3 FA, alpha linolenic acid than most grains and stored forages (Elgersma et al., 2006; Schroeder et al., 2004; Dhimani et al., 2005; Scollan et al., 2006). Grassland plant tissues are primarily photosynthetic tissues with chloroplasts that contain a high proportion of the unsaturated fatty acids linoleic and alpha linolenic acid. In addition to the high proportion of alpha linoleic acid, with high-quality forages, rumen conditions such as (i) low pH, (ii) high rate of passage and low fluid dilution, and (iii) high levels of degradable carbohydrates may promote high production or lower utilization of CLA and vaccenic acid (Schroeder et al., 2004).

Because chloroplast membranes contain a high proportion of linoleic and alpha linolenic acid, the concentrations of these unsaturated fatty acids are often highest when plants are in stages of development with a high leaf-to-stem ratio (e.g., at a vegetative or regrowth stage) as compared to plants that are elongating or have a high proportion of stem tissue (Dewhurst et al., 2006). Although some studies have found that linoleic acid and alpha linolenic acid concentrations (i) differed among harvests, (ii) were lowest in summer compared to other seasons, or (iii) increased with nitrogen fertilizer, the explanation for these differences often appears to be due to leaf-to-stem ratio differences in the plants among harvests and seasons (Dewhurst et al., 2006). Polyunsaturated fatty acids also can be oxidized when forages are harvested and wilted for silage, and especially when forages are dried for hay. When plants are grazed or harvested, plant enzymes, called lipases, release alpha linolenic acid and linoleic acid from damaged plant membranes, and the polyunsaturated fatty acids (PUFAs) can be degraded. Since leaves contain more of the unsaturated fatty acids than stems, leaf loss during haymaking further reduces the linoleic and alpha linolenic acid concentration of hay (Dewhurst et al., 2006).

In addition, plants that are grazed, rather than dried for hay or ensiled, have higher concentrations of carotenoids and vitamin E than most conserved forages and grain crops that are fed to livestock (Lopez-Bote et al., 1998; Nozière et al., 2006). For instance, Nozière et al. (2006) cited one study that showed an 83% decrease in carotenoid content when forage was harvested as hay compared to direct-cut silage. They attribute most of the carotenoid loss to ultraviolet ray exposure, but they acknowledge that oxidation also can degrade carotenoids. Lopez-Bote et al. (1998) found that the pasture consumed by foraging hens contained 13-fold more vitamin E than that present in the typical grain feed for commercial laying hens in Spain.

**ASSESSMENT OF THE PRESENT HUMAN HEALTH BENEFITS**

**EVOLUTIONARY HISTORY**

Ruminant animals evolved grazing or browsing plants, and ruminant digestive systems require some plant fiber (i.e., cellulose and hemicellulose) to maintain a high rumen pH and to improve rumen health. Similarly, some argue that humans evolved as hunter-gatherers and that therefore humans are healthier when they consume a diet similar to a “hunter-gatherer” diet. This is described as a diet high in fruit and vegetables (fiber, vitamins, and micronutrients), meat from pastured livestock, and fish (for protein, omega-3 FA, more unsaturated fat, and fat-soluble vitamins) (Cordain et al., 2005). Further, when humans adopted agriculture, most ruminant animals grazed grasslands and crop residues. It is only since the industrialization of agriculture that ruminant animal diets have been dominated by grain crops and stored forages.
Fatty acids are usually composed of 4 to 30 carbon atoms. How the carbon atoms are connected in a molecule determines how the fat is categorized and often how it functions. Fatty acids are characterized as either saturated, if the carbon atoms are saturated with hydrogen atoms (attached to hydrogen atoms), or unsaturated, if there is a double bond between two or more of the carbon atoms in the chain. Monounsaturated fatty acids have one double bond; polyunsaturated fatty acids (PUFAs) have two or more double bonds in a fatty acid chain. Saturated fatty acids are usually solid at room temperature, and livestock products such as meat, cheese, and butter commonly contain more saturated fat than unsaturated fat. Unsaturated fatty acids are typically liquid at room temperature and predominate in olive and canola oil.

One class of fatty acids that is beneficial for human health is omega-3 fatty acids (FA). Omega nomenclature describes the position of the first double bond in the carbon chain relative to the methyl group (CH₃) at one end of the chain; carbons are numbered from the opposite end as they are when labeling other fatty acids. Omega-3 FA (also described as n-3 fatty acids) have the first double bond on the third carbon from the terminal methyl group, whereas omega-6 fatty acids have first double bond on the sixth carbon from the terminal methyl group. Alpha linolenic acid (also called ALA or 18:3, n-3) and linoleic acid (also called 18:2, n-6) are omega-3 and omega-6 fatty acids, respectively, that are only produced in plants (see Fig. 11-la and b). The omega-6 FA linoleic acid is a common fatty acid in plants and animal products and accounts for the majority of American’s polyunsaturated fatty acid intake (Clancy, 2006). Because these fatty acids are desirable for human health and cannot be synthesized by humans, we describe them as essential fatty acids. These fatty acids are required for structural support of cell membranes, phospholipid synthesis, eicosinoid synthesis, and neurological development. Eicosinoids are important compounds that are involved in inflammatory and blood clotting pathways, and they are also integral to cell signaling pathways. The eicosinoids synthesized from ALA and linoleic acid have different biological effects, and the dietary ratio of ALA and linoleic acid may modulate the synthetic pathways.

It is estimated that 48 to 75% of the total fatty acids in forage plants are ALA (Dhiman et al., 2005; Scollan et al., 2006). Some grains such as flaxseed (Linum usitatissimum L.), canola (Brassica napus L.), soybeans (Glycine max L), walnuts (Juglans regia L.), and wheat (Triticum aestivum L.) germ are also good sources of ALA (Clancy, 2006). Plant ALA is the building block for the production of the longer chain omega-3 fatty acids that also are important and beneficial for human health: eicosapentaenoic acid, or EPA (20:5, n-3), and docosahexaenoic acid, or DHA (22:6, n-3). Omega-3 fatty acids are available in the highest concentrations in fish that eat algae, but EPA, DHA, and ALA also are present in lower concentrations in the meat, milk, and eggs of livestock that graze pastures.

Conjugated linoleic acid (CLA) is a form of linoleic acid that has two conjugated double bonds, meaning that the double bonds are one carbon bond apart in the fatty acid chain. Although there are a number of isomers of CLA, cis-9, trans-11 CLA (also called rumenic acid; see Fig. 11-1c) is the main isomer found in products of livestock that graze pasture, along with smaller amounts of trans-10, cis-12 CLA. The numbers indicate which carbons have double bonds, and cis, trans nomenclature denotes the position of the hydrogen atoms around the double bond. Cis indicates that the two hydrogen atoms are on the same side as the carbon atoms, and trans indicates that the two hydrogen atoms are on opposite sides of the carbon atoms. Ruminant livestock products, especially milk, are the main source of CLA in the human diet. Conjugated linoleic acid is produced by bacteria that biohydrogenate linoleic acid and alpha linolenic acid in the rumen, where it can eventually pass to the intestine, blood stream, and the mammary gland. Trans-vaccenic acid or trans-11 18:1 (TVA) is an intermediate of the rumen biohydrogenation of linoleic acid and ALA. Trans-vaccenic acid also can leave the rumen and be delivered to the mammary gland, similar to CLA. There is some evidence that humans also can convert TVA to CLA (Elgersma et al., 2006; Palmquist et al., 2005).
Fig. 11-1. (a) Linoleic acid (C18:2 n-6) is a polyunsaturated fatty acid that contains two double bonds both in the cis configuration, one at carbon 9 and the other at carbon 12. (b) Alpha linolenic acid (C18: 3 n-3) is a polyunsaturated fatty acid that contains three double bonds, all in the cis configuration, located at carbons number 9, 12 and 15. (c) Conjugated linoleic acid cis-9, trans-11, contains two double bonds; this isomer has one in the cis configuration at carbon number 9 and the other in the trans configuration at carbon number 11.

GLOSSARY

**Alpha linolenic acid** (ALA), also referred to as 18:3 n-3, is a polyunsaturated fatty acid of the omega-3 family that is only produced by plants.

cis-9, trans-11 conjugated linoleic acid (CLA), also called rumenic acid, is the main isomer of CLA found in products of livestock fed pasture. *Cis* indicates that the two hydrogen atoms are on the same side as the carbon atoms; *trans* indicates that the two hydrogen atoms are on opposite sides of the carbon atom.

**Linoleic acid**, also referred to as 18:2 n-6, is a polyunsaturated fatty acid of the omega-6 family that is only produced by plants.

**Monounsaturated fatty acids** have one double carbon bond. Unsaturated fatty acids are liquid at room temperature and predominate in olive and canola oil.

**Omega nomenclature** describes the position of the first double bond in the carbon chain relative to the methyl group (CH₃) at one end of the chain.

**Omega-3 family of fatty acids** (n-3 fatty acids) have the first double bond on the third carbon from the terminal methyl (CH₃) group at one end of the chain. In omega nomenclature, carbon atoms are numbered from the opposite end that other fatty acids are numbered. They are beneficial to human health.

**Omega-6 family of fatty acids** have first double bond on the sixth carbon from the terminal methyl group (CH₃). Some are essential for human health.

**Polyunsaturated fatty acids** (PUFAs) have two or more double carbon bonds.

**Saturated fatty acids** have carbon atoms that are attached to hydrogen atoms and are usually solid at room temperature. Livestock products and some tropical fats are high in saturated fat.

trans-10, cis-12 conjugated linoleic acid (CLA) is an isomer of CLA, found in products of livestock fed pasture, but in smaller quantities than the cis-9, trans-11 CLA isomer.

Vaccenic acid or trans-11 18:1 (TVA) is an intermediate of the rumen biohydrogenation of linoleic acid and alpha-linolenic acid. There is some evidence that humans also can convert TVA to CLA and that it has beneficial health effects.

**Unsaturated fatty acids** have one or more double bonds between two or more of the carbon atoms in the chain. Unsaturated fatty acids are typically liquid at room temperature.
HUMAN HEALTH BENEFITS OF UNSATURATED FATS, CONJUGATED LINOLEIC ACID, AND OMEGA-3 FATTY ACIDS

From epidemiologic evidence, it has long been thought that higher intakes of saturated fat are associated with an increase in coronary heart disease (a narrowing or blockage of the vessels that provide oxygen to the heart muscle). One possible mechanism by which the risk for coronary heart disease may increase with increasing saturated fatty acid intake is by an increase in delivery of cholesterol from the low-density lipoprotein (LDL cholesterol—the “lousy” cholesterol) to vessel walls, thus developing plaques. When sufficient cholesterol is deposited in vessel walls (i.e., plaques are formed), blood flow to the heart muscle is restricted, potentially damaging the muscle.

Data from clinical studies suggest that saturated fats increase the circulating concentration of LDL cholesterol despite the fact that saturated fatty acids also increase high-density lipoprotein (HDL cholesterol—the “healthy cholesterol”—associated with removal of cholesterol from vessel deposits). Meat and milk from ruminant animals contain a relatively high proportion of saturated fats; however, in grassland-raised livestock, the proportion of saturated fats is lower than in livestock raised on grain-based diets. Moreover, the changes in specific saturated fatty acids also suggest that the fatty acid profile of the milk fat from grazing ruminants will raise blood LDL less than that from cattle fed corn (Zea mays L.) silage total mixed rations. For example, Dewhurst and colleagues (2006) reported that animals consuming corn silage total mixed rations had a higher concentration of lauric (12:0), myristic (14:0), and palmitic (16:0) acid and a lower concentration of stearic acid (18:0) than cattle consuming pasture. These differences are significant since lauric, myristic, and palmitic acids raise circulating LDL cholesterol concentration, whereas stearic acid, even though it is a saturated fatty acid, does not raise plasma LDL-cholesterol concentration (Judd et al., 2002). Thus, not only does grazing reduce the total amount of saturated fatty acids in the milk fat, but the profile of the saturated fatty acid does not raise blood LDL cholesterol as much.

Several studies have been conducted in humans using natural sources of CLAs from CLA-enriched ruminant products. In these studies, there is generally a mixture of naturally occurring isomers, the predominate form being the cis-9, trans-11 CLA isomer. However, during the process of naturally enriching these food products, additional changes to the overall fatty acid composition of the products occur. These changes make it difficult to attribute health benefits specifically to the CLA isomer. Nevertheless, one study showed that after consumption of dairy products enriched with naturally occurring isomers of CLA and trans fatty acids, no significant change in body weight, inflammatory markers, insulin, glucose, triacylglycerols, or total, LDL, and HDL cholesterol occurred (Tricon et al., 2006). However, there was a small increase in the ratio of LDL to HDL cholesterol. Overall, increased consumption of full-fat dairy products and naturally derived trans fatty acids did not cause significant changes in cardiovascular disease risk variables. In this study, the higher CLA dairy products did not appear to have a significant effect on the blood lipid profile.

Another study, designed to investigate the differential effects of the 9,11 CLA and the 10,12 CLA isomers, showed that the plasma triglyceride concentration and the LDL-to-HDL cholesterol concentration was higher after supplementing with the 10, 12 isomer compared with the 9,11 isomer (Tricon et al., 2004). Neither isomer had an effect on body weight, insulin concentration, or insulin sensitivity. These results suggest that there are opposing effects of the different isomers for some biomarkers.

In a third study, individuals who consumed CLA-enriched butter, high in ruminant trans (monomers and CLA) and monounsaturated fatty acids, had significantly lower total and HDL cholesterol compared with individuals who consumed a control butter with higher amounts of saturated fatty acids (Tholstrup et al., 2006).

Overall, in studies of humans, there do not appear to be significant benefits associated with consuming products containing higher concentrations of naturally occurring isomers of CLA. It is difficult to conclude that any observed effect is associated with only CLA since many fatty acids change in these products. These data are in contrast to data derived from experiments using animal models. In animal studies, CLA isomers have been shown to be antiadipogenic (i.e., prevents development of adipocytes, a primary fat storage cell), anticarcinogenic, antiatherogenic, antidiabetogenic, and possess antiinflammatory properties. The reasons for the dichotomy of
EFFECT OF VARIOUS FATTY ACIDS ON LDL, HDL, TRIGLYCERIDES, AND THE RISK FOR HEART DISEASE

The following table summarizes the effect of different classes of fatty acids on the change in circulating blood concentration of LDL cholesterol, HDL cholesterol, triglycerides, and risk for coronary heart disease. The changes in LDL and HDL cholesterol assume that there is 1% of energy replacement of the listed fatty acid for dietary carbohydrate, and risk for coronary heart disease depends on other changes in the diet.

<table>
<thead>
<tr>
<th>Fatty Acid Type</th>
<th>LDL cholest.</th>
<th>HDL cholest.</th>
<th>Triglycerides</th>
<th>Relative risk for coronary heart disease</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated fatty acids</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lauric, Myristic, Palmitic</td>
<td>0.039-0.052</td>
<td>0.010-0.027</td>
<td>-0.019 to -0.017</td>
<td>1.03-1.06</td>
</tr>
<tr>
<td>Stearic</td>
<td>-0.004</td>
<td>0.002</td>
<td>-0.017</td>
<td>1.10</td>
</tr>
<tr>
<td>Monounsaturated fatty acids</td>
<td>-0.009</td>
<td>0.008</td>
<td>-0.019</td>
<td>0.95</td>
</tr>
<tr>
<td>Polyunsaturated fatty acids</td>
<td>-0.019</td>
<td>0.006</td>
<td>-0.026</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Adapted from Mensink et al. (2003) and Hu et al. (1997, 1999).

response and effect seen between human studies and animal studies are unclear but may be related to metabolic differences among various mammalian species or study design (e.g. dose used, length of the intervention, stage of physiologic development).

The predominate omega-3 fatty acids in the human food supply are alpha linolenic acid, eicosapentaenoic acid, and docosahexaenoic acid. Alpha linolenic acid (ALA) is the omega-3 fatty acid (18 carbons) acid found in many forage plants and grains and is the predominate omega-3 fatty acid in animals that consume these feeds. Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are longer chain omega-3 fatty acids (20 and 22 carbons, respectively) typically found in algae and in fish. The health benefits associated with omega-3 fatty acid consumption have been more thoroughly studied for the longer chain omega-3 fatty acids from fish and fish oil.

Epidemiologic evidence suggests that increased consumption of ALA is associated with a decreased risk for fatal coronary heart disease (albeit in men, there may be an increased risk for prostate cancer) (Brouwer et al., 2004) and sudden cardiac death (Albert et al., 2005). These positive findings of heart disease protection are consistent with the results of a secondary prevention trial, the Lyon Diet Heart Study, that was designed to compare the Mediterranean-type diet to a “prudent” diet. In this study, not only was intake of ALA different between the two diets (1.9 g per day for the Mediterranean-type diet versus 0.67 g per day for the prudent diet), but the overall dietary pattern was different. Those consuming the higher ALA, Mediterranean-type diet had a lower risk for all-cause mortality, cardiac death, and nonfatal heart attacks (de Lorgeril et al., 1999). In this particular study, the specific role that ALA may have in reducing risk for these diseases remains unclear.

Researchers have conducted several trials to understand the specific health benefits of ALA. In a two-year study of people with multiple cardiovascular risk factors, the ALA-supplemented group had a lower concentration of blood-clotting protein (fibrinogen) but a higher concentration of triglycerides, a lower concentration of HDL cholesterol, and a higher ratio of total-to-HDL cholesterol (Bemelmans et al., 2002). Except for the decreased fibrinogen concentration, the changes in the lipid biomarkers associated with the higher ALA intake suggest that there may be an increased risk for coronary heart disease. However, the estimated 10-year risk for heart disease was not different for the two groups (Bemelmans et al., 2002). In another intervention study
of subjects with mildly high levels of cholesterol, ALA lowered triglycerides, HDL cholesterol, LDL cholesterol, and the ratio of total cholesterol to HDL cholesterol compared to an average American diet. In this study, ALA consumption also significantly reduced markers of inflammation. These results suggest that ALA may inhibit vascular inflammation and "activation" of cells lining the blood vessels compared to the average American diet and a diet enriched with linoleic acid (Zhao et al., 2004).

Studies of animal models and cellular systems suggest that ALA may help stabilize heart rhythm. These effects may be the mechanism by which ALA reduces sudden cardiac death (Albert et al., 2005). Moreover, the effects of ALA on markers of inflammation suggest that ALA may reduce these risk factors for coronary heart disease. Additional studies in humans are needed to increase our understanding of the effects of ALA on lipid and lipoprotein biomarkers for coronary heart disease.

Conversion of ALA to the longer chain, and perhaps more biologically active omega-3 fatty acids (EPA and DHA) may also provide some health benefits. However, the rate of conversion appears to be low and has been reported to range from essentially 0 to about 20%. The range may be associated with the intake of other fatty acids or dietary components as well as genetic make-up (Goyens et al., 2006).

FACTORS INFLUENCING CONCENTRATION OF POLYUNSATURATED FATTY ACIDS, CONJUGATED LINOLEIC ACID, AND OMEGA-3 FATTY ACIDS

MILK FAT IN DAIRY COWS

In an extensive review, Dewhurst et al. (2006) summarized the research on factors that enhance PUFAs in the milk of dairy cows on high forage-based diets. They described research on forage species, conservation methods, and management conditions that inhibit degradation of PUFA in the plant tissues or rumen, resulting in high recovery of forage PUFA in dairy milk. Plant and microorganism enzymes break down lipids into free fatty acids in a process called lipolysis. Rumen microorganisms can then hydrogenate the unsaturated fatty acids and make them more saturated in a process called biohydrogenation. Factors that reduce PUFA lypolysis and biohydrogenation can result in more PUFA in milk and meat. For instance, cows fed red clover (Trifolium pratense L.) and white clover (Trifolium repens L.) silage as compared to grass silage produced milk with higher concentrations of ALA and linoleic acid. Recovery of ALA from red clover silage was higher than from grass because, compared to grass, red clover has less lipolytic enzyme activity that degrades PUFA. Decreased lipolysis has also been associated with (i) plant maturity, (ii) substituting dietary fiber with starch, and (iii) decreased nitrogen content in high starch diets. In addition, when cows or sheep grazed pasture species that are high in tannins, such as birdsfoot trefoil (Lotus corniculatus L.) or sulla (Hedysarum coronarium L.), they produced milk that was higher in ALA than when they grazed perennial ryegrass (Lolium perenne L.). High recovery of ALA was attributed to tannin inhibition of strains of biohydrogenating ruminal bacteria species: Butyribrio fibrisolvens (Dewhurst et al., 2006).

HAY VERSUS SILAGE

Oxidation and loss of PUFA is usually higher when forage is dried to make hay, compared with wilting it for silage. However, although silage preserves more plant PUFA than hay, research has shown that cows fed hay produced milk with more ALA than cows fed silage. The authors credit the higher recovery of ALA from the hay to reduced biohydrogenation of ALA in the rumen. Milk CLA and vaccenic acid levels, however, did not differ in the cows fed silage or hay (Dewhurst et al., 2006).

ALPINE EFFECT

Cows that grazed pastures at high altitudes (4180–6960 ft [1275–2120 m]) in Alpine dairy studies in Switzerland produced milk with higher levels of PUFA—and often CLA and ALA—than cows that grazed lowland pastures (1970–2130 ft [600–650 m]) dominated by perennial ryegrass and white clover, and supplemented with corn and grass hay (Collomb et al., 2002a, 2002b; Leiber et
Lambs that grazed mountain pastures in Norway also had more PUFA than did lambs raised on improved lowland pastures (Adnoy et al., 2005). Explanations for the elevated PUFA with altitude differ among studies. Some have hypothesized that the milk ALA levels were elevated because the cows experienced an energy shortage at high altitudes and compensated by drawing on body reserves of ALA (Leiber et al., 2005). Others have suggested that diverse pasture species at high altitudes contained compounds that inhibited plant lipolysis or rumen biohydrogenation (Collomb et al., 2002a; Leiber et al., 2005). Dewhurst et al. (2006) noted that red clover and legumes with tannins were present at high altitudes in the Swiss studies and that other pasture species may also have contained enzymes and compounds, such as saponins, proanthocyanidins, and catecholamines, that could have reduced lipolysis.

**FAT QUALITY OF PASTURED BEEF AND POULTRY PRODUCTS**

Similar to dairy cattle, diets high in PUFA and factors that reduced biohydrogenation of PUFA in the rumen of beef cattle led to high concentrations of PUFAs in beef (Scollan et al., 2006). Beef from cattle that grazed pasture or stored forages have been reported to have more conjugated linoleic acid (ranging from 1.6 to 4.6-fold more), more omega-3 fats ALA, EPA, DPA, and DHA (ranging from 2.5 to 4.4-fold more), and a higher ratio of polyunsaturated to unsaturated fats than cattle fed rations high in grain and corn silage (Poulson et al., 2004; Scollan et al., 2006). In addition, the ratio of polyunsaturated to unsaturated fats, and total omega-3 FA in beef increased with the proportion of pasture in the diet and the amount of time that the cattle were on pasture (Scollan et al., 2006). In addition to fat quality differences, pastured beef and poultry have been found to be leaner than cattle and poultry fed grain-based diets in confinement (Rule et al., 2002; Castellini et al., 2002). In beef, the longissimus muscle, also known as the ribeye area, is the surface area of the muscle at the 12th rib and is used as an indicator muscle in carcass grading. Researchers found that the ratio of PUFA to saturated fats decreased as the intramuscular fat in the longissimus muscle increased (Scollan et al., 2006). If livestock are fed oil crops or supplements that are high in unsaturated fat, such as canola and flaxseed oil, the supplemented livestock often have higher PUFA concentrations.

Although research on pastured poultry is limited, in one study, the egg yolks of free-range hens had almost threefold more total omega-3 FA (ALA, EPA, DPA, and DHA) than the eggs of the commercially fed hens. In addition, the ratio of omega-6 to omega-3 in the yolks of the pastured hens was significantly lower than in the commercially fed hens (Lopez-Bote et al., 1998).
VITAMIN A CONCENTRATION IN EGG YOLKS
This photograph of egg yolks from pastured and confined hens illustrates differences in vitamin A concentration. The two egg yolks on the left are from laying hens raised in confinement on commercial hen mash diet; the six on the right are from sister laying hens raised on mixed grass and legume pastures supplemented with commercial hen mash. Egg yolks of hens raised on pasture had 62% more vitamin A.

Further, Castellini et al. (2002) found that broiler chickens fed an organic concentrate diet and given access to a grass paddock produced more omega-3 FA and polyunsaturated fat than did chickens raised in confinement on the same organic concentrate diet.

VITAMIN CONTENT OF PASTURED LIVESTOCK PRODUCTS
In addition to fatty acid differences, researchers have found that grass and pastures have concentrations of vitamin E that were in the order of 5- to 13-fold higher than the common concentrate livestock feeds (Lopez-Bote et al., 1998; Rey and Lopez-Bote, 2001). Grassland plants also range from 5- to 1400-fold higher in carotenoids than hay and the common concentrate livestock feed, respectively. Furthermore, the meat, milk, and eggs of livestock that grazed pasture had higher concentrations of vitamins A, E, and beta carotene (Prache et al., 2003; Nozière et al., 2006). Beef cattle and sheep fed on pasture and silage, for example, had higher concentrations of the antioxidants vitamin E and beta-carotene in their meat than did beef cattle and sheep fed or finished on concentrate or grain and silage diets (Daly et al., 1999; Descalzo et al., 2004; Poulson et al., 2004; Scollan et al., 2006). Similarly, in Spain, Rey and Lopez-Bote (2001) found that the meat of pigs raised on pasture and acorns had more vitamin E than did pigs fed a mixed grain diet in confinement, and, although the pastured poultry were supplemented with grain and calcium, poultry that foraged pasture plants produced eggs that contained significantly higher concentrations of vitamin A, vitamin E, folic acid, and B12 than did hens fed commercial grain and mineral mixes in confinement (Tolan et al., 1974; Lopez-Bote et al., 1998).

Searles and Armstrong (1969), monitoring the vitamin E, vitamin A, and carotene content of dairy cattle butter over 15 months, attributed changes in butter vitamin A and carotene concentrations to the availability of fresh pasture. Vitamin A and carotene concentrations in butter were highest in late spring and lowest in late winter and early spring. Vitamin E values were lowest in early spring, increasing as the grazing season progressed and peaking in early autumn (see Fig. 11-2). The researchers attributed the peak in early autumn vitamin E to increased plant vitamin
Fig. 11–2. Mean monthly vitamin A, carotene, and vitamin E content of Alberta butter from 18 processing facilities (July 1966 to July 1967). Vertical bars present the range of values each month. From Searles and Armstrong (1969). Used by permission of the Journal of Dairy Science.
E concentrations with advanced plant maturity. As Moore (1948) noted, previous studies showed that silage preserves vitamins better than hay. Pastured dairy cattle that consumed silage as compared to hay and concentrate diets produced milk with higher concentrations of carotenoids and retinol (Nozière et al., 2006). And Hidiroglou et al. (1994) documented that pasture and silage provide higher concentrations of vitamin E than does stored feeds.

**IMPACTS AND TARGETS**

**GRASSLAND AGRICULTURE OPPORTUNITIES FOR HUMAN NUTRITION**

Grassland livestock systems that are managed to optimize animal intake and recovery of forage PUFA have the potential to produce milk, meat, and eggs with more omega-3 and CLA and fat-soluble vitamins at a lower environmental and economic cost than most confinement livestock production systems today (see Chapters 7 [Singer et al., 2009] and 10 [Lasley et al., 2009], this volume). Grassland livestock producers, for instance, can combine or stack enterprises to optimize grassland productivity, for example, by grazing heifers and dry cows after milk cows, or cograzing sheep with beef cattle. Pastured poultry such as laying hens, meat birds, and turkeys also can forage pasture regrowth after ruminant grazers, and they scavenge for invertebrates in manure deposits, possibly distributing manure and reducing fly populations.

**ADDED-VALUE OPPORTUNITIES FOR PRODUCERS AND CONSUMER EDUCATION**

In many cases, pasture-based livestock producers direct market their grass-fed livestock products for higher prices than confinement-fed products. In 2007, the USDA defined a grass-fed standard required for livestock products that are marketed as grass fed.

In addition to the elevated healthful fat and vitamin concentrations, some producers market their 100% “grass-fed” beef as having no risk of contracting bovine spongiform encephalopathy, also known as mad cow disease. The majority of consumers, however, are unaware of the possible human health benefits of grassland livestock products. Therefore, consumer demand is limited and few processors and national supermarket companies differentiate grassland livestock products, resulting in a lack of economic incentives for expanding grassland livestock production. In the United States, policymakers and funding agencies have provided few resources to research the impacts of grassland agricultural products on human health, to provide programs to educate consumers about the potential benefits of pastured-livestock products, or to promote market development. These factors limit the opportunities for growth of grassland livestock markets and production.

Organic markets are the exception because producers who raise livestock on grassland according to USDA national organic agriculture certification requirements can take advantage of national market price premiums. Although the amount of pasture required may differ among regions and certifiers, the national certified organic standards require livestock ruminants to obtain some feed from pasture. Consequently, many grassland-livestock producers report that it was not difficult to transition to organic management and receive price premiums for their products.

**NEEDS AND CHALLENGES FOR ACHIEVING GRASSLAND AGRICULTURE HUMAN HEALTH BENEFITS**

As discussed, a number of opportunities exist to further forage-based strategies that may enhance the nutritional value of livestock products for humans. These include (i) screening and selecting for forage species and genotypes that are high in PUFA and that have enzymes and/or compounds that reduce lipolysis and biohydrogenation of healthful PUFAs, including identifying genes for these traits; (ii) identifying strategies to modify the rumen ecosystem to reduce biohydrogenation; and (iii) identifying stored forage rations that optimize healthful fat and vitamin recovery from conserved feeds. Animal management studies that identify strategies to produce grass-fed
"Grass and forage shall be the feed source consumed for the lifetime of the ruminant animal, with the exception of milk consumed before weaning. The diet shall be derived solely from forage consisting of grass (annual and perennial), forbs (e.g., legumes, Brassica), browse, or cereal grain crops in the vegetative (pre-grain) state. Animals cannot be fed grain or grain byproducts and must have continuous access to pasture during the growing season. Hay, haylage, baleage, silage, crop residue without grain, and other roughage sources may also be included as acceptable feed sources. Routine mineral and vitamin supplementation may also be included in the feeding regimen. If incidental supplementation occurs due to inadvertent exposure to non-forage feedstuffs or to ensure the animal's well being at all times during adverse environmental or physical conditions, the producer must fully document (e.g., receipts, ingredients, and tear tags) the supplementation that occurs including the amount, the frequency, and the supplements provided." (USDA-ARS, 2008)

beef that is tender and acceptable to consumers should continue to be supported. Research being conducted to supplement livestock raised in confinement with feeds high in PUFA such as canola, soybean, flaxseed, and fish oil also could be integrated into grassland systems to produce livestock products with health benefits at a lower cost to the producer and to the environment.

One of the major obstacles for this research is that methods for fatty acid and vitamin analyses are labor intensive and expensive, requiring expertise and costly equipment, such as a gas chromatography (fatty acid analyses) and high pressure liquid chromatography (vitamins). We need research to develop more efficient, inexpensive methods to measure fatty acids and vitamin content, to better understand the connection between grassland livestock products and human health.
For market development, methods to prevent oxidation of unsaturated fatty acids that can result in off flavors and shorter shelf life also would be helpful. Since many grassland products also are elevated in vitamin E, which prevents oxidation, this may not pose a serious problem; however, consumer perception of desirable livestock product flavor and meat fat marbling is usually based on livestock products that were finished on grain. Educating consumers that pasture-based livestock products may taste different, and that lean meat may receive a lower USDA grade but have higher levels of omega-3 fat, CLA, and vitamins, would benefit grassland livestock production. Consumer education programs also should include informing consumers that meat with less marbling should be prepared differently than high-fat meat.

Finally, our understanding of the human health impacts of grassland-based livestock products is limited. To date, most human health research has focused on single component comparisons of some of the nutritional differences of grassland-based livestock products, such as studies on the effects of only omega-3 FA or CLA. As discussed in this chapter, many grassland-based livestock products have higher concentrations of a number of PUFA's and vitamins compared with confinement-based livestock products. To fully understand the impact of forage-based livestock products on human health, we need human nutrition studies that compare grassland- versus confinement-raised livestock products rather than just one nutritional component, and that examine entire human diets of grassland-based dairy, meat, and eggs.

REFERENCES


ADDITIONAL READING

