Tasco: Influence of a brown seaweed on antioxidants in forages and livestock—A review[1]

V. G. Allen*†[2], K. R. Pond†, K. E. Saker§, J. P. Fontenot¶, C. P. Bagley, R. L. Ivy††, R. R. Evans††, R. E. Schmidt#, J. H. Fike#, X. Zhang#, J. Y. Ayad*, C. P. Brown*, M. F. Miller†, J. L. Montgomery†, J. Mahan‡‡, D. B. Wester‡, and C. Melton***

Departments of *Plant and Soil Science, †Animal Science and Food Technology, and ‡Range, Wildlife, and Fisheries Management, Texas Tech University, Lubbock, 79409; §Department of Large Animal Clinical Sciences, Virginia-Maryland Regional College of Veterinary Medicine, Virginia Polytechnic Institute and State University, Blacksburg 24061-0442; Departments of ¶Animal and Poultry Sciences and #Crop and Soil Environmental Sciences, Virginia Polytechnic Institute and State University, Blacksburg 24061; Mississippi State University, **Starkville 39762 and ††Prairie 39761; and ‡‡USDA-ARS, Lubbock, TX 79415

ABSTRACT: Tasco-Forage, an extract from the brown seaweed *Ascophyllum nodosum*, has increased antioxidant activity in both plants and animals. Turf and forage grasses exhibited increased amounts of α-tocopherol, ascorbic acid, β-carotene, and increased activities of superoxide dismutase, glutathione reductase, and ascorbate peroxidase in response to exogenous application of Tasco. Endophyte (*Neotyphodium coenophialum* [(Morgan-Jones and Gams) Glenn, Bacon, and Hanlin]-infected tall fescue (*Festuca arundinacea* Schreb.) can increase oxidative stress. Both high environmental temperatures and increased body temperatures increase respiratory rates, which increase free radical production. Steers that grazed infected fescue had diminished immune function and vitamin E, Cu, and Se status, indicating less ability to deal with oxidative stress. Two applications of Tasco-Forage (3.4 kg/ha in water solution) to infected fescue during the growing season improved steers' immune function, and the effect lasted through cross-country transportation and a 160-d feedlot finishing period. Grazing infected fescue reduced serum cholesterol, but the effect was reversed by Tasco, indicating effects on lipid metabolism. Applying Tasco to low-endophyte fescue seemed to have an immune-dampening effect on steers, at least during the grazing season. At slaughter, marbling was greater in retail cuts of meat and meat had a longer shelf-life if steers had grazed the Tasco-treated fescue, regardless of the endophyte. Direct supplementation to steers with Tasco-EX (extract) during the final 14 d in the feedyard also extended shelf-life of strip loins. Supplementation of Tasco-EX or Tasco-14 (meal) to porcine reproductive and respiratory syndrome-stressed pigs during the nursery phase improved weight gain and feed intake within 35 d. Supplementing Tasco-EX in drinking water failed to reduce morbidity and mortality in transported heifers stressed by *Pasturella haemolytica*. The mode of action of Tasco is not clear, but antioxidants and specific vitamins may be involved. Supplementation with certain antioxidants can have beneficial effects, but inappropriate use can have detrimental effects. Although positive effects on stress tolerance and carcass composition are apparent, further research is needed to elucidate these relationships and to provide predictable responses.

Key Words: Health, Immunology, Seaweeds, Stress

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Introduction

Seaweeds are predictable sources of plant growth regulators, especially cytokinin (Senn, 1987; Crouch and Van Staden, 1993; Jameson, 1993). R. E. Schmidt and co-workers (Nabati, 1991; Yan, 1993; Sun, 1994) demonstrated improved stress tolerance of several turfgrasses in response to an extract from *Ascophyllum nodosum*. They observed increased concentrations of nutrient antioxidants including α-tocopherol and ascorbic acid as well as the antioxidant enzyme superoxide dismutase (**SOD**; Zhang and Schmidt, 1999). These observations led to experiments with livestock grazing tall fescue infected or not with the endophyte fungus *Neotyphodium coenophialum* ([Morgan-Jones

[1]Approved by the Dean of the College of Agriculture and Natural Resources, Texas Tech Univ. Publ. No. T-4-491.

[2]Correspondence: E-mail: felician@ttacs.ttu.edu.

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and Gams] Glenn, Bacon, and Hanlin; Glenn et al., 1996). Although presence of the endophyte imparts stress tolerance to the plant (Hoveland, 1993), it results in several disorders in livestock commonly referred to as fescue toxicity (Stuedemann and Hoveland, 1988). Immune function was impaired (Dawe et al., 1997; Saker et al., 1998) but this was reversed by pasture applications of Tasco-Forage, a proprietary product based on *A. nodosum* (Allen et al., 2001; Saker et al., 2001). Antioxidants are essential in mediating and protecting the immune system (Dubeski, 1999) and to offset oxygen free radicals produced during stress and disease (Halliwell, 1996). Supplemental vitamin E is used to extend shelf-life of meat during retail display by improving color stability, reducing lipid oxidation, and delaying metmyoglobin formation (Faustman et el., 1989; Arnold et al., 1993; Smith et al., 1996). Treating pastures with Tasco or directly supplementing steers during the final 14 d on the feedlot also extended beef color stability (Montgomery et al., 2001).

Tasco may have value in up-regulating antioxidant responses in both plants and animals. Effects on immune function and shelf-life of meat during retail display suggest a relationship with antioxidants as a mode of action.

Oxidative Stress and Antioxidants

Oxygen, although essential to life, is a toxic substance. As atmospheric oxygen levels rose over geologic time to present-day levels, respiring organisms evolved elaborate defense mechanisms against oxygen toxicity (Halliwell, 1996). Gerschman et al. (1954) proposed that formation of oxygen radicals was responsible for the damaging effects of oxygen. Halliwell (1996) in his review of Gerschman et al. (1954) suggests that "in its simplest form, this theory states that oxygen toxicity is due to excess formation of superoxide radical ($O_2^{\cdot -}$) and that the superoxide dismutase enzymes are important antioxidant defenses." Antioxidants scavenge or prevent formation of free radicals. Free radicals are species capable of independent existence that contain one or more unpaired electrons (Halliwell, 1996). Free radicals result from several sources, including electromagnetic radiation from the environment, accidents of chemistry, as deliberate defense mechanisms against infection, or for use in physiological functions such as regulation of blood pressure and intercellular signaling (Fridovich, 1986; Babior and Woodman, 1990; Moncada and Higgs, 1993). Even though the general perception of antioxidants has been that they are essential to prevent formation of free radicals or to interrupt chain reactions that free radicals precipitate, indiscriminate use of antioxidants raises concerns. For instance, supplementing β-carotene to smokers apparently accelerated the development of lung cancer (a-Tocopherol, β-Carotene Prevention Study Group, 1994). Conversely, oxygen metabolites are generated during normal immune cell response (Dubeski, 1999). Phagocytic cells generate large amounts of $O_2^{\cdot -}$ as part of the mechanism that kills foreign organisms (Babior and Woodman, 1990).

An approximate balance is maintained between production of oxygen species and antioxidant defenses, but if the balance is shifted in favor of reactive oxygen species, oxidative stress results (Halliwell, 1996; Sies, 1991). Mild oxidative stress often results in up-regulation of the synthesis of antioxidant defense systems to restore the balance (Iqbal et al., 1989); however, major derangements of cell metabolism resulting in cell injury and death can occur with severe oxidative stress (Sies, 1991). Enzymes involved in antioxidant defenses include SOD, which acts by catalyzing the conversion of $O_2^{\cdot -}$ to hydrogen peroxide (H_2O_2; McCord and Fridovich, 1969; Halliwell, 1996). Selenium-containing glutathione peroxidase is likely the most important H_2O_2-removing enzyme in animals (Chance et al., 1979).

Diet may prevent or diminish oxidative stress to some extent. α-Tocopherol, the major component in vitamin E, and ascorbic acid are important antioxidants. α-Tocopherol inhibits lipid peroxidation, and ascorbic acid may have multiple antioxidant properties. Current information suggests that an optimal dietary intake of specific antioxidants may aid in protection against cardiovascular disease, some forms of cancer, intracranial hemorrhage, and other disorders in humans, but more information is needed to define optimal levels and conditions. Supplementation of livestock diets with vitamin E subsequently has extended meat shelf-life during retail display and reduced drip loss (Mitsumoto et al., 1998), and it may reduce morbidity and mortality following stress (McDowell et al., 1996). Effects of dietary deficiencies of Se, Cu, Fe, Zn, and other nutrients involved in antioxidant function have long been recognized in human and livestock nutrition and health. The beneficial effect of a diet high in fruits, vegetables, grains, and nuts is perhaps due to the antioxidants they contain (Larson, 1988; Halliwell, 1996). Larson (1988) suggested that the evidence supports at least a partial antioxidant role in vivo for many classes of plant metabolites. Recent research with the brown seaweed *Ascophyllum nodosum* has demonstrated antioxidant-altering properties in plants treated with an extract from the seaweed and in animals fed the seaweed-treated plants or fed seaweed in the diet.

*Seaweeds and Tasco (*Ascophyllum nodosum*)*

Seaweeds have been used in animal feeds, as soil conditioners, and as a source of minerals for plants and animals since antiquity, but reported benefits have largely been based on producers' experience and unreplicated studies. Some claims seem unfounded and have frequently been discounted. *Ascophyllum nodosum* is the most widely researched seaweed species for agricultural purposes. Evidence of plant growth hormones in seaweed was reported as early as the 1950s (Senn, 1987). Seaweed now is recognized as an excellent source of natural plant growth regulators with demonstrated

activity (Crouch, 1990; Crouch and Van Staden, 1993; Jameson, 1993), which include cytokinins (Blunden, 1977), auxins (Sanderson et al., 1987), and gibberellins (Wildgoose et al., 1978). Seaweeds contain substituted phenols and polyphenols, a class of compounds that have antioxidant activity (Le Tutour, 1990). Vitamins and vitamin precursors contained in seaweeds include a-tocopherol (Jensen, 1969), β-carotene, niacin, thiamin, and ascorbic acid (Jensen, 1972).

Ascophyllum nodosum is found growing in the littoral zone (coastline between high and low tides) of the North Atlantic Ocean extending from Nova Scotia to Norway. Tasco is a proprietary product from *A. nodosum* harvested off the coast of Nova Scotia (Acadian Seaplants Ltd., Dartmouth, Nova Scotia, Canada). Tasco-EX and Tasco-Forage are water-soluble extracts from *A. nodosum* derived with an alkaline hydrolysis procedure. Tasco-EX is used for livestock feeding, and Tasco-Forage is applied in water solution to plants (see Fike et al., 2001 for approximate chemical composition). Tasco-14 is a meal derived from solar-dried, intact *A. nodosum* (Table 1). Research with both plants and livestock during the past 10 yr has suggested that application of Tasco to plants or direct ingestion by livestock upregulates antioxidant function in both the plant and the animal (Ayad, 1998; Fike et al., 2001; Montgomery et al., 2001).

Table 1. Approximate composition[a] of Tasco-14, an *Ascophyllum nodosum* seaweed meal used in livestock feeds

Item	Value
Crude fiber, %	6.0
Carbohydrates,%	52.0
Ash, %	22.0
Moisture, %	12.0
Crude protein, %	6.0
Minerals	
Aluminum, ppm	20–100
Arsenic, ppm	< 3
Calcium, %	1.0–3.0
Copper, ppm	4–15
Iodine, ppm	< 1,000
Magnesium, %	0.5–1.0
Manganese, ppm	10–50
Phosphorus, %	0.1–0.2
Potassium, %	2–3
Selenium, ppm	< 1
Sodium, %	2.4–4.0
Sulphur, %	2.0–2.3
Zinc, ppm	35–100
Amino acids, g of amino acid/100 g of protein	
Alanine	5.3
Arginine	8.0
Aspartic acid	6.9
Cystine	trace
Glutamic acid	10.0
Glycine	5.0
Histidine	1.3
Isoleucine	2.8
Leucine	4.6
Lysine	4.9
Methionine	0.7
Phenylalanine	2.3
Proline	2.6
Serine	3.0
Threonine	2.8
Tyrosine	0.9
Valine	3.7

[a]Acadian Seaplants Limited, Dartmouth, Nova Scotia.

Plant Effects

Plant growth regulators differ from fertilizers. Plant growth regulators alter cell division, root and shoot elongation, initiation of flowering, and other metabolic functions, whereas fertilizers simply supply minerals needed for the nutrition and normal growth of the plant. Cytokinin is regarded as the most important plant growth regulator in seaweed (Senn, 1987). However, trace minerals present in seaweed extract may play a role in plant nutrition and physiology, probably as enzyme activators. This is the case for Mo, a metal ion essential for the activity of xanthin dehydrogenase, an enzyme tightly related to antioxidant activity in stressed plants (Sagi et al., 1998).

In general, plants under stress have shown a reduction in cytokinin levels (Hare and Van Staden, 1997), apparently in response to increased internal ethylene production, among other possible compounds. Ethylene reduces cytokinins and auxins, leading to alterations in tissue differentiation (Sanyal and Bangerth, 1998). Research with plants treated with exogenous cytokinin has demonstrated improved drought tolerance (Yan, 1993), greater salt tolerance (Nabati et al., 1994), increased root and shoot growth (Goatley and Schmidt, 1990), and increased total nonstructural carbohydrates (Kane and Smiley, 1983). Seaweed extract from *Ascophyllum nodosum* has also been shown to elicit these responses in grasses (Schmidt and Zhang, 1997; Yan, 1993; Nabati et al., 1994). Plant responses to seaweed extract generally have been greater than when purified cytokinin was applied alone (Goatley and Schmidt, 1991), and the magnitude of response may relate to the balance of plant growth-regulating substances in seaweed.

Plant growth and stress tolerance are regulated largely by hormonal balance that determines acceleration or restraint of growth. Rapid growth is usually coupled to transport of cytokinins from roots to shoots, and slow growth results from a drop in cytokinin transport and an enhanced mobilization of abscisic acid through xylem sap (Peuke et al., 1994). Cytokinin has a dual effect regarding the production of oxygen free radicals under stress conditions (McKersie and Leshem, 1994). The first is prevention of free radical formation through inhibition of xanthine oxidation by the enzyme xanthine oxidase. Cytokinin has a structural resemblance to xanthine and acts as a competitive inhibitor of xanthine oxidase and xanthine dehydrogenase, thus reducing the amount of free radicals formed

in the cells. The second mechanism is by direct scavenging of free radicals. Salinity, drought, and other stresses induce the generation of these activated oxygen species (Kayupova and Klyshev, 1987; Elstner et al., 1988).

The mechanism of increased stress tolerance in plants due to seaweed extract may be through an effect of cytokinin on oxygen free radicals, but increased activity of several other antioxidants in seaweed-treated grasses also has been documented. Superoxide dismutase, glutathione reductase, and ascorbate peroxidase each were increased ($P < 0.05$) in 'KY-31' tall fescue (*Festuca arundinacea* Schreb.) in response to application of Tasco-Forage (Figure 1; Ayad, 1998). Increased α-tocopherol, β-carotene, ascorbic acid, and SOD activities in seaweed-treated turfgrasses have been measured (Schmidt and Zhang, 1997; Zhang, 1997; Zhang and Schmidt, 1999; Figures 2 and 3). The ability of Tasco to influence plant endogenous antioxidant activity has been demonstrated by both foliar application (Zhang and Schmidt, 1999; Fike et al., 2001) and soil application (Ayad, 1998).

Tasco-Forage applied to infected and uninfected tall fescue pastures in Virginia increased SOD activity, and the effect lasted throughout the grazing season (Allen et al., 1997; Fike et al., 2001; Figure 4). Tasco-Forage (3.4 kg/ha) was applied in water solution in April and July, and the effect was measurable into November. These results were repeated over 3 yr and in Mississippi as well as Virginia (Fike et al., 2001). Presence of the

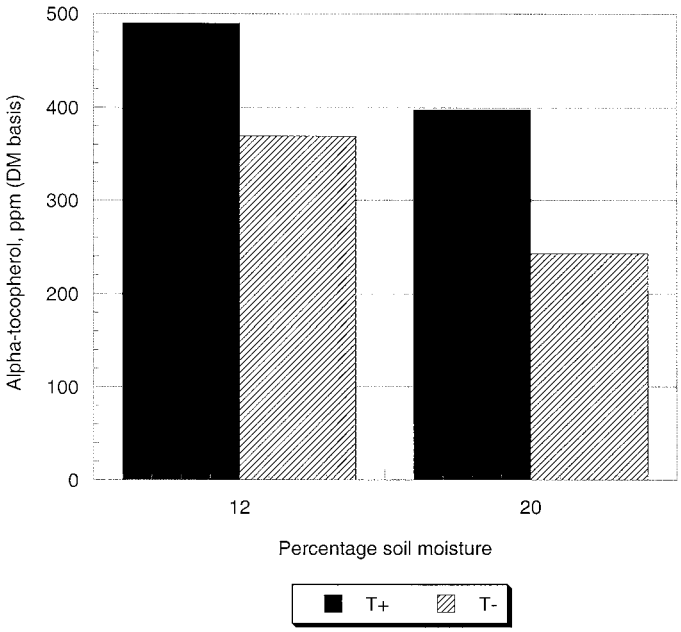

Figure 2. α-Tocopherol of Kentucky bluegrass treated (T+) or not (T–) with 326 g of *Ascophyllum nodosum* extract/ha at two soil moisture levels. α-Tocopherol differed due to *A. nodosum* ($P < 0.01$) but did not interact with soil moisture. Adapted from Zhang and Schmidt (1999).

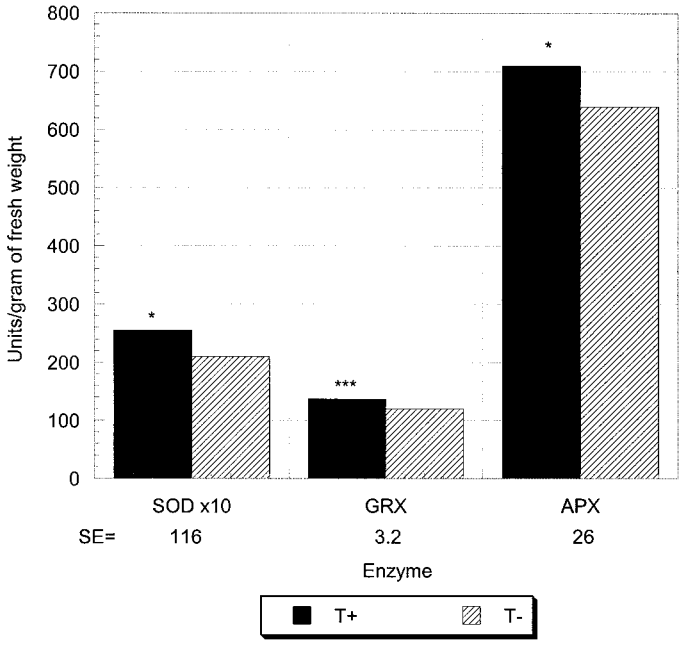

Figure 1. Superoxide dismutase (SOD), glutathione reductase (GRX), and ascorbate peroxidase (APX) in 'KY-31' tall fescue treated (T+) or not (T–) with 3.4 kg of Tasco-Forage/ha in a 2-yr field experiment. Data are averaged over endophyte level (infected and non-infected) and year. *, ***Effect of treatment ($P < 0.05$ and 0.001, respectively). Adapted from Ayad (1998).

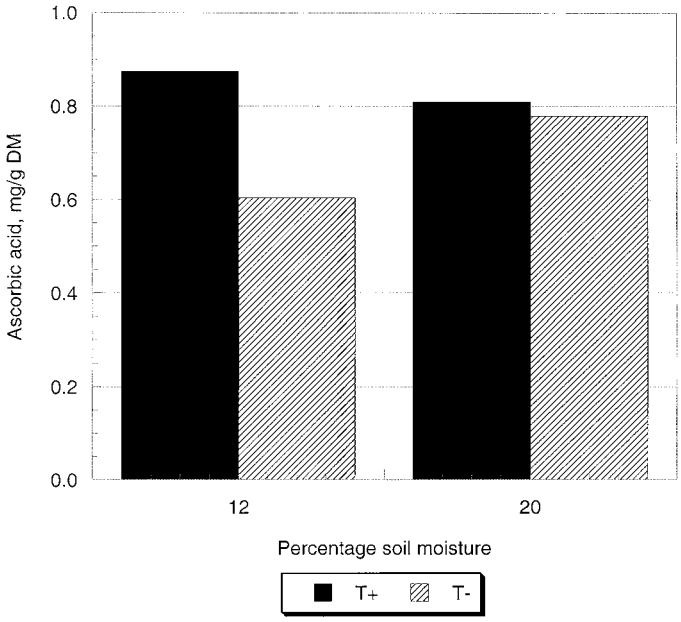

Figure 3. Ascorbic acid of Kentucky bluegrass treated (T+) or not (T–) with 326 g of *Ascophyllum nodosum* extract/ha at two soil moisture levels. Ascorbic acid differed due to *A. nodosum* ($P < 0.01$) and soil moisture ($P < 0.05$) but no interaction was present. Adapted from Zhang and Schmidt (1999).

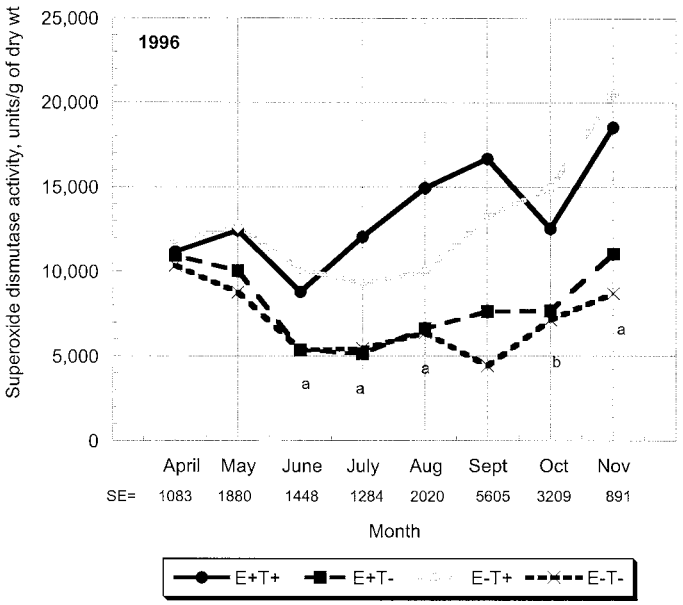

Figure 4. Superoxide dismutase activity in endophyte-infected (E+) and -free (E–) tall fescue treated (T+) or not (T–) with 3.4 kg of Tasco-Forage/ha in April and July in a pasture experiment and sampled at 28-d intervals during the growing season. [a]Effect of Tasco ($P < 0.05$); [b]Effect of Tasco ($P < 0.10$). Adapted from Allen et al. (1997).

endophyte also may influence SOD. Fike et al.(2001) found that the endophyte had no effect on SOD in Virginia but increased activity in fescue grown in Mississippi. Ayad (1998) reported that the endophyte increased SOD activity by about 23% in genetically similar infected and uninfected 'KY 31' tall fescue grown in the southern High Plains of Texas. Climatic stress may interact with the endophyte to alter effects on SOD.

Animal Effects

Antioxidant responses have been measurable in livestock that either grazed Tasco-treated forage or were directly supplemented with Tasco-EX (extract) or Tasco-14 (meal). Lambs that grazed for 22 d on tall fescue (70 to100% infected) treated with 0, 1.7, or 3.4 kg Tasco/ha exhibited a linear increase ($P < 0.05$) in daily gains, and serum vitamin A ($P < 0.13$) and whole-blood Se ($P < 0.10$) tended to increase (Fike et al., 2001). Beef steers that grazed Tasco-treated infected or uninfected tall fescue in Virginia during 1995 also exhibited a strong trend ($P < 0.10$) for increased whole-blood Se by the end of the grazing season in September (Fike et al., 2001). Later work confirmed this effect in both serum and whole-blood Se (W. Cradduck, V. Allen, and P. Brown, unpublished data).

There seems to be a relationship among the endophyte, Tasco, and vitamin E status in grazing beef steers. The evidence suggests an interaction when infected fescue is treated with Tasco compared with effects when Tasco is applied to uninfected fescue. Effects of both endophyte and Tasco seem long-lasting. Season-long pasture experiments in Virginia and Mississippi demonstrated lower serum vitamin E in steers that had grazed infected, compared with uninfected tall fescue (Fike et al., 2001). Effects of Tasco on serum vitamin E were inconclusive during the pasture phase. Following the pasture phase, all steers were transported to Texas for feedlot finishing. The lower serum vitamin E due to endophyte was measurable on arrival in Texas, but the effect of endophyte on vitamin E was at least partially offset if the pasture had been treated with Tasco (Allen et al., 2001).

Dietary vitamin E consists primarily of α- and γ-tocopherol and is absorbed in a manner similar to fat (Sokol, 1996). Vitamin E is absorbed into the intestinal mucosal cell and, once inside the enterocyte, is incorporated into chylomicrons. Sokol (1996) suggested that any pathologic process that impairs digestion and absorption of dietary fat can lead to poor absorption of vitamin E. There is a strong correlation between plasma tocopherol concentrations and total plasma lipid concentration due to the high lipid solubility of vitamin E and its transport in lipoproteins (Horwitt et al., 1972). Thus, it has been suggested that serum vitamin E should be normalized to the total plasma lipid concentration to evaluate tocopherol status (Horwitt et al., 1972).

The relationship of vitamin E to lipid metabolism is of particular interest in interpreting effects of the endophyte and Tasco. Stuedemann et al. (1985) found a relationship of the endophyte with lowered plasma cholesterol, total lipids, and lipid metabolism in both cows and steers during the grazing season. Allen et al. (2001) confirmed this effect of infected fescue in steers transported from Virginia and Mississippi to Texas. Furthermore, the effect on cholesterol was reversed if infected fescue had been treated with Tasco. However, when serum vitamin E was normalized with serum cholesterol, effects of endophyte were still apparent but no effect of Tasco on the ratio was observed. Because vitamin E is transported in the blood by plasma lipoproteins and erythrocytes, the ratio is particularly valuable in pathological states in which altered lipoprotein concentrations and vitamin E deficiency may be expected (Traber et al., 1993). When plasma lipids and lipoprotein concentrations are reduced, such as is observed with effects of endophyte on cholesterol, vitamin E deficiency would be overestimated.

At slaughter, concentrations of vitamin E in liver were greater if steers had grazed Tasco-treated pastures prior to finishing in drylot, regardless of the endophyte (Montgomery et al., 2001). Unfortunately, no data were available on vitamin E concentrations in muscle. It is not clear why liver vitamin E would reflect treatments applied to pasture grazed 160 d prior to the feedlot period. Vitamin E, initially transported in chylomicrons, is released to tissues or transferred to lipoproteins but eventually much of the vitamin E returns to the liver in chylomicron remnants (Sokol,

1996). Turnover of vitamin E is estimated to be 5 to 20 d in liver (Burton and Ingold, 1993) and large amounts never accumulate because of the function of tocopherol in transfer protein (Sokol, 1996).

There are several interesting parallels between known effects of vitamin E and effects obtained with Tasco. Vitamin E fed to beef cattle during feedlot finishing has extended shelf-life by improving color stability, reducing lipid oxidation, and delaying metmyoglobin formation (Faustman et al., 1989a,b; Smith et al., 1996). Montgomery et al. (2001) found that color stability during retail display was prolonged in steaks from steers that had grazed Tasco-treated tall fescue prior to feedlot finishing. It is not known whether this was due to vitamin E, other antioxidants, or unidentified factors. Direct feeding of Tasco-EX to steers during the final 14 d in the feedlot also resulted in improved color stability (Figure 5; D. Messer, K. Pond, and V. Allen, unpublished data).

Mitsumoto et al. (1998) found that dietary supplementation with vitamin E for 1 wk prior to slaughter delayed lipid oxidation in beef steaks and reduced drip loss, compared with controls. In another experiment Mitsumoto et al. (1995) found that dietary vitamin E reduced drip loss but longissimus steaks had greater cooking loss. Similarly, Montgomery et al. (2001) reported greater cooking loss in beef longissimus steaks from steers that grazed Tasco-treated fescue followed by finishing in drylot, and the effect was unrelated to endophyte status in the fescue. Drip loss was not measured in that experiment.

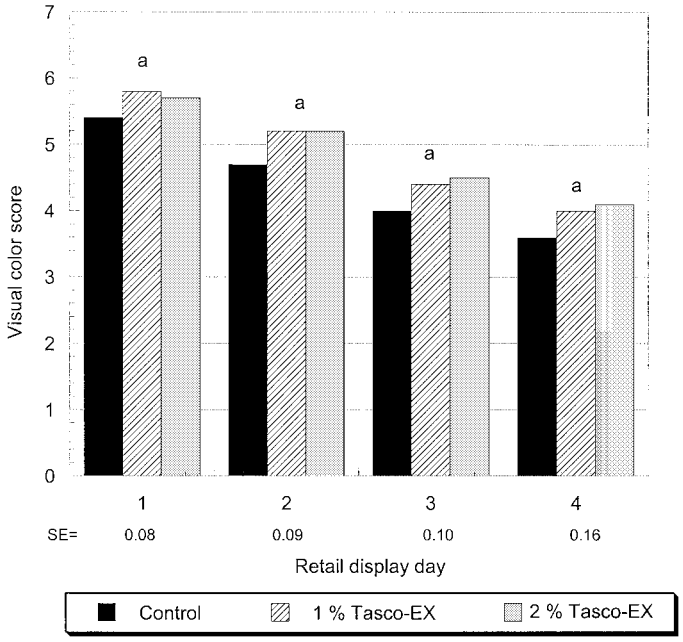

Figure 5. Visual color values of beef longissimus steaks during retail display following removal of vacuum packing from feedlot-finished steers fed 0, 1, or 2% Tasco-Ex as a percentage of the diet dry matter during the final 14 d in the feedlot. Means are averaged over four periods; meat was removed from vacuum packaging and steaks were cut on postmortem d 7, 14, 21, and 28. (D. Messer, K. Pond, and V. Allen, unpublished data). [a]Control differs from the mean of the treated ($P < 0.01$).

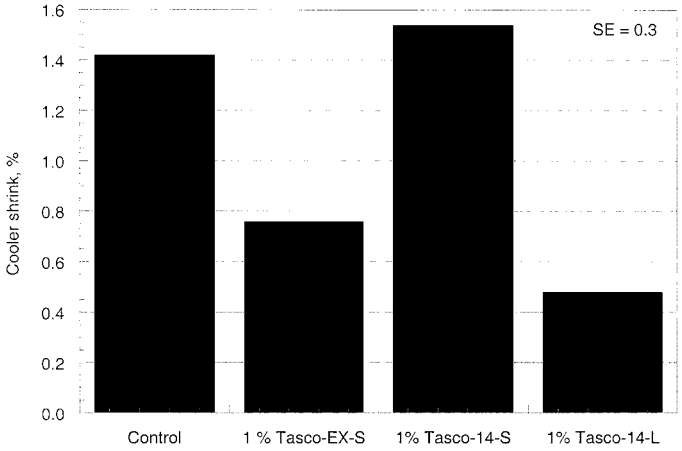

Figure 6. Cooler shrink in swine fed Tasco-Ex and Tasco-14 during the first 10 d (S) or Tasco-14 during the entire 5 wk (L) of the nursery phase after weaning. Tasco was fed at 1% of the daily DM intake during the treatment period. Treatment groups were fed a similar diet without Tasco during the growing and finishing phases. Tasco-Ex-S tended to differ from the control ($P < 0.10$) and Tasco-14-L differed from the control ($P < 0.03$). K. Pond, V. Allen, and J. Montgomery, unpublished data.

Less drip loss from thawed pork chops obtained from vitamin E-supplemented swine was reported by Asghar et al. (1991). Direct supplementation of Tasco-EX and Tasco-14 to pigs during the nursery phase resulted in less cooler shrink (Figure 6; K. R. Pond, V. G. Allen, and J. Montgomery, unpublished data). Pigs were supplemented with either Tasco-EX or Tasco-14 for the first 10 d or with Tasco-14 during the entire 5 wk of the nursery period at 1% of the daily DM intake. Effects of a 10-d supplementation period with the extract seemed to have effects similar to those of a 5-wk supplementation period with the meal. A 10-d supplementation period with the meal did not produce results different from controls. All treatment groups received the same diet during the growing and finishing phases and no further supplementation was imposed after the nursery phase. Inclusion of either Tasco-EX for 10 d or Tasco-14 for 35 d in the diets at the nursery phase altered the percentage of free, bound, and immobilized water in muscle after slaughter (Figure 7); this may help to explain differences in cooler shrink. Feeding Tasco-14 for 10 d did not seem to elicit responses different from controls.

The mechanism of effect on drip loss, cooler shrink, and altered partitioning of water form in these experiments is not known but may be related to vitamin E and other antioxidants and effects on lipid metabolism. Vitamin E is known for its role as a scavenger of free radicals, thus protecting cell membranes from oxidative

damage (Sokol, 1996). Mitsumoto et al. (1995) suggested that dietary vitamin E stabilized cell integrity and enhanced the ability of beef muscle to retain sarcoplasmic components that resulted in less drip.

Steers that grazed fescue pastures treated with Tasco-Forage had higher marbling scores, regardless of the endophyte (Allen et al., 2001). The greater degree of marbling may provide further evidence of altered lipid metabolism due to Tasco. Direct feeding of Tasco to steers during the finishing period has had variable effects on marbling at slaughter. The amount of Tasco supplemented as well as the time at which it is introduced into the diet may affect results. Steers fed Tasco-EX at 2% of the diet during the first 10 d on the feedlot had higher ($P < 0.05$) marbling scores at slaughter than unsupplemented steers (J.W. Johnson, K. Pond, and V. Allen, unpublished data). However, feeding 0, 1, and 2% Tasco-EX during the final 14 d of the feedlot finishing period did not influence marbling in steers, although color stability was improved (D. Messer, K. Pond, and V. Allen, unpublished data).

Immune Function

Interrelationships among Tasco, the endophyte in tall fescue, and immune function have been demonstrated. Presence of the endophyte was related to lower phagocytic activity, oxidative burst, and major histocompatibility complex class II expression in steers (Saker et al., 1998, 2001; Allen et al., 2001). Steers that grazed infected tall fescue treated with Tasco-Forage responded with increased phagocytic activity (Figure 8) and major histocompatibility complex class II expression (Allen et al., 2001; Saker et al., 2001). This increased immune response continued while steers were on pasture, throughout cross-country transportation, and during a 160-d feedlot finishing period (Allen et al., 2001). The enhanced immunity seems to be related to an increase in antioxidant activity in both plants and animals (Allen et al, 1997; Fike et al., 1997; Schmidt and Zhang, 1997). Vitamin E is closely related to immune function (Sokol, 1996; Dubeski, 1999). Vitamin E deficiency in cattle reduces the ability of phagocytes to engulf and kill invading pathogens (Dubeski, 1999), and feeding vitamin E at levels greater than normal requirements stimulates immunity (Bendich, 1993; Hogan et al., 1993). In steers grazing infected tall fescue, lowered phagocytic activity was paralleled by lowered serum vitamin E (Fike et al., 2001; Saker et al., 2001). Treating the infected fescue with Tasco increased both phagocytic activity and serum vitamin E. Although not measured in these experiments, the previously reported effects of Tasco on a-tocopherol in grasses suggests that it may have played a role in effects on the grazing steers (Zhang and Schmidt, 1999). Superoxide dismutase was increased in the fescue in response to Tasco (Fike et al., 2001) and also may have been related to enhanced

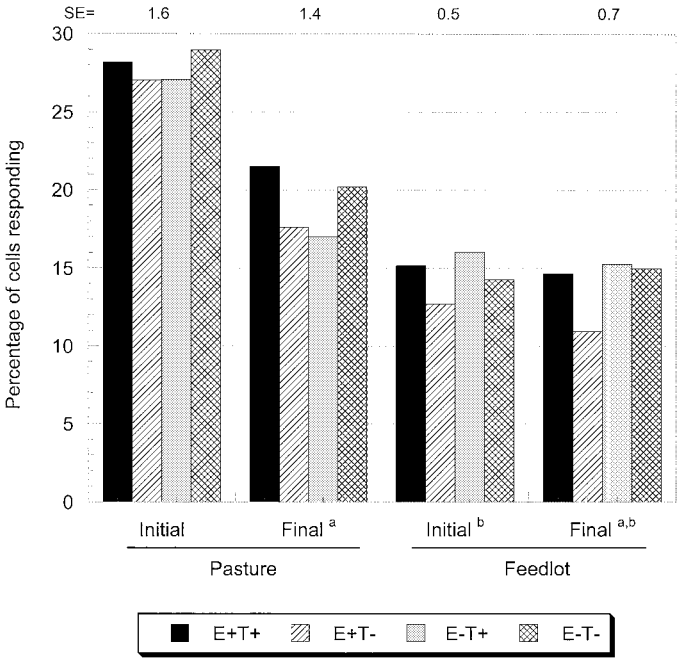

Figure 8. Monocyte phagocytic activity in steers that grazed endophyte-infected (E+) or endophyte-free (E–) tall fescue in Virginia and Mississippi during 1996 and 1997 that was either treated (T+) or not (T–) with Tasco-Forage, a brown seaweed extract. Steers were finished on the feedlot in Texas following the pasture phase (adapted from Saker et al., 2001 and Allen et al., 2001). [a]Endophyte × Tasco interaction ($P < 0.05$); [b]effect of Tasco ($P < 0.02$).

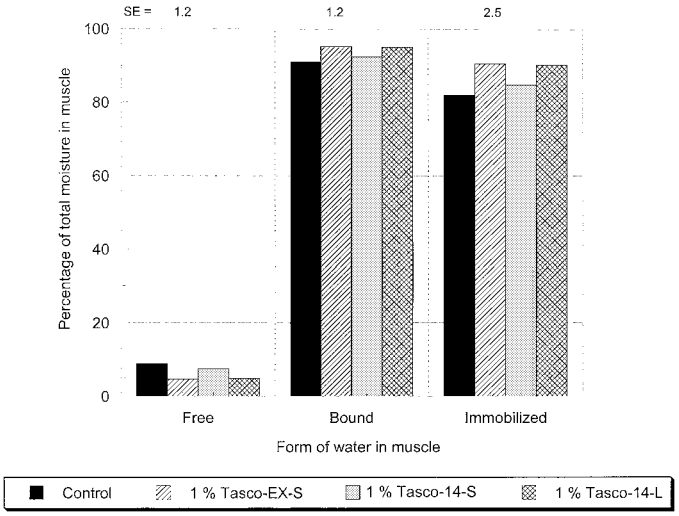

Figure 7. Percentage of free, bound, and immobilized water in muscle from postslaughter swine that had been fed Tasco-Ex and Tasco-14 during the first 10 d (S) or Tasco-14 during the entire 5 wk (L) of the nursery phase after weaning. Tasco was fed at 1% of the daily DM intake during the nursery phase and treatment groups were fed a common diet without Tasco during the growing and finishing phases. The control differed from the mean of the treatments ($P < 0.05$) for each water fraction. (J. Montgomery, K. Pond, and V. Allen, unpublished data).

immune function. Copper in plant SOD may help to upregulate SOD activity in cattle, but Cu has been shown to be lower in infected fescue (Dennis et al., 1998) and steers (Saker et al., 1998) that grazed infected fescue. Copper in plant SOD may directly improve phagocytic cell function, because this is altered by dietary Cu changes. Changes in blood Cu levels of steers that grazed Tasco-treated fescue were not detected (Fike et al., 2001), but blood Cu may be too insensitive as a Cu status marker. Microbicidal activity is contingent on a free-radical process, and it is suspected that increased immunity is perhaps one manifestation of a generalized increase in SOD activity. Other antioxidants also may have been involved, and both enzyme and nutrient antioxidants are known to increase in grasses following Tasco application (Ayad, 1998; Zhang and Schmidt, 1999). Although not measured, dietary intake of α-tocopherol, ascorbic acid, and β-carotene was likely higher in steers that grazed the Tasco-treated forage than in those that grazed the untreated fescue. Important antioxidants that can be affected by diet include vitamin E, glutathione peroxidase, SOD, and catalase, and these depend on sufficient vitamin E, Se, Cu, Zn, Mn, and Fe in the diet (Dubeski, 1999). Although cattle synthesize ascorbic acid, amounts may not meet requirements under stress, and supplementation with dietary sources could be beneficial if protected from ruminal degradation (Dubeski, 1999).

Although treating infected fescue with Tasco-Forage seemed beneficial in reversing the depression in immune function, applying Tasco-Forage to uninfected fescue seemed to have an immune-dampening effect, at least during the grazing season (Saker et al., 2001). Dubeski (1999) suggested that a small excess intake of certain nutrients, including β-carotene, vitamin E, Zn, and Se seems to enhance immune response, but when they are supplied above a certain threshold, immunity can be depressed. This may have played a role in the observed result with uninfected tall fescue. Superoxide dismutase was increased in uninfected fescue and other antioxidants were likely increased (Ayad, 1998; Fike et al., 2001; Zhang and Schmidt, 1999). Immunosuppressive effects of antioxidants in the absence of oxidative stress have been observed in vitro (Gougerot-Pocidalo and Revillard, 1993).

Research in Japan with edible seaweeds has suggested possible immunomodulating activities in hot-water-soluble extracts. *Hijikia fusiforme* (hijiki) showed an enhancing activity for proliferative response of spleen cells in endotoxin-nonresponder *C3H/HeJ* mice, and a possible immunopotentiating activity against carcinogensis was suggested (Okai et al., 1998). An extract from *Laminaria japonica* (makonbu) was shown to enhance DNA synthesis of spleen cells from mice (Okai et al., 1996). Their results suggest immunomodulating activity.

Effects of Tasco on immune function do not seem to be restricted to effects on forage. Steers in the feedlot fed Tasco-14 at 1.5 and 3% of dry matter intake exhibited greater immune response to intradermal injection with phytohemagglutinin than steers fed no Tasco, but performance of steers was reduced by Tasco supplementation (V. Allen, K. Pond, and K. Saker, unpublished data).

Enhanced immune response suggests Tasco may help to reduce morbidity and mortality during times of stress. However, initial studies with calves fed Tasco-EX or Tasco-14 following transportation, vaccination, and sale barn stresses have indicated a trend for increased morbidity due to Tasco treatment. Crossbred beef heifers purchased through local sales barns in Tennessee were given Tasco-Ex in the drinking water on arrival at the farm (V. G. Allen and D. Thompson, unpublished data). Calves readily consumed the supplemented water but Tasco did not reduce incidence or mortality from chronic severe bronchopneumonia. Both *Pasturella haemolytica* and *P. multocida* were isolated from lung tissue. The timing of introducing Tasco into the diet and the length of the supplementation period may be crucial.

Supplementing vitamin E to receiving calves has frequently but not consistently reduced morbidity and mortality (McDowell et al., 1996). The response may be influenced by previous nutrition, degree of stress, or other factors (Dubeski, 1999). Furthermore, dietary supplementation seems more effective than injecting vitamin E, which may increase morbidity and reduce weight gain (Dubeski, 1999).

Other research with Tasco has been more promising. Lactating mares fed 1% Tasco-EX in the concentrate for 14 d prior to weaning foals exhibited little change in neutrophil:lymphocyte ratio during a 56-d period after weaning. The neutrophil:lymphocyte ratio increased ($P < 0.05$) in control mares 14 d after weaning, indicating a greater level of stress (H. Brady, J. Morrow-Tesch, K. Pond, and V. Allen, unpublished data).

Porcine reproductive and respiratory syndrome (**PRRS**) was an unrecognized viral disease of swine until it was described in the United States in 1987 (Albina, 1997). Within herds, the disease spreads rapidly, and up to 95% of pigs can be affected within 2 to 3 mo. This disease affects pigs of any age but is characterized by abortion, premature farrowing, stillborn and mummified pigs, and respiratory disease and chronic poor performance of nursing and weaned pigs. Of major economic importance, PRRS is thought to affect more than two-thirds of the herds in the United States (Bautista et al., 1993).

Pigs that had been exposed to PRRS and were symptomatic were supplemented with 0, 0.5, or 1% Tasco-EX or with 3% Tasco-14 during a 5-wk nursery phase. Pigs supplemented with either form or rate of Tasco gained more ($P < 0.05$) body weight during the 5-wk period than did controls (Figure 9; K. Pond, V. Allen, and C. Melton, unpublished data). Improved ($P < 0.05$) feed intake and feed conversion also were recorded in the Tasco-supplemented groups, compared with controls. By the end of the feeding period, supplemented

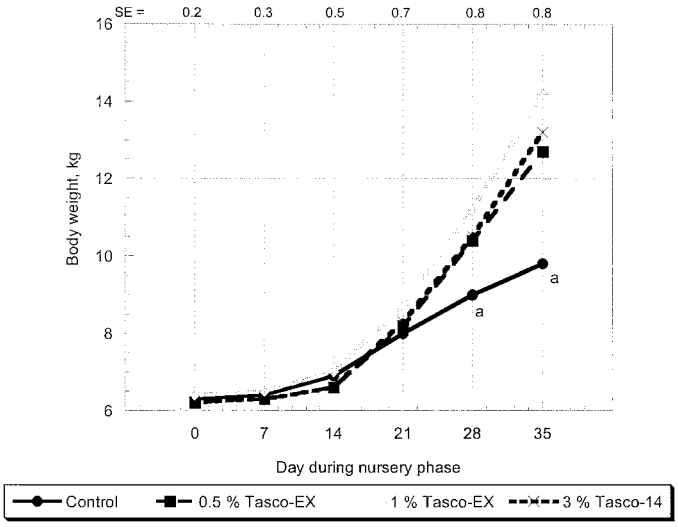

Figure 9. Body weight of postweaned pigs that were supplemented with either 0.5 or 1% Tasco-Ex or 3% Tasco-14 as a percentage of the daily dry matter intake during 35-d nursery phase. [a]The control differed from the mean of the treated ($P < 0.01$). K. Pond, V. Allen, and C. Melton, unpublished data.

pigs tended to have slightly higher rectal temperatures than controls. Altered rectal temperature (either higher or lower) in relation to Tasco has been a nearly consistent finding in studies with cattle, but the cause is as yet unknown (Allen et al., 2001; Saker et al., 2001; V. G. Allen and K. R. Pond, unpublished data).

Vacca and Walsh (1954) reported an antibacterial activity from an extract of *Ascophyllum nodosum*. Antibacterial activity was found against 10 of 11 organisms tested in vitro. Activity against both Gram-positive and Gram-negative types was observed and included *Escherichia coli*. Vacca and Walsh (1954) investigated two species of seaweed, *A. nodosum* and *Enteromorpha compressa*, but only *A. nodosum* gave promising results. These results are interesting in light of recent research at Texas Tech University (Behrends et al., 2000). Preliminary studies suggest that supplementing Tasco-EX to steers during the final 14 d in the feedyard reduced numbers of both *E. coli* and, specifically, O157:H7 present in feces and on the hide, but more research is needed to verify these findings.

The immune system is complex and its interaction with the neuroendocrine system is regulated by cytokines secreted by white blood cells. Cytokines induce fever, depress appetite and feed intake, and influence metabolic adaptations to infection as they regulate the immune response (Still et al., 1997). It is possible that at least some of the effects of Tasco on livestock are due to effects of cytokines. These effects include altered rectal temperatures, reduced feed intake, and either no effect on performance or a slight decrease in gain that have been observed in some experiments.

There seem to be several parallels between effects of vitamin E and effects of Tasco on animal responses, but other factors are likely involved. The increased serum Se in both lambs and steers that grazed Tasco-treated tall fescue could indicate an increase in Se-dependent glutathione peroxidase (Fike et al., 2001; W. Cradduck, V. Allen, and P. Brown, unpublished data). Glutathione reductase was increased in tall fescue within 1 d of application of Tasco in a greenhouse experiment (Ayad, 1998). Copper is known to be lower in infected tall fescue (Dennis et al., 1998), and this was reflected in a decrease in serum and plasma Cu in steers by the end of the grazing season (Saker et al., 1998). Even though Tasco did not seem to alter Cu in either the plant or the animal, Cu plays an integral roll in SOD and ceruloplasmin, both antioxidants, and free Cu is a powerful pro-oxidant (Halliwell, 1996). Other nutrient and enzyme antioxidants may well be involved.

In summary, nutrition, immune function, and antioxidant activity are closely interrelated. During times of stress, livestock are more susceptible to infectious disease because of stress-induced immunosuppression. Increased oxidative stress due to disease and the resulting up-regulation of an immune response increases the needs for both enzymatic and nutrient antioxidants. Tasco-Forage applied to grasses has increased concentrations of both enzyme and nutrient antioxidants in the forage, including several that can be effectively supplemented in the diet. Steers that grazed treated pastures responded with improved immune function, carcass characteristics, and shelf-life of meat, particularly if steers were stressed by the endophyte in tall fescue. Treating uninfected tall fescue may result in immunosuppression, at least during the grazing season, but seemed beneficial when grazing was followed by stress of transportation followed by feedlot finishing. Whether or not a higher dietary intake of antioxidants is related to the observed effects needs further investigation. Direct supplementation of livestock with Tasco also seems promising to extend shelf-life and enhance immune response, but more information is needed on its mode of action and method of administration. Although some responses of livestock seem strikingly similar to those observed following vitamin E supplementation, it is likely that vitamin E is not the only factor involved.

Implications

Antibiotics revolutionized human and animal health during the last century, but increasing concerns with antibiotic resistance, food safety, and animal welfare have called many practices into question and increased interest in nutraceuticals. Intricate interrelationships exist among nutrition, immune and endocrine function, antioxidant systems, health, and production. Tasco, an extract or meal from the brown seaweed *Ascophyllum nodosum*, has demonstrated plant growth-regulating activity and up-regulates several enzyme and nutritive antioxidants when applied to plants. At least some of the antioxidant response is imparted to livestock that

graze treated forage or are fed these products directly. If treatment of forage or direct feeding of Tasco can predictably trigger desirable responses, then improved animal health, reduced plant and animal stress, prolonged shelf-life, and increased safety and quality of plant and animal products seem possible. The economic benefits would be huge.

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