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Seaweed extract research and applications in agriculture

***A**BSTRACT*

Seaweed extract products are receiving increasing attention as nutrient supplements in integrated crop nutritional programs. These products are currently applied to crops for beneficial effects attributed to the presence of natural plant growth hormones (i.e. cytokinins, auxins) as well as other plant biostimulants (e.g. betaines, polyamines, oligosaccharides), which can improve plant resistances and tolerances to environmental, disease and insect stresses. University and commercial research has demonstrated wide-ranging benefits which support the use of seaweed extracts for improving many aspects of crop growth and development. This paper presents a brief overview of past and current research reflecting on plant responses to seaweed extract applications.

INTRODUCTION

Seaweeds and seaplants are an integral part of the coastal ecology and landscape. Seaweeds such as the brown algae *Ascophyllum nodosum* (commonly known as Norwegian Kelp) grow in abundance within the littoral zone, that area periodically covered by rising or receding tides. For centuries, agricultural areas close to these coastal zones have utilized seaweeds as a valuable source of organic matter for various soil types and for many different fruit and vegetable crops (1). Today, seaweed meals and soil amendments are available in ready-to-apply dry form for use in crop soils and home gardens alike. Moreover, high quality liquid and powder seaweed extract products can be found in pure form, or in recipe formulations with or without ingredients ranging from traditional (e.g. fertilizers, pesticides, etc.) to non-traditional products (e.g. humates, fish products, etc.) (2-4). Of all the seaweeds and extract products currently on the market, *Ascophyllum* is the most widely used and researched seaweed species in agriculture.

APPLICATION METHODS, RATES AND TIMINGS

Current users of seaweed extracts utilize the product in a number of ways. Foliar applications are most popular for direct applications. In addition, seed treatments have been shown to promote early germination and enable plants to better deal with stresses during plant establishment (1, 5). Soil applications and root dipping into seaweed extract solution (6) are also practiced under some conditions (1). Our field research has shown that seaweed extracts can also be applied through irrigation, fertigation (drip or perforated tube), or furrow-run systems. Moreover, they are often applied with other products which in some cases, have been reported to heighten efficacy when applied with seaweed extracts (e.g. fungicides, herbicides) (7).

Different application rates and timings are routinely examined over a wide range of temperate, tropical and subtropical food crops, as well as turfgrass and ornamental species. Rates and timings for various seaweed extract products have been shown to be crop specific and can result in very different crop responses (Table I). However, application rates usually range from about 0.2 to 1.5 kg of seaweed solids per hectare, per application. In many cases, early applications of either liquid or soluble powder extracts are most beneficial in helping crops deal with early season temperature and disease stresses while helping to maximize yield potential.

RESEARCH: THE KEY TO UNDERSTANDING

Ongoing research has helped to further elucidate the biochemical basis of the many beneficial effects caused by seaweeds and seaweed extracts. But a number of questions remain. Just what is it about seaweeds that help improve yields? Does it have something to do with the organic matter? Is it the mineral fraction? Maybe the plant carbohydrates? Or is there something else? International research programs are currently generating a wealth of information to complement existing literature in the search for answers to plant responses to seaweed extract applications (see review 10). However, a large body of fundamental and applied research remains confidential and proprietary to various seaweed extract manufacturers and producers.

Cytokinins

A scan of the scientific literature shows that seaweeds are active sources of many helpful ingredients. The most notable of these are the plant growth substances and in particular, a class of plant growth regulators (PGRs) called cytokinins (8-10). Adenine is the parent molecule of this family of plant hormones that includes the natural PGRs zeatin, zeatin riboside, isopentenyl adenine and dihydrozeatin. There are roughly 16-18 cytokinins produced naturally by plants and marine algae. These natural compounds are slightly different from synthetic PGRs not naturally produced by plants such as kinetin or

Table I. Yield response to alkaline-extracted *Ascophyllum nodosum* seaweed extract applications to several crops tested in commercial field trials.
Research performed in commercial trials with independent research organizations as part of Acadian Seaplants Limited field trials product testing program.

Crop	Variety	Year	Application timings	Noted responses
Apples	Rome	1993	Foliar applications at prebloom (2x) 3 applications post bloom	Improved yield Improved fruit quality Decreased insect pressure
Tomatoes	cv. 9174 cv. 8892	1992 1993 1994	Foliar applications at transplant, lay-by and fruit set	Increase in total and marketable yield Slight increase in Brix
Potatoes	Atlantic Chipeta	1996 1996	As seed treatment Foliar applications at tuber set, 10-14 days later, and late bloom	Increase in yield Decrease in nematode and wireworm damage
Carrots	Bolero Nanda Maestro	1997	Foliar applications 3 times up to pencil stage of development	Increase in yield Increase in carrot size
Watermelon	Calsweet Nova	1995	Applied at transplant (in fertigation water) Foliar applications at pre-bloom, fruit-set, and 14 days after fruit-set	Increase in yield Increase in BRIX
Grapes	Flame Thompson	1998 1993	Foliar applications at 20 and 50 cm cane (pre-bloom), early shattering and sizing	Increase in yield Slight increase in BRIX
Peppers	Emerald Green Bell	1992	Foliar applications at seedling and approximately 2-4 weeks thereafter	Improved yield Greater number of large fruit

* Application rates are crop and timing specific, and vary with product type. Products, as tested, were liquid and powder forms of alkaline-extracted *Ascophyllum nodosum* seaweed extracts.

benzyladenine (11, 12). Cytokinins are necessary compounds in plant growth and development and, with the help of another family of PGRs, the auxins, help to stimulate cell division and protein synthesis (10, 12). Cytokinins, required by plants in very small amounts, are implicated in all phases of plant growth from root formation to bud, stem and leaf development. Seaweed extracts have been shown to alter cellular structure (13) and when applied directly to a crop, can provide growers with a valuable tool with which to influence fruit and vegetable yield and quality.

Given cytokinins' role as stimulators of the synthesis of enzymes and structural proteins, it follows that seaweed extracts may play a direct role in the manufacture of proteins used to protect plants against various pressures. For example, new research at Texas Tech and Virginia Tech Universities indicates that alkaline-extracted *Ascophyllum* extracts can directly improve stress tolerance in plants and animals (14-19). It was found that ergot-type alkaloids generated by fungi in endophyte-infected tall fescue caused health and immune problems in grazing animals. This resulted in more animal sick-time and added veterinarian expenses. However, when this seaweed extract was applied to fescues, not only were plants tolerant to environmental stresses, the grazing animals demonstrated fewer health-related problems. The ability of the *Ascophyllum* seaweed to impart stress tolerance to treated grasses while provoking a positive immune response in grazing animals can have widespread implications. Texas Tech researchers are currently examining other immuno-related benefits which may transcend several animal groups in addition to continuing research on stress tolerance in grazing crops.

Table II. Several enzymatic and non-enzymatic antioxidants found to be affected by seaweed extract treatments in current research.

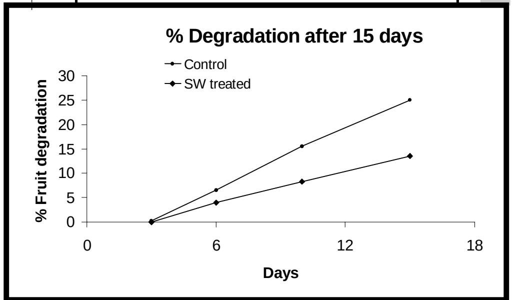
Antioxidant	Reference document
ENZYMATIC	
Superoxide dismutase (SOD)	15, 16, 18
Glutathione peroxidase	ongoing
Glutathione reductase	18
Ascorbate peroxidase	18
NON-ENZYMATIC	
α-tocopherol (Vitamin E)	14, 15
β-carotene (Vitamin A)	14, 15, 17
Ascorbate (Vitamin C)	ongoing

Antioxidants

The Texas Tech and Virginia Tech research has focused primarily on antioxidant synthesis and direct or indirect plant responses (Table II). The antioxidant compounds being examined in this research include the enzymes superoxide dismutase, glutathione reductase, glutathione peroxidase, ascorbate peroxidase, and some non-enzymatic antioxidants such as α-tocopherols, β-carotenes and ascorbate. To further substantiate these findings, recent European plant disease research examined the effects of mildew (*Plasmopara viticola*) on peppers (*Capsicum annuum*) and of mildew (*Phytopthora capsici*) on grapes (*Vitis vinifera*), with and without seaweed extract treatments (20). It was revealed that seaweed extract treatments caused a reduction in mildew infection by promoting the plants ability to fight fungal pathogens through increases in endogenous peroxidase activity. Interestingly, peroxidases were previously detected in *Ascophyllum* (21) and similar increases in plant peroxidase activity were found in the Texas and Virginia research. Moreover, the seaweed-treated peppers and grapes appeared to have a higher endogenous concentration of capsidiol, a phytoalexin compound produced by plants as a first line of defense against fungal attack (20). Although the mode of action is unclear, it appears that seaweed extract treatments may promote the synthesis of capsidiol in these plants.

In short, these results support commercial research findings which have shown that some crops demonstrate heightened disease resistance following *Ascophyllum* extract treatment. In fact, higher antioxidant activity can manifest itself in other beneficial ways. For example, cell breakdown and hastened maturity can be promoted by the presence of oxidizing free radicals (e.g. superoxide, hydroxyl radicals, etc.). Higher antioxidant activity can protect cellular membrane integrity against oxidation and lead to a stimulation of cellular processes thereby retarding the senescence process. This effect is often observed with other PGRs (e.g. gibberellins). Stimulation of antioxidants can also result in longer shelf life for fruits and vegetables by destroying oxidizing compounds before they are allowed to proliferate within the plant system to induce breakdown. Our research found the shelf life of seaweed treated watermelon and nectarines to be significantly longer than control groups when

Figure 1 - Increase in shelf life of nectarines as a result of *Ascophyllum* seaweed extract (SW) applications.



measured as fruit degradation over several weeks (Figure 1).

Betaines, Polyamines and Oligosaccharides

Another class of compounds called betaines has been implicated in the stimulation of cellular metabolism (22). In plants, betaines contribute to the formation of methionine, an important amino acid and intermediary towards the synthesis of polyamines and ethylene (Figure 2). The synthesis of polyamines, compounds long regarded as plant stimulants and protectors of cellular components, may thereby benefit from the presence of additional betaines. Moreover, betaines act as cellular protectants by contributing to the osmotic potential of the cell. By stabilizing turgor pressure and osmotic balance, cellular membranes are not permitted to collapse or face undue stress from a lack of cellular water. Protecting membrane integrity allows cells to function normally under a range of stressful conditions. Although scientific articles in support of these observations have been published, the direct mechanism or mode of seaweed extract action on betaine production is not well understood.

Polyamines such as putrescine, spermine, spermidine and cadaverine are produced in most plants from the metabolic intermediate S-adenosyl methionine, or SAM. SAM is also a precursor in ethylene production. Ethylene, which is widely regarded as a plant retardant and membrane destabilizer, has effects that can directly contrast those of polyamines. Some plant physiologists regard polyamines as PGRs since they can lead to membrane stability and improved stress tolerance.

Another new class of potential growth modulators are the oligosaccharides. Although little is known about their mechanisms of action, oligosaccharides may have a growth promoting effect on differing cellular processes either directly or through the generation of secondary mechanisms (23, 24).

Macro- and Micro-Nutrients

Other compounds found in *Ascophyllum* seaweeds include a host of primary and secondary nutrients important to plant cell nutrition. In addition, *Ascophyllum* contains an abundance of naturally chelating polysaccharides such as alginic acid, which can form complexes with cations such as Cu, Fe, Mn, Mg and Ca. Alginic acid is composed of mannuronic and guluronic acid subunits, each capable of complexing with cations. Likewise, mannitol, a sugar alcohol present in abundant quantities, exhibits similar chelating action. The end result of a higher concentration of chelated minerals is greater bioavailability of the nutrients to treated crops. Improved efficacy and uptake are just a few of the research ideas being examined (28).

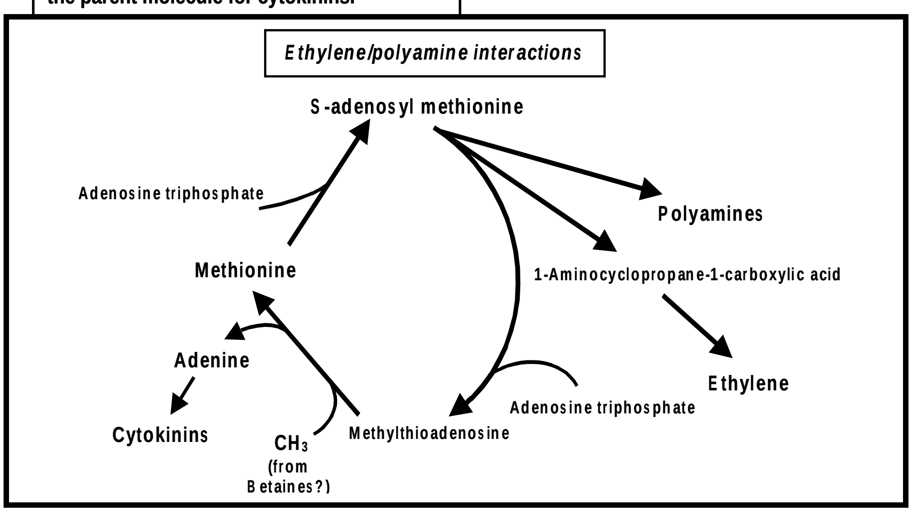
Insect Repression

Recent studies by USDA researchers indicate that tobacco and tomato plants genetically altered to produce more endogenous cytokinins appear to repel insects and may have a toxic effect on attacking insect pests (25). These research results become more convincing when considering that natural cytokinin products have shown similar repressive effects when applied exogenously (Figure 3). However, effects against insects may be less of a direct effect on the invading pest as it is an enhancement of the production or secretion of secondary metabolic compounds, many of which by their nature, possess insecticidal properties (e.g. oxidants, alkaloids). Although the specific mode(s) of cytokinin action against insects remains uncertain, this research is producing patented technologies for insect control in many agricultural crops that is attracting the attention of major industry players.

Protein Synthesis and Systemic Acquired Resistance (SAR)

It is well known that plants synthesize compounds to protect themselves from fungal or insect attack. Some of these products are produced as a wound response while others can directly attack invaders. The term Systemic Acquired Resistance (SAR) has been forwarded to describe the ability of the plant to be "vaccinated" against diseases, etc. As such, the plant generates or acquires internal resistances (systemic) in response to some protein stimuli in a manner similar to the inoculation of animals against diseases. The theory surrounding SAR is quite similar to the mechanisms involved in the seaweed extract-induced plant resistance described earlier (i.e. seaweed effects against mildew infection of grapes and peppers). Similar plant reactions have been noted in response to the external application of other products. For example, there are products currently available which enhance the production of chitinases (which can help dissolve the chitin shell of attacking insects) and polygalacturonase inhibitor proteins (which help plants fend off disease pathogens) (26).

Figure 2 - Simplified illustration of the interaction between betaines, polyamines and ethylene, including the generation of adenine, the parent molecule for cytokinins.



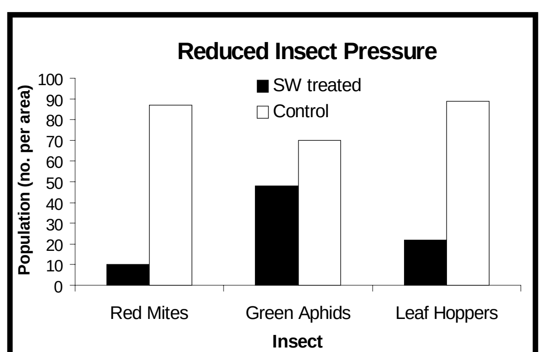


Figure 3 - Reduction in insect pests as a result of *Ascophyllum* seaweed extract (SW) applications to apples. Population counted as no. per area measured (as no. per leaf or no. per 100 leaves).

SEAWEEDS AND OTHER NON-TRADITIONAL PRODUCTS

Seaweed extracts are often used in conjunction with other products, both traditional and non-traditional. The use of non-traditional products such as humates and fish emulsions have received tremendous attention in recent years. However, the nutrient content of these products is as varied as the sources from which they are derived. Alternative products can be used to furnish primary and secondary nutrients, improve soil cation exchange capacity, increase the presence of plant growth hormones, and stimulate plant defense mechanisms against diseases and insects (27). Non-traditional products are often regarded as safer alternatives to many chemical products and are held as a more natural remedy for crop ailments. In addition, proprietary fermented product formulations are often used with seaweeds. These products may contribute bioactive or mineral components to the crop while concurrently eliciting secondary effects on crop nutrition by enhancing the bioavailability of nutrients already present either in the products, the atmosphere or the soil. In short, seaweed extracts, traditional and non-traditional products serve to complement each other and can furnish a wide variety of chemical, physical or biological improvements to the crop and its growing environment.

CONCLUSION

From a scientific standpoint, a large body of literature has been amassed to support the use of seaweeds and seaweed extracts in agricultural programs. It should be cautioned however, that dried seaweed or seaweed extracts are not stand-alone products and should be used within regular crop management programs to be most effective. From a grower standpoint, field trial results have shown significant improvements in overall yields and/or fruit/vegetable quality for a variety of crops. It is the goal of current research programs to investigate and support these field observations with concrete data on what beneficial effects are being realized and why.

In summary, the future of seaweed product use remains promising. As research continues to shed light on new and exciting avenues for existing and novel applications, seaweed products will continue to gain further acceptance into conventional mainstream crop management programs. If current research is any barometer, the benefits of seaweed extracts and *Ascophyllum* extracts in particular, may be more widespread than anyone realizes and may have far-reaching implications in the agriculture of the new millennium.

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