Increased Value-Added Products from Brassicaceae Oilseed Crops

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Introduction

Brassicaceae crops are among the oldest cultivated crops. Written records of man cultivating Brassicaceae crops date back to 1500 BC, and archaeological evidence of the crops importance date back to 5000 BC. Turnip rape, synonymous with Polish rapeseed, (Brassica rapa) seems to have been the earliest oilseed species cultivated. Over 2000 years ago turnip rape was grown in cultivation from northern Europe to eastern China. Argentine rapeseed (B. napus) developed in the Mediterranean area where the wild diploid forms of its ancestral species co-exist in nature. Cultivation of oilseed B. napus probably started in Europe during the middle ages where its oil was used as a lamp oil.

During World War II, the allied armies and navies were deprived of rapeseed oil, which at that time was produced mainly in Asia, and mostly in China. At that time, rapeseed oil was an essential lubricant because it could cling to water- and steam-washed metal surfaces better than any other oil. Since the naval ships and trains of the time were steam-powered, and with the Asian rapeseed oil supplies cut off, Canada was asked to undertake production of the crop. The spring-planted types of B. napus were introduced first, followed shortly after by the earlier maturing B. rapa spring-types.

It quickly became evident that both these crop species were well adapted to the Canadian climate and required only minor modifications to the existing grain growing and handling system. Reduced price supports following the war and the replacement of steam power by diesel caused the Canadian crop to falter.

From the outset, Canadian researchers realized that rapeseed could be a major source of edible oil for Canada, which until that time was importing almost 90% of its edible oil needs. Nutritionists were interested in rapeseed oil because it differed from other edible vegetable oils in its fatty acid composition. Rapeseed oil contains significant amounts of erucic acid, which is a fatty acid chain of 22 carbon atoms, as opposed to the carbon chain lengths of 16 and 18 carbons found in most vegetable oils. However, feeding studies with laboratory rats in the late 1940s and early 1950s suggested that erucic acid had a detrimental affects on human health and breeding efforts were initiated to reduce erucic acid level in rapeseed oil. Within a short period of time, the first low erucic B. napus variety was released in 1968, and the first B. rapa variety released in 1971. As a result, Canada completely converted its 4 million acres to low erucic varieties within two years, although high glucosinolates content in the seed meal was a major constraint to marketing. High glucosinolate rapeseed meal when fed to pigs and poultry reduced feed efficiency and weight gains. Again breeding efforts resulted in the B. napus cultivar 'Bronowski' with very levels of glucosinolates in the seed meal. The low glucosinolate characteristic was rapidly incorporated into high-yielding varieties. At this time a new name was required to distinguish these genetically different crop cultivars from the old traditional rapeseed cultivars. The name canola was trademarked to define oil from either B. napus or B. rapa having less than 2% erucic acid in the seed oil and less than 30 μmol g-1 of aliphatic glucosinolates in the defatted seed meal.

The world renowned Canadian rapeseed breeder, R.K. Downey said "The Canadian development of the rapeseed/canola crop is frequently referred to as a Cinderella story. The crop has undergone a great metamorphosis in quality and production since it was first grown as an emergency war measure on a few acres in 1942". Indeed, the quality aspects of rapeseed were dramatically altered over a short time period through traditional plant breeding, and as a result the canola industry we know today evolved. Now canola is second only to soy as the most important source of vegetable oil in the world. In 2000–2001, world production of canola (including rapeseed) totaled 33.9 million tones, or 13% of the total oilseed production.

Value-added products from Brassicaceae oilseed crops

Future US agriculture needs to be more sustainable and internationally competitive. It is essential that growers reduce crop inputs and produce more diverse products. Product identity and specialty high value crops and crop products will increase farmer profitability, which will increase sustainability. Increased demand for the added-value products will result in higher crop value, greater rural stability, and expand US home use and export potential.

As noted, Brassicaceae oilseed crops have two saleable harvested products: the seed oil and the seed meal. Traditionally, the oil has been the primary product of value with canola/rapeseed oil prices ranging between $0.30 to $0.35/lb. Low glucosinolate canola or rapeseed meal has potential as livestock feed, but must compete in the feedstock market with soy meal, which is more sought after. As a result canola seed meal sells for between $0.05 to $0.10/lb.

In recent years breeders and other researchers have examined alternative uses for Brassicaceae seed oils and seed meal and breeders have made modifications both to oil fatty acid profile as well as seed meal glucosinolate content and profile in attempts to increase the value of these crops.

Value added modification of edible oil

Many would argue that canola oil offers consumers a high value product with lowest saturated fat content of any vegetable or animal fat and a good balance of essential and non-essential fatty acids. However, recent medical research has proven that hydrogenated fats which contain trans fatty acids have adverse effects on human heath when included in diets. Indeed, the Food and Drug Administration has started the process whereby food labeling will require trans-fats to be listed on all food products.

Traditional canola oil is usually hydrogenated to avoid off-flavors in high temperature frying and to increase shelf life of the oil products. Rancidity and off-flavors in canola oil are caused by high linolenic content (18:3 fatty acid), and hence hydrogenated products made from traditional canola cultivars are relatively high in trans fats. This has lead several breeding groups to develop low linolenic acid content cultivars. Low linolenic acid cultivars produce oils that show higher thermal stability, lower levels of oxidation products, and increased shelf life with minimal hydrogenation. These new canola cultivars offer canola a potential advantage over other vegetable oils, which would increase the demand for canola products. At present only spring-planted low linolenic cultivars are available. However, The University of Idaho of Idaho breeding group has been developing winter canola (B. napus) lines with high concentrations of oleic acid (greater than 75%) and with low linolenic acid (less than 3%) for over 10 years. Advanced breeding lines have been identified with desirable oil quality and quantity and with canola-quality seed meal. These lines are at a suitable developmental stage that they are currently being tested throughout the Pacific Northwest. If available these specialty canola cultivars will offer growers in the Pacific Northwest an advantage over other North American canola produces who do not have the opportunity to grown winter crops.

Until recently canola oil had to be derived from either B. napus or B. rapa cultivars. Two mustard species, Oriental mustard (B. juncea) and yellow mustard (S. alba) have been used as a source of edible (and industrial) oil in some parts of the world. However, both species have evolved in agriculture as condiment spice crops and seed meal glucosinolate content is significantly higher than even the older B. napus or B. rapa rapeseed cultivars making the seed meal completely unsuitable as livestock feed. In addition the seed oil fatty acid composition is suitable neither as edible or industrial class oils. Breeders in Canada and Australia have developed B. juncea lines with canola-quality oil characteristics and with low glucosinolate canola-quality seed meal. Currently in Canada two cultivars are being commercialized ('Arid' and 'Amulet') which produce canola-quality oil and seed meal and the Canadian authorities have approved canola status to such B. juncea cultivars.

Similarly, breeders at the University of Idaho have modified the fatty acid profile of yellow mustard oil to be indistinguishable from canola oil and identified a single gene which blocks the production of all p-hydroxybenzyl glucosinolate in seed meal hence reducing total seed meal glucosinolates to below 20 µmol g-1 of defatted seed meal. As yet no application has been made to the FDA requesting edible oil status for yellow mustard, although one can surmise that application will be made in the future.

Availability of canola-quality Oriental and yellow mustard will greatly expand the potential acreage base of canola in the US. The high insect and disease resistance of yellow mustard is expressed in the canola-quality types and would alleviate the necessity for high input cost of insecticide and fungicide in US canola production.

Added-value modifications of industrial oil

Few commercially available oilseed crops have the potential to produce high concentrations of erucic acid in their seed oil. The notable two being high erucic acid rapeseed (HEAR) and crambe. High erucic acid content gives the oil unique industrial use properties. HEAR oil has a high degree of lubricity compared to other vegetable or animal fats and is remarkably stable at high temperatures. As a result the excellent lubricity of HEAR oils can be seen from their use in the textile, steel and shipping industries as lubricants in spinning, metal molding, rolling fabrication and drilling oils. High fire and smoke points (271o C), enable HEAR oil to withstand high temperatures that lubricating and heat transfer oils are subject to, yet remain fluid at low temperatures. For example, adding a few ounces of HEAR oil per ton of steel, where molten steel (2,500o F) is poured through water-cooled molds, makes an excellent mold lubricant. Finally HEAR oil can be used as lubricant directly or in lubricant formulations.

Similarly, hydrogenated derivatives of erucic acid have unique industrial properties. Erucamide is the best known premium product made from erucic acid. Erucamide is used as in mold release agents, slip-promoters, and antiblock agents for plastic films of polyethylene. Adding erucamide to plastics at low concentrations has two functions; (1) as a lubricant to speed and ease production of plastic parts; and (2) to provide a thin film layer on the plastic surface, preventing the film sheets from adhering together. Recent work has shown that moderate to high erucic acid in feedstock oil, combined with low polyunsaturated fats has potential as a high quality engine oil.

Renewable aspects of biofuel, combined with increased cost of fossil fuel have increased interest in commercial biodiesel units. Biodiesel is the term used to describe transesterified vegetable (or animal oil) that is made by mixing raw oil with alcohol (usually ethanol or methanol) such that the fatty acid chains are cleaved and separated from the glycerol molecule to make a fuel with very similar properties to fossil fuel that can be used in diesel engines without engine modifications.

Biodiesel fuels are more environmentally friendly with nearly half the CO and CO2, the major detrimental greenhouse gases, than fossil fuels. In addition, biodiesel is highly biodegradable and is a safer fuel because it has a lower flash point. The major limitation to greatly increased biodiesel use includes; (1) the cost of the raw oil feedstocks is too high, making the fuel non-competitive with fossil fuel, and (2) the quality of fuel. There are two quality aspects of biodiesel that need to be addressed.

The first quality deficiency of biodiesel relates to gelling at low temperatures, a feature which is directly related to the proportion of saturated fats in the raw oil. Soy oil is relatively high (15%) in saturated fats and soy biodiesel will start to gel at temperatures just below -10o C. HEAR oil contains significantly less saturated (3%) fats and HEAR biodiesel can be used as fuel down to -27o C (8o C higher than fossil diesel). The second quality factor concerns NOx emissions, which are directly related in biodiesel to the concentration of polyunsaturated fats in the feedstock oil. Soy oil has 55-60% polyunsaturated fats and soy biodiesel has 22% higher NOx emissions compared to fossil diesel. HEAR is low in polyunsaturated fats and HEAR biodiesel has significantly lower NOx emissions than soy biodiesel only slightly higher NOx emissions compared to fossil fuel.

Researchers disagreed about the performance of biodiesel from different feedstocks. Many, however, agree that HEAR oil is an excellent fuel feedstock and the longer chain fatty acids add greater lubricity to the fuel. This may become increasingly important as the level of sulfur, which is added to fossil diesel as a lubricant, is significantly reduced over the next few years because of the adverse effects of sulfur emissions on our atmosphere. Biodiesel contains no sulfur, yet a 0.5% mix of biodiesel to fossil diesel provides the same level of lubrication as the sulfur concentrations used in diesel today.

Breeding efforts at the University of Idaho have focused on developing rapeseed and mustard cultivars with very low saturated fats and polyunsaturated fats that are specifically designed to address the quality deficiencies outlined above. The aim is to develop Brassicaceae oil feedstock with less than 2% saturated fats and less than 6% polyunsaturated fats.

Other users of HEAR oil that have been examined include printing inks, paints, biodegradable plastic, surfactants. Although the quality of these products are equal or better than petroleum based alternatives, the cost and consistent availability of HEAR oil has greatly limited large-scale commercialization. This could change if a reliable and cheaper source of HEAR oil were available.

One should always remember that the seed oil makes up only between 25-45% of the total harvestable product. The success of an industry based on only value added oil is likely to be limited unless the seed meal can be modified to have similarly increased value. Indeed the demand for all of the above industrial and edible oils and oil products would increase dramatically with a significant increase in the value of the seed meal.

Value added modification of seed meal as live stock feed

The introduction of low glucosinolate canola cultivars from Canada opened the door for increased use of canola seed meal as a livestock feed. Canola meal is high in protein (>32%). and is usually moderate to low in crude fiber (<12%) which make a suitable live stock feed supplement. However, canola meal has, and will continue, to compete with soy meal which is preferred by many stockmen and has been in surplus in recent years. Thus the price of canola meal is unlikely to significantly increase in the near future. Canola has shown good potential as a feed supplement in dairy units, and with the increasing number of dairy farms in the Pacific Northwest demand for canola meal may increase.

Breeders throughout the world have tried to address the feed value of Brassicaceae seed meal for over

50 years but have made little advancement either in increasing protein content or reducing fiber. The breeding efforts in yellow mustard to develop low glucosinolate canola-quality feed meal may result in a feed with lower fiber as the seed to seedcoat ratio is greater. However, many believe that it will be unlikely that livestock feed value will be sufficient to have a large impact on grower profits.

Value added modification of seed meal as biological soil fumigant

Plant health can be affected by a variety of soil-borne pests and diseases, including; bacteria, fungi, nematodes, insects, and weeds. Effective control of these pests has been achieved by the use of synthetic soil fumigants, some of which are the most dangerous pesticides used in agriculture. Soil fumigants are nonselective pesticides, which are applied before a crop is planted to eliminate pests. Environmental concerns have caused restrictions on registration and use of synthetic fumigants in many countries. This has generated interest in biological control of soil-borne pests.

Some plants produce compounds that directly or indirectly impact their biological environment. These compounds fall within a broad category of compounds called allelochemicals, and influence the growth, health, or behavior of other plant or animal organisms. Using plant-produced allelochemicals in agricultural and horticultural situations could reduce synthetic pesticide use, reduce the associated potential for environmental contamination, and contribute to a more sustainable agricultural system.

Glucosinolate compounds that occur in Brassicaceae crops may represent a viable source of allelochemical control for various soil-borne plant pests. Insecticidal, nematicidal, fungicidal, and phytotoxicty effects have been associated with tissues of Brassicaceae plants. Glucosinolates themselves are not biologically active, but serve as the precursor for the formation of a variety of potential allelochemicals. Much of the past emphasis and available literature has focused on isothiocyanates, apparently the most important of those allelochemicals. Any delivery system designed to take advantage of this chemistry must consider the fact that glucosinolates must be enzymatically hydrolyzed and that multiple pesticidal compounds are possibly produced.

Glucosinolate types in Brassicaceae species are highly variable. For example, the main glucosinolate in yellow mustard (S. alba) is p-hydrozy-benzyl glucosinolate, while Oriental seed (B. juncea) is dominated by allyl glucosinolate, and rapeseed (B. napus) contains 4 major glucosinolates: 2-hydroxy-3-butenyl, 3-butenyl, 4-pentenyl, and 2-hydroxy-4-pentenyl. Different glucosinolate types produce different forms of isothiocyanates which may have greater or lesser allelopathic effect on different soil pests.

The Rapeseed, Canola & Mustard Breeding group have been developing Oriental and yellow mustard suitable for the Pacific Northwest for over 11 years. The group has released an Oriental mustard ('Pacific Gold') and yellow mustard ('IdaGold') cultivars which both have high seed meal glucosinolate content and glucosinolate types which a readily degraded into isothiocyanates. Over the past two years this group has conducted a number of greenhouse and field studies to examine the herbicidal, insecticidal, and phytotoxicity effects of these seed meals when used as a soil amendment.

Herbicidal efficacy of Brassicaceae seed meal

In a greenhouse study, Sunshine® mix potting soil was incorporated with ½- and 1-Mt/ha equivalents of Athena canola (B. napus), IdaGold yellow mustard (S. alba), and Pacific Gold Oriental mustard (B. juncea) seed meals with the potting mix, with a no amendment treatment as control. After adding the seed meal, 20 g of wild oat (Avena fatua), and 2 g each of wild mustard (Brassica nigra), and pigweed (Amaranthus spp.) were mixed with 0.5m2 of compost. After incorporation, seedling flats were arranged on a bench in a randomized complete block design. After three weeks, weed plants were counted for each flat and biomass was measured in grams. This study was repeated three times.

IdaGold seed meal has significantly more herbicidal activity on wild mustard and pigweed compared to the control or the other seed meals examined. Averaged over the three weed species, 1 Mt/ha of IdaGold amended into the soil had less than one third the number of weed emerge compared to the no treatment control (Table 1), while the other treatments were not significantly different from the control. Pacific Gold did have good herbicidal activity on wild oat but not wild mustard or pigweed. Indeed, it was interesting to note that in Pacific Gold treatments the wild oats did not emerge, while in the IdaGold treatment, wild oat emerged and later died after 14 days. Similarly, weed biomass was significantly reduced by incorporation to either IdaGold or Pacific Gold seed meals compared to either the control or Athena meal treatment (Table 2).

In a 2002 field study, two strawberry cultivars, 'Fort Laramie' and 'Rainier' were planted into field plots with different soil amendment treatments. Soil amendment treatments were as follows: 2-Mt/ha equivalent rates of Athena, IdaGold, or Pacific Gold seed meal incorporated into the soil, a weed-free control that was hand weeded, and a control where weeds were allowed to grow freely. Each plot consisted of 12 strawberry plants transplanted by hand 14 days after meal incorporation, on a 30 cm spacing x 2 rows 80 cm apart. The experimental design was a split- plot with treatments assigned as main-plots and strawberry cultivars as sub-plots. In 2003 the study was repeated. However in this year strawberry transplanting was carried out 14 days after the seed meal was incorporation and also on the same day as incorporation.

In strawberry field trials in 2002, IdaGold provided significantly better weed control than other treatments and was not significantly different from the weed-free plots (Table 3). Weed populations were markedly reduced in the second year crop where the strawberry plants were fully established and competed better with weeds. All meal treatments caused high phytotoxicity on first year strawberry transplants, although the plants recovered quickly and no transplants died in any treatment. Despite initial damage, both mustard meal treatments produced significant yield increases over the no treatment control. Transplanting strawberry plants at the time of seed meal amendment caused significantly greater phytotoxicity and yield reduction in the Athena and Pacific Gold treatments compared to delayed transplanting 14 days after meal incorporation (Table 4). As in the previous year, damage symptoms only lasted a short time. In 2003, all meal treatments produced strawberry yields equal or better than the no weed control. When transplanting was carried out the same day as meal incorporation, IdaGold treatment produced significantly high yield than the other treatments and was not significantly lower than when transplanting was delayed 14 days.

Overall, IdaGold and Pacific Gold both showed high potential as an alternative bio-herbicide in strawberry production. Further field testing will be required to determine rates and timing of incorporation for maximum effect and productivity.

Black vine weevil control of Brassicaceae seed meal

Black vine weevil (Otiorhynchus sulcatus (F.)) larvae cause significant root damage and have major economical impact in the US horticultural industry. In container situations, chemical control, though costly, can be effective. Furthermore, there are no effective pesticides or pest management strategies available for controlling black vine weevil larvae in field or nursery landscape situations.

Black vine weevil adults were collected from hops yards and maintained in a laboratory colony. After adult weevils began oviposition, eggs were collected. One hundred pots, each containing one rhododendron plant were established outdoors prior to inoculation. Pots were brought into the lab and infested with 100 eggs and 50 emerging larvae. Pots remained in the lab under artificial light to help establish and normalize inoculation placement before being returned to the outdoor bed. After 50 days pots were treated with either Pacific Gold or Idagold seed meal. Each meal treatment was prepared as 3, 6 and 12% of the potting media and a no meal control. After a further 50 days the larvae were separated from the soil and rooting systems by aide of a light water stream, pressure, soaking, filtration, and manual inspection. All larvae recovered were counted, whether they were alive or dead.

Further experiments were initiated to evaluate the effect of volatiles produced by Pacific Gold meal on the survival of black vine weevil eggs. Twenty eggs were placed inside small dishes inside Petri dishes and sealed with Pacific Gold meal ranging from 0.0025 to 0.05 g. The meal was contained within a small plastic dish and had 2.5 ml of deionized water added just prior to sealing each glass dish. The numbers of emerged larvae were counted after 8 days.

Pacific Gold meal amendment caused 100% mortality of black vine weevil larvae in pots even at the lowest incorporation rate. Similar concentrations of IdaGold meal had no effect on weevil mortality. One hundred percent mortality was obtained with incorporating 200x10-4 g into soil in a 10x10x10 cm pot (Figure 1). In conclusion, Pacific Gold seed meal has very high potential as a bio-pesticide to be used in controlling black vine weevil larvae in horticultural tree production although phytotoxicity effects need to be considered.

Phytotoxicity effects of Brassicaceae seed meal on horticultural trees

Cedar, cherry, dogwood and fir trees were chosen for glasshouse phytotoxicity testing of Athena (B. napus), Pacific Gold, and IdaGold seed meal mulches. Seedling trees were established in 1 liter pots for four weeks and tree height and caliper measured prior to treatment. One Mt/ha equivalent rates of seed meal was applied to the compost surface and incorporated by watering. After two months, final plant heights and caliper measurements were collected to determine plant growth.

Phytotoxicity studies on rhododendron and yew were carried out under field conditions using round microcosms 1m in diameter and 2m deep with inverted soils to simulate situations that exist in new urban landscapes. In early June 2003, one-year-old yew and rhododendron plants were transplanted into each microcosm and irrigated with above ground sprinklers. Three mulch treatments were applied: a no mulch control, 5 cm mulch with traditional bark, and 5 cm mulch with a 90:10 mix of traditional bark with Pacific Gold seed meal. Plant height and diameter were recorded after applying the mulch treatments 4 days after transplanting. The complete design was an eight replicate randomized complete block. Plant height and diameter measurements were repeated after eight weeks of growth.

Glasshouse studies of phytotoxicity on nursery trees showed varying results (Table 5). IdaGold meal showed phytotoxicity on cedar growth while Pacific Gold proved toxic to dogwood tree growth. With cherry and fir, Pacific Gold treatments resulted in higher growth compared to the control. Athena meal treatments generally resulted in better tree growth. Under field conditions, phytotoxicity of Pacific Gold meal resulted in decreased plant height in both rhododendron and yew plants, and significant reduction in rhododendron plant diameter compared to pure bark mulching (Table 6).

Conclusion

Seed oil and meal properties of Brassicaceae crops are relatively easy to modify, offering the potential of increased value to future crops. Highest crop value and profitability will be achieved with higher value to both oil and seed meal. Industrial Brassicaceae oils offer unique opportunities in developing a range of lubricants, surfactants, printing inks, and biofuel, which have yet to be realized. The true potential of these products could be realized if the seed meal were used as a biofumigant in intensive agricultural and horticultural situations. In these cases the seed meal would be the highest value and the oil would be a by-product, resulting is high volume, low cost oil to industrial and fuel needs. It should, however, be noted that specific oil types will be required for many industrial and fuel uses. Overall, 'designer' oil and seed meals will offer greater value –added potential to Pacific Northwest Brassicaceae crops.

Acknoledgements

I would like to thanks Dr. J.P. McCaffrey for allowing me to present some of his work on black vine weevil mortality. Thanks also to Monty Hamilton and Clayton Seamons who are graduate students working on the effects of Brassicaceae seed meal on pests and plant phytotoxicity.

Table 1. Number of wild mustard, wild oat and pig weed seeding emerged after soil was amended with 0.5t/acre and 1t/acre of Athena, IdaGold, or Pacific Gold seed meal and a no treatment control.

Treatment	Rate	Wild Mustard	Wild Oat	Pig Weed	Total
	- t/a -	Plants/m^2			
Control	-	47^{ab}	71^{a}	219^{ab}	269^{ab}
Athena	0.5	54^{a}	51^{b}	289^{a}	304^{a}
	1.0	26^{bc}	48^{bc}	224^{ab}	229^{ab}
Pacific Gold	0.5	47^{ab}	41^{cd}	261^{a}	270^{ab}
	1.0	55^{a}	21^{c}	184^{ab}	203^{ab}
IdaGold	0.5	14^{c}	46^{bc}	132^{b}	153^{c}
	1.0	7^{c}	34^{d}	60^{c}	87^{c}

Values within columns with different superscript letter are significantly different ($P<0.05$).

Table 2. Biomass of wild mustard, wild oat, and pig weed seeding emerged after soil was amended with 0.5t/acre and 1t/acre of Athena, IdaGold, or Pacific Gold seed meal and a no treatment control.

Treatment	Rate	Wild Mustard	Wild Oat	Pig Weed	Total
	- t/a -	g/m^2			
Control	-	161^{a}	41^{ab}	106^{ab}	202^{a}
Athena	0.5	136^{a}	47^{a}	77^{b}	183^{ab}
	1.0	124^{a}	47^{a}	78^{b}	171^{ab}
Pacific Gold	0.5	99^{ab}	13^{c}	161^{a}	113^{c}
	1.0	72^{bc}	4^{d}	141^{a}	77^{d}
IdaGold	0.5	136^{ab}	31^{b}	22^{c}	166^{b}
	1.0	58^{c}	13^{c}	18^{c}	72^{d}

Values within columns with different superscript letter are significantly different ($P<0.05$).

Table 3. Strawberry phytotoxicty, number of weeds observed and crop yield after soil was amended with 1t/acre Athena, Pacific Gold and IdaGold seed meal, along with a no weed control and a weed free treatment from field studies carried out on first year crop 2002 where strawberry plants were transplanted 14d after meal treatment, and second year crop (2003) where established plants were side-dressed with meal treatments.

Treatment	Year 1 crop - 2003			Year 2 crop – 2003		
	Plant Damage	Weed plants	Crop Yield	Plant Damage	Weed plants	Crop Yield
	- 1 to 9 -	-Ct/m^2-	-Mt/ha-	- 1 to 9 -	-Ct/m^2-	-Mt/ha-
Weedy control	2.7^{b}	112^{a}	5.2^{c}	3.2^{b}	11^{a}	47.9^{b}
Athena	2.7^{b}	25^{b}	9.9^{bc}	2.7^{b}	4^{b}	55.2^{a}
Pacific Gold	5.8^{a}	16^{c}	11.4^{b}	5.0^{a}	1^{c}	55.9^{a}
IdaGold	7.2^{a}	1^{d}	12.7^{ab}	3.0^{b}	0^{c}	47.6^{b}
Control	2.5^{b}	0^{d}	18.9^{a}	1.7^{b}	0^{c}	47.9^{b}

Values within columns with different superscript letter are significantly different ($P<0.05$).

Table 4. Strawberry phytotoxicty, number of weeds observed and crop yield after soil was amended with 1t/acre Athena, Pacific Gold and IdaGold seed meal, along with a no weed control and a weed free treatment from field studies carried out on first year crop where strawberry plants were transplanted 14d after meal treatment, and where strawberry plants were transplanted 14d after meal treatment.

Treatment	Transplant 14d after meal			Transplant 0d after meal		
	Plant Damage	Weed plants	Crop Yield	Plant Damage	Weed plants	Crop Yield
	- 1 to 9 -	-Ct/m^2-	-Mt/ha-	- 1 to 9 -	-Ct/m^2-	-Mt/ha-
Weedy control	2.5^{b}	15.5^{a}	13.4^{c}	3.2^{b}	12.5^{a}	9.7^{c}
Athena	3.7^{b}	6.0^{b}	23.3^{a}	5.5^{a}	1.0^{b}	12.1^{b}
Pacific Gold	5.8^{a}	11.5^{a}	18.1^{b}	5.8^{a}	0.5^{bc}	12.5^{b}
IdaGold	6.7^{a}	0.5^{c}	22.9^{a}	6.0^{a}	0^{c}	21.3^{a}
Control	2.1^{b}	0^{c}	18.7^{b}	2.2^{b}	0^{c}	13.1^{b}

Values within columns with different superscript letter are significantly different ($P<0.05$).

Table 5. Phytotoxicity effects of Athena, Pacific Gold and IdaGold seed meal, and a no treatment control, on cedar, cherry, dog wood and fir growth (plant height increase).

Treatment	Cedar	Cherry	Dog Wood	Fir
	cm			
Control	49^{a}	35^{b}	172^{b}	21
Athena	46^{ab}	44^{a}	182^{a}	20
Pacific Gold	51^{a}	44^{a}	165^{c}	23
IdaGold	40^{b}	36^{b}	189^{a}	22

Values within columns with different superscript letter are significantly different (P<0.05).

Table 6. Phytotoxicity effects of standard bark mulch, 90:10 bark:Pacific Gold meal mulch, and a no treatment control, increase of Rhododendron and Yew plant height and width increase.

Treatment	Rhododendron	Yew		
	Height	Diameter	Height	Diameter
	cm			
Control	34^{a}	39^{a}	37^{a}	21
Standard Bark	34^{a}	40^{a}	36^{a}	20
Bark & P. Gold	29^{b}	35^{b}	32^{b}	22

Values within columns with different superscript letter are significantly different (P<0.05).

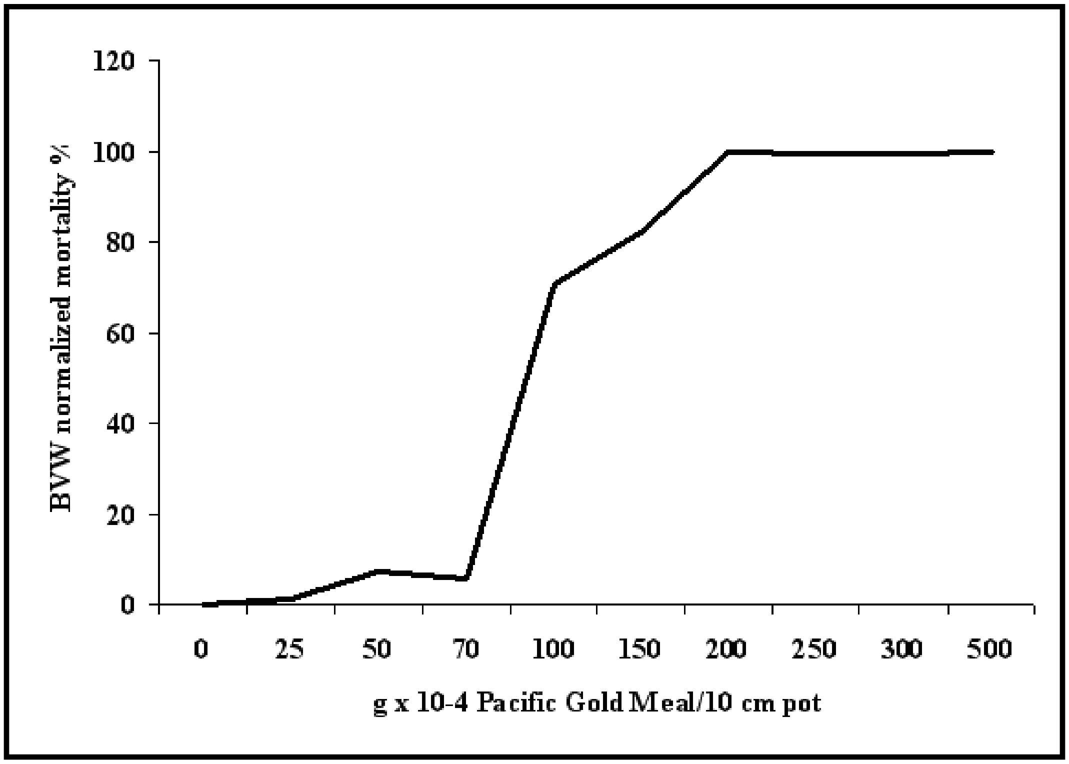

Figure 1. Mortality of Black Vine Weevil after treatment with increasing concentrations of Pacific Gold (B. juncea) seed meal.