RESEARCH ARTICLE

Composition of a low erucic acid, low fiber field pennycress (*Thlaspi arvense* L) grain referred to as CoverCress™ developed through breeding and gene editing

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Field pennycress (*Thlaspi arvense* L.) can be domesticated and cultivated as an annual in a corn/pennycress/soybean rotation where pennycress is sown and harvested as a cash cover crop. To improve the nutritional profile, pennycress was modified in two ways to achieve the same alterations in characteristics: 1) through selection of mutants and 2) through gene editing. These alterations resulted in a low erucic acid, lower fiber phenotype and the resulting products from these combinations are referred to as CoverCress CCWG-1 and CoverCress CCWG-2, respectively. CCWG-1 and CCWG-2 were planted as cover crops in five U.S. locations in the fall and the grain was harvested in the subsequent June. The grain was treated with 83.3 mM copper sulfate solution as a potential palatability agent for the naturally high glucosinolate levels, and was subsequently analyzed for nutrient (proximates, minerals, fatty acids, amino acids, and vitamins) and anti-nutrient (sinapine, glucosinolates, mold) content. The low erucic acid, lower fiber phenotype was consistently achieved across five lots. Generally, the nutrient content for both CCWG-1 and CCWG-2 were similar to canola grain. Canola grain contains the anti-nutrient sinapine but is significantly reduced to below the level of detection in CoverCress grain. As expected, CoverCress grain contains about 10 times more glucosinolates than canola. Based on the composition of CoverCress grain, it may provide a source of energy and amino acids to animals with restricted inclusion based on the glucosinolate content.

Key Words: *Pennycress; CoverCress; Low-erucic acid; Cover crop; Gene editing*

INTRODUCTION

Field pennycress (*Thlaspi arvense* L.) is an annual weed that grows over the winter in Eurasia and North America. It is a member of the Brassicacae family, commonly known as the mustard family. Field pennycress contains high levels of oil (~25-30%) that makes it a desirable ultra-low carbon fuel feedstock. The potential commercial value of field pennycress production has been researched extensively in a variety of leading laboratories including the National Center for Agricultural Innovation, USDA ARS, Peoria, IL, Western Illinois University, Illinois State University and the University of Minnesota. The cumulative literature and experience establish that field pennycress can be domesticated and cultivated as a winter annual in a corn/pennycress/soybean rotation where pennycress is sown and harvested as a cash cover crop as reported by Phippen and Phippen [1] and Sedbrook et al., [2].

In addition to this primary value for fuel, the seed could provide an energy source for animal feeds such as chicken feed, however, the oil typically contains >35% erucic acid. Erucic acid is a 22-carbon monounsaturated acid that is absorbed, distributed and metabolized like other fatty acids involving primarily metabolism via mitochondrial beta-oxidation and, to a lesser extent, peroxisomal beta-oxidation. Like other longer-chain fatty acids, the rate of mitochondrial beta oxidation is comparatively lower for erucic acid; however, elevated erucic acid levels induce liver peroxisomal oxidation pathways as a mechanism of compensation. Interest in the safety of erucic acid occurred when results of studies in rats associated the dietary intake of high doses of erucic acid with myocardial lipidosis and heart lesions [3]. Oilseed rape conventionally contains similarly high levels of erucic acid. Low erucic acid varieties were identified and marketed as canola, which have been shown to be safe to broiler chickens when incorporated in diets up to 25% inclusion. Reduction in erucic acid is achieved through disruption of Fatty Acid Elongation 1 (FAE1), resulting in higher levels of oleic (18:1). It is through this same mechanism that erucic acid levels have been lowered in pennycress [4].

Field pennycress is also high in fiber, which can impact digestibility as a feed ingredient. The production of seed coat fiber was first characterized in the model plant Arabidopsis. Arabidopsis seed coats derive their brown color from the accumulation of Proanthocyanidins (PAs), a class of flavonoid chemicals (polymerized flavan-3-ols, or condensed tannins) that protect against a variety of biotic and abiotic stresses and help maintain seed dormancy and viability [5]. PAs start out as colorless epicatechin compounds until they are transported to the vacuole where they are polymerized and oxidized as the seed desiccates. In Arabidopsis, PAs are only produced in a narrowly defined cell layer in the endothelium of the seed, and the genes TTG1, TT8/bHLH042, and TT2/MYB123 have been demonstrated as being the three main regulators of PA biosynthesis in seed coat [6,7]. Gonzalez et al. [8] described how the TTG1 works in a complex with a particular combination of MYB class and bHLH class transcription factors to regulate epidermal development of the seed coat. Loss-of-function mutants in these genes exhibit the transparent "testa" phenotype as a result of low levels of oxidized PAs in the seed coat. Similarly, the transparent testa phenotype was observed with loss-of-function mutations in orthologs of these genes in pennycress [9], resulting in reduced fiber content. This phenomenon has been observed in other brassicas such as canola and is characterized by yellow seeds that have more oil because of the resulting thinner seed coat and larger embryo [10].

Meal from these brassicas has also been shown to be useful in animal feed because of the relatively lower fiber and higher metabolizable energy [11,12]. Reduction of erucic acid and fiber levels in pennycress has been achieved through conventional breeding and gene editing for loss of function in the associated gene pathways. A low-erucic acid, lower-fiber pennycress is being

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developed under the trade name of CoverCress™. CoverCress1 represents a clear opportunity for sustainable optimization of certain agricultural systems. It serves as an important winter cover, working within the no/low-till cropping systems to prevent soil erosion from fallow fields and improve soil nitrogen management. As part of the safety assessment of this new grain for animal feed, a comprehensive compositional study was conducted on both the mutant breeding line and gene edited lines.

MATERIALS AND METHODS

CoverCress line development

Two studies were conducted to assess the composition of CoverCress grain. The first study utilized grain from a low-erucic acid, lower-fiber variety of CoverCress developed through breeding by identification of mutants. One parent line, referred to as MN106-V300, was developed via Ethyl Methane Sulfonate (EMS) mutation breeding. This line contains a mutation to the FAE1 gene (specifically, a cytosine to thymine change at base position 1018bp), resulting in a premature stop codon and complete loss of function of the gene, causing a reduction in erucic acid level [13]. The second parent line, referred to as Y1126, was isolated from a cultivated field in Grantfork IL and was identified as a lower-fiber phenotype with a yellow seed coat. This line contains a naturally-occurring deletion of 21bp in the Transparent Testa Glabra 1 (TTG1) gene. This mutation results in a deletion of 7 amino acids in the conserved area of TTG1 protein, leading to a complete loss of function. The MN106-V300 and Y1126 lines were crossed in the fall, and F2 plants carrying homozygous mutant alleles for these genes were further propagated in bulk, first in local greenhouses in the spring and then in the field in an 0.3-acre increase planted at Sigel, IL in the subsequent fall. Seeds from this increase were harvested in bulk in the spring, and this seed formed the foundation source. It should be noted that this source is segregating for all background genetics that differ between Y1126 and MN106-V300 and fixed only for FAE1 and TTG1. This line is referred to as CoverCress Whole Grain (CCWG-1).

The second study used a line that was generated through application of gene editing techniques resulting in lines of low-erucic acid, lower-fiber pennycress and is referred to as CCWG-2. To generate this line, mutations were introduced into a pennycress cultivar using a CRISPR/SpCas9 DNA construct designed to target genomic edits to the FAE1 and TT8 genes.

This transgene construct was delivered to a pennycress cultivar using a disarmed Agrobacterium tumefaciens strain (GV3101) and a standard floral dip transformation method. Presence of the edits in T1 plants was confirmed through multiple methods including confirmatory PCR screening of a fragment of the T-DNA. Seed from the progeny T2 generation was screened for segregants that did not have the transgene.

Resulting progeny in the T3 generation were screened again for negative presence of DsRED and Cas as well as homozygous edits to TT8 and FAE1. The resulting edited plants contain small indels in both the FAE1 and TT8 genes that lead to loss of function due to premature stop codons. The edited plants produced yellow seed (a marker for low fiber) and low accumulation of erucic acid in seeds and were taken forward for subsequent characterization and seed bulk up.

Grain production

Two studies were conducted to measure the nutrient and antinutrient content of CoverCress grain. In Study A, CCWG-1 was grown in five locations (Venedy, IL; Sigel, IL; Havana, IL; and two locations in Mt. Pulaski, IL). In Study B, CCWG-2 was grown in five locations (Havana, IL; Arenzville, IL; Mt. Pulaski, IL: and two locations in Martinsville, IL).

Treatment of grain with copper sulfate

Native pennycress and CoverCress grain contain high levels of glucosinolates in the form of aliphatic sinigrin (approximately 35-110 µ moles/g meal). Glucosinolates are considered an antinutrient and can prevent the absorption of iodine and may affect thyroid function in target species [14]. Glucosinolates can also impart a bitter flavor which may affect feed consumption [15]. Copper sulfate treatment has been suggested to overcome the deleterious effects of glucosinolates for other high glucosinolate grains [14,16,17]. It was theorized that copper may reduce or mask the bitter taste of glucosinolates, improving palatability. Therefore, both the CCWG-1 and CCWG-2 grains were pre-treated with copper sulfate prior to characterization of the grain composition and use in subsequent broiler feeding studies.

Three hundred grams of CCWG-1 grain from each of the five locations was blended with 45 ml of 83.3 mM copper sulfate pentahydrate solution and referred to as CCWG-1-$CuSO_4$. Four hundred and sixty grams of CCWG-2 grain from each of the five locations were blended with 60 ml of 83.3 mM copper sulfate pentahydrate solution and referred to as CCWG-2-$CuSO_4$. Samples were stored at 2 to 8°C.

Methods of analysis

The five lots of CCWG-1-$CuSO_4$ and CCWG-2-$CuSO_4$ were analyzed in duplicate by EPL Bio Analytical Services (Niantic, IL) following Good Laboratory Practices (GLP) and by Dairyland Laboratories (Arcadia, WI) a commercial laboratory that uses methods on the latest research findings and technical methodologies available to the feed industry. Dairyland Laboratories (DLL) participates in the National Forage Testing Association, North American Proficiency Testing Program (NAPT), and American Association of Feed Control Officials (AAFCO) [18] Proficiency Testing Program. These programs help laboratories generate accurate and precise analyses.

The list of analytes and the respective Standard Operating Procedure (SOP) used by each lab are shown in Table 1. The details of the specific analytical methodology used can be obtained from the respective laboratories (Table 1).

Data handling

The data for each study consisted of five samples each from one of five locations grown in Illinois with duplicate values for each sample. The duplicates were averaged to give one value for each of the five samples. For the data generated by EPL, Statistical Consultants Plus, LLC (Fenton, MO) calculated measures of data dispersion (variability/standard deviation and data ranges) and measures of central tendency (mean and median) for each analyte using the analytical data from the five test substances each representing five different field locations using SAS [19], *version* 9.4. For the data generated by Dairyland Laboratories, Hartnell International Consulting LLC (St.Peters, MO) calculated measures of data dispersion (variability/standard deviation and data ranges) and measures of central tendency (mean and median) for each analyte. Measures were calculated using Microsoft Excel.

RESULTS AND DISCUSSION

Study A–CCWG-1-$CuSO_4$

Proximates: Table 2 contains the results of proximate analyses. In general, data were in agreement between laboratories except for Acid Detergent Fiber (ADF), Neutral Detergent Fiber (NDF) and crude fat. The two labs used different fat extraction methods. Methodology was also different for the analysis of ADF and NDF, however, in both cases the ADF and NDF analyses were conducted on the residue after fat extraction. It is postulated that Dairyland Laboratories's method extracted more fat from the product than EPL's method and that EPL's assessment of ADF and NDF may be higher because of residual fat, which inflated the ADF and NDF values. In addition, there was greater variation noted with EPL's fat values than with Dairyland Labs. The Fiber Best Practices Working Group under AAFCO's Laboratory and Services Committee provides a detailed discussion on the critical factors in determining fiber in feed and forages [18]. As expected, mean moisture levels were 15.6-17.1% because of the addition of the copper sulfate solution to the CoverCress grain. Mean and median values are similar for all parameters, indicating that the values from the five lots are evenly distributed, i.e. the data are symmetrical in distribution (Table 2).

Amino acid analysis: Table 3 contains the amino acid profile of CCWG-1-$CuSO_4$ when expressed on a 100% dry matter basis and Table 4 contains the amino acid profile of CCWG-1-$CuSO_4$ when expressed on a % of total protein basis. The amino acid values from the five lots showed a symmetrical distribution with the means and median values being similar. EPL consistently had lower variability (smaller standard deviations) than Dairyland Laboratories. Dairyland reported numerically higher values for most amino acids whether expressed as a percent of dry matter or as a percent of protein. Dairyland had a higher percentage of total amino acids when expressed as total amino acids as a percent of crude protein (97% *vs.* 89.4%) (Tables 3 and 4).

Table 1

List of analytes measured by EPL Bio Analytical Services (EPL) and Dairyland Laboratories (DLL) and Standard Operating Procedures (SOP)

Analyte	EPL SOP	Dairyland laboratories SOP
Moisture/Dry matter	GSOP-NC-4	DLARC.SOP.FEED.WCFEED.Lab Dry matter 105 3hr.001
Crude protein	GSOP-NC-20	DLARC.SOP.FEED.WCFEED.Leco528.008
Ash	GSOP-NC-2	DLARC.SOP.FEED.WCFEED.Ash.003
Crude fiber	GSOP-NC-5	DLARC.SOP.FEED.WCFEED.Crude fiber.006
Acid Detergent Fiber (ADF)	GSOP-NC-3	DLARC.SOP.FEED.WCFEED.Sequential NDF/ADF/Lignin analysis.000
Neutral Detergent Fiber (NDF)	GSOP-NC-9	DLARC.SOP.FEED.WCFEED.Sequential NDF/ADF/Lignin analysis.000
Total Dietary Fiber (TDF)	GSOP-NC-359	Not measured
Crude fat (Acid hydrolysis)	GSOP-NC-141	DLARC.SOP.FEED.WCFEED.AH Fat.002
Minerals (Ca, P, Mg, K, Na, S, Cu, Mn, Fe, Zn)	GSOP-NC-60	DLARC.SOP.FEED.WCFEED.ICP analysis.006
Chloride	GSOP-NC-328	DLARC.SOP.FEED.WCFEED.Salt.006
Carbohydrates	GSOP-NC-494	Not measured
Cysteine and Methionine	GSOP-NC-279	DLARC.SOP.FEED.WCFEED.Cysteine and Methionine.000
Tryptophan	GSOP-NC-22	DLARC.SOP.FEED.WCFEED.Tryptophan analysis.001
15 Amino acids	GSOP-NC-58	DLARC.SOP.FEED.WCFEED. Amino acid analysis.000
Fatty acids	GSOP-NC-319	DLARC.SOP.FEED.WCFEED.Fatty acid analysis.004
Vitamin B1 (Thiamine)	GSOP-NC-262	Not measured
Vitamin B2 (Riboflavin)	GSOP-NC-46	Not measured
Vitamin B6 (Pyridoxine)	GSOP-NC-220	Not measured
Folic acid	GSOP-NC-26	Not measured
Niacin	GSOP-NC-28	Not measured
Tocopherols (Alpha, beta, gamma, delta)	GSOP-NC-341	Not measured
Fumonisins (B1, B2, B3)	GSOP-NC-336	Not measured
Aflatoxin (B1, B2, G1, G2), T-2 Toxin, Ochratoxin-A	GSOP-NC-337	Not measured
Deoxynivalenol, 3/15-acetyl-deoxynivalenol, Zearalenone	GSOP-NC-338	Not measured
Ergosine, Ergotamine,Ergoocornine, Ergocryptine,Ergocristine	GSOP-NC-456	Not measured
Sinapine	GSOP-NC-208	Not measured
Sinigrin	GSOP-NC-650	Not measured

Table 2

CCWG-1-$CuSO_4$ proximates (100% dry matter basis)

	Analytical			Standard		Range	
Lab1	Variable	Units	Mean	Deviation	Median	Minimum	Maximum
EPL	Moisture	%	17.1	0.23	17	16.9	17.4
DLL	Moisture	%	15.6	0.34	15.5	15.1	16.1
EPL	Dry matter	%	82.9	0.23	83.1	82.7	83.1
DLL	Dry matter	%	84.4	0.34	84.5	83.9	84.9
EPL	Crude fiber	%	23.1	1.28	22.8	21.5	25
DLL	Crude fiber	%	23	1.72	22.7	20.9	24.9
EPL	Acid detergent fiber	%	30.1	1.54	29.9	28	32.1
DLL	Acid detergent fiber	%	13.9	1.58	13.5	12.1	15.8
EPL	Neutral detergent fiber	%	29.5	1.55	29.2	27.7	32
DLL	Neutral detergent fiber	%	20.3	2.76	19.3	17.3	24.5
EPL	Total dietary fiber	%	30	0.97	29.8	28.9	31.5
EPL	Crude protein	%	25.1	1.53	25.5	22.6	26.7
DLL	Crude protein	%	25.5	1.63	25.6	22.7	26.7
EPL	Crude fat	%	32.7	1.26	33.1	30.6	33.7
DLL	Crude fat	%	36.3	0.52	36.5	35.5	36.7
EPL	Carbohydrates	%	36.9	1.61	36.9	34.6	38.5
EPL	Ash	%	5.3	0.39	5.5	4.9	5.7
DLL	Ash	%	5.8	0.4	5.9	5.3	6.2

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories.

Table 3
CCWG-1-$CuSO_4$ Amino Acids (100% dry matter basis)

Analytical				Standard		Range	
Lab1	Variable	Units	Mean	Deviation	Median	Minimum	Maximum
EPL	Alanine	%	1.18	0.074	1.18	1.08	1.28
DLL	Alanine	%	1.2	0.107	1.2	1.09	1.38
EPL	Arginine	%	1.53	0.071	1.55	1.42	1.6
DLL	Arginine	%	1.82	0.159	1.86	1.58	1.98
EPL	Aspartic acid	%	2.03	0.245	1.99	1.74	2.42
DLL	Aspartic acid	%	2.34	0.335	2.3	2.01	2.89
EPL	Cystine	%	0.41	0.053	0.44	0.32	0.45
DLL	Cysteine	%	0.41	0.058	0.42	0.31	0.47
EPL	Glutamic acid	%	3.79	0.289	3.82	3.34	4.13
DLL	Glutamic acid	%	4.16	0.407	4.19	3.65	4.77
EPL	Glycine	%	1.56	0.087	1.57	1.42	1.66
DLL	Glycine	%	1.69	0.159	1.68	1.52	1.95
EPL	Histidine	%	0.69	0.026	0.7	0.64	0.71
DLL	Histidine	%	0.59	0.058	0.59	0.51	0.65
EPL	Isoleucine	%	1.01	0.05	1.03	0.94	1.07
DLL	Isoleucine	%	0.93	0.111	0.92	0.77	1.08
EPL	Leucine	%	1.72	0.125	1.71	1.54	1.89
DLL	Leucine	%	1.91	0.22	1.9	1.65	2.26
EPL	Lysine	%	1.28	0.05	1.29	1.2	1.33
DLL	Lysine	%	1.4	0.077	1.43	1.29	1.48
EPL	Methionine	%	0.41	0.026	0.42	0.36	0.43
DLL	Methionine	%	0.48	0.047	0.47	0.42	0.53
EPL	Phenylalanine	%	1.13	0.06	1.15	1.03	1.18
DLL	Phenylalanine	%	1.2	0.135	1.2	0.99	1.36
EPL	Proline	%	1.25	0.06	1.27	1.17	1.32
DLL	Proline	%	1.38	0.079	1.2	1.27	1.48
EPL	Serine	%	1.01	0.072	1.02	0.92	1.12
DLL	Serine	%	1.13	0.116	1.12	1.03	1.32
EPL	Threonine	%	1.14	0.053	1.15	1.06	1.21
DLL	Threonine	%	1.25	0.106	1.25	1.14	1.42
EPL	Tryptophan	%	0.35	0.011	0.35	0.34	0.37
DLL	Tryptophan	%	0.52	0.035	0.52	0.48	0.57
EPL	Tyrosine	%	0.64	0.026	0.63	0.61	0.67
DLL	Tyrosine	%	0.88	0.102	0.86	0.74	1.02
EPL	Valine	%	1.3	0.063	1.32	1.21	1.37
DLL	Valine	%	1.45	0.148	1.47	1.24	1.65

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories.

Fatty acid characterization: Tables 5 and 6 contain the fatty acid profile of CCWG-1-$CuSO_4$ when expressed on a 100% dry matter basis and percent of total fatty acids, respectively. In general, there was good agreement between laboratories. The fatty acid values from the five lots showed a symmetrical distribution with the means and median values being similar. The major fatty acids are oleic (40% of the fatty acids) followed by linoleic (34.5% of the fatty acids) and linolenic (~18% of fatty acids). These three fatty acids comprise over 90% of the fatty acids in CCWG-1-$CuSO_4$. No long chain polyunsaturated long chain fatty acids such as EPA and DHA were detected. Results confirm that CCWG-1-$CuSO_4$ contains negligible levels of erucic acid. Dairyland Laboratories did not detect it and EPL reported erucic acid to be less than 0.1% of the total fatty acids (Table 5 and 6).

Glucosinolate characterization and quantification: The sole glucosinolate, sinigrin, averaged 85.7 and 86.9 µmoles/g of CCWG-1-$CuSO_4$ for the two detection methods (Table 7). The median value was higher than the mean due to one lot containing almost half the amount of sinigrin as the other four lots. This is reflected by the low minimum value as compared to the maximum value. The much lower sinigrin level in the one lot may have resulted from the soil conditions at that site.

Minerals and vitamins: Table 8 contains the results of the mineral analyses. EPL reported consistently higher mineral levels than Dairyland Laboratories, with the exception of zinc. The discrepancy between labs is unexplained. Generally, the values for the five lots had symmetric distribution. One location had a sulfur level that was 50% of the others. This lower sulfur value corresponds to the lower glucosinolate level of the sample from the same location. Glucosinolates are secondary sulfur compounds commonly found in brassica species [20], which suggests there is a plausible relationship between both values being lower at this site. The reason for the lower level at one location as compared to the other four locations is not clear but may have been a result of the soil fertilization. As expected, mean copper values were approximately 800 ppm because of the addition of copper sulfate. The analytical results confirm that the target level of 800 ppm copper was achieved (Table 8).

Table 4

CCWG-1-$CuSO_4$ Amino acids (% of protein basis)

Analytical				Standard		Range	
Lab1	Variable	Units	Mean	Deviation	Median	Minimum	Maximum
EPL	Alanine	%	4.7	0.082	4.75	4.59	4.78
DLL	Alanine	%	4.73	0.251	4.68	4.46	5.11
EPL	Arginine	%	6.11	0.232	6.21	5.71	6.26
DLL	Arginine	%	7.12	0.241	7.22	6.79	7.36
EPL	Aspartic acid	%	8.09	0.561	7.82	7.68	9.06
DLL	Aspartic acid	%	9.15	0.914	8.89	8.38	10.73
EPL	Cystine	%	1.65	0.245	1.75	1.21	1.78
DLL	Cysteine	%	1.6	0.268	1.65	1.16	1.83
EPL	Glutamic acid	%	15.1	0.292	15	14.75	15.45
DLL	Glutamic acid	%	16.32	0.822	16.11	15.5	17.69
EPL	Glycine	%	6.2	0.062	6.21	6.13	6.29
DLL	Glycine	%	6.63	0.366	6.56	6.27	7.22
EPL	Histidine	%	2.75	0.113	2.78	2.56	2.86
DLL	Histidine	%	2.32	0.122	2.3	2.16	2.48
EPL	Isoleucine	%	4.03	0.077	4.02	3.93	4.14
DLL	Isoleucine	%	3.62	0.233	3.57	3.4	4.02
EPL	Leucine	%	6.84	0.149	6.82	6.72	7.08
DLL	Leucine	%	7.47	0.512	7.29	7.08	8.37
EPL	Lysine	%	5.1	0.171	5.07	4.85	5.28
DLL	Lysine	%	5.51	0.139	5.5	5.3	5.68
EPL	Methionine	%	1.62	0.014	1.62	1.61	1.64
DLL	Methionine	%	1.88	0.121	1.86	1.74	2.03
EPL	Phenylalanine	%	4.5	0.051	4.52	4.42	4.54
DLL	Phenylalanine	%	4.69	0.249	4.64	4.37	5.06
EPL	Proline	%	4.98	0.254	5.06	4.55	5.17
DLL	Proline	%	5.42	0.399	5.34	4.93	5.9
EPL	Serine	%	4.04	0.103	4.03	3.91	4.19
DLL	Serine	%	4.42	0.313	4.35	4.05	4.89
EPL	Threonine	%	4.55	0.076	4.54	4.48	4.68
DLL	Threonine	%	4.91	0.243	4.85	4.62	5.26
EPL	Tryptophan	%	1.41	0.052	1.39	1.37	1.5
DLL	Tryptophan	%	2.05	0.066	2.06	1.96	2.12
EPL	Tyrosine	%	2.55	0.139	2.49	2.41	2.75
DLL	Tyrosine	%	3.43	0.215	3.34	3.27	3.8
EPL	Valine	%	5.2	0.102	5.2	5.08	5.34
DLL	Valine	%	5.69	0.267	5.61	5.48	6.14

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories.

Table 5

CCWG-1-$CuSO_4$ fatty acids (100% dry matter basis)

Analytical				Standard		Range	
Lab1	Variable	Units	Mean	Deviation	Median	Minimum	Maximum
EPL	Myristic (C14:0)	%	0.02	0.001	0.02	0.02	0.02
DLL	Myristic (C14:0)	%	0	0	0	0	0
EPL	Palmitic (C16:0)	%	0.79	0.085	0.82	0.67	0.88
DLL	Palmitic (C16:0)	%	0.75	0.063	0.74	0.67	0.82
EPL	Palmitoleic (C16:1)	%	0.03	0.005	0.03	0.02	0.03
DLL	Palmitoleic (C16:1)	%	0	0	0	0	0
EPL	Heptadecanoic (C17:0)	%	0.01	0.001	0.01	0.01	0.01
DLL	Heptadecanoic (C17:0)	%	0	0	0	0	0
EPL	Heptadecenoic (C17:1)	%	0.01	0.001	0.01	0.01	0.02
DLL	Heptadecenoic (C17:1)	%	NA	NA	NA	NA	NA
EPL	Stearic (C18:0)	%	0.2	0.024	0.19	0.17	0.23
DLL	Stearic (C18:0)	%	0.18	0.02	0.18	0.16	0.21
EPL	Oleic (C18:1)	%	8.04	0.962	8.04	6.73	9.19

DLL	Oleic (C18:1)	%	7.45	0.815	7.35	6.36	8.28
EPL	Linoleic (C18:2)	%	6.87	0.605	7.19	6.08	7.46
DLL	Linoleic (C18:2)	%	6.4	0.57	6.35	5.55	6.93
EPL	Linolenic (C18:3)	%	3.62	0.241	3.68	3.34	3.87
DLL	Linolenic (C18:3)	%	3.07	0.196	2.98	2.82	3.27
EPL	Nonadecenoic (C19:1)	%	0.01	0.001	0.01	0.01	0.01
DLL	Nonadecenoic (C19:1)	%	NA	NA	NA	NA	NA
EPL	Arachidic (C20:0)	%	0.03	0.004	0.03	0.03	0.04
DLL	Arachidic (C20:0)	%	0	0	0	0	0
EPL	Eicosenoic (C20:1)	%	0.16	0.011	0.16	0.15	0.17
DLL	Eicosenoic (C20:1)	%	0	0	0	0	0
EPL	Eicosadienoic (C20:2)	%	0.03	0.002	0.03	0.03	0.03
DLL	Eicosadienoic (C20:2), Eicosatrienoic(C20:3)	%	0.45	0.179	0.51	0.17	0.64
EPL	Behenic (C22:0)	%	0.02	0.002	0.02	0.02	0.02
DLL	Behenic (C22:0)	%	NA	NA	NA	NA	NA
EPL	Erucic (C22:1)	%	0.06	0.013	0.07	0.04	0.08
DLL	Erucic (C22:1)	%	0	0	0	0	0
EPL	Lignoceric (C24:0)	%	0.02	0.002	0.02	0.01	0.02
DLL	Lignoceric (C24:0)	%	0	0	0	0	0
EPL	Nervonic (C24:1)	%	0.08	0.007	0.07	0.07	0.08
DLL	Nervonic (C24:1)	%	0	0	0	0	0

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories; NA: Not Analyzed; The following fatty acids were below the level of detection for Lab EPL: Arachidonic (C20:4), Capric (C10:0), Caproic (C6:0), Caprylic (C8:0), Docosadienoic (C22:2), Eicosatrienoic (C20:3), Gamma Linolenic (C18:3), Heneicosanoic (C21:0), Lauric (C12:0), Myristoleic (C14:1), Nonadecanoic (C19:0), Pentadecanoic (C15:0), Pentadecenoic (C15:1), Tricosanoic (C23:0); for Lab DLL: Arachidonic (C20:4), Docosahexanoic acid (C22:6); Eicosapentaenoic acid (C20:5).

Table 6

CCWG-1-$CuSO_4$ Fatty acids as a percent of total fatty acids

Analytical				Standard		Range	
Lab1	**Variable**	**Units**	**Mean**	**Deviation**	**Median**	**Minimum**	**Maximum**
EPL	Myristic (C14:0)	%	0.09	0.006	0.09	0.09	0.1
DLL	Myristic (C14:0)	%	0	0	0	0	0
EPL	Palmitic (C16:0)	%	3.98	0.066	4	3.86	4.02
DLL	Palmitic (C16:0)	%	4.06	0.076	4.04	4	4.2
EPL	Palmitoleic (C16:1)	%	0.15	0.012	0.16	0.13	0.16
DLL	Palmitoleic (C16:1)	%	0	0	0	0	0
EPL	Heptadecanoic (C17:0)	%	0.03	0.018	0.03	0	0.05
DLL	Heptadecanoic (C17:0)	%	0	0	0	0	0
EPL	Heptadecenoic (C17:1)	%	0.07	0.011	0.08	0.06	0.09
DLL	Heptadecenoic (C17:1)	%	NA2	NA	NA	NA	NA
EPL	Stearic (C18:0)	%	1	0.044	1.02	0.94	1.04
DLL	Stearic (C18:0)	%	0.99	0.05	1.01	0.91	1.03
EPL	Oleic (C18:1)	%	40.14	1.223	40.55	38.5	41.55
DLL	Oleic (C18:1)	%	40.07	0.943	40.19	38.61	41.06
EPL	Linoleic (C18:2)	%	34.41	0.611	34.2	33.8	35.3
DLL	Linoleic (C18:2)	%	34.48	0.337	34.39	34.17	34.94
EPL	Linolenic (C18:3)	%	18.15	0.722	17.9	17.55	19.4
DLL	Linolenic (C18:3)	%	16.55	0.632	16.32	16.18	17.67
EPL	Nonadecenoic (C19:1)	%	0.03	0.018	0.03	0	0.05
DLL	Nonadecenoic (C19:1)	%	NA	NA	NA	NA	NA
EPL	Arachidic (C20:0)	%	0.03	0.004	0.03	0.03	0.04
DLL	Arachidic (C20:0)	%	0	0	0	0	0
EPL	Eicosenoic (C20:1)	%	0.16	0.011	0.16	0.15	0.17
DLL	Eicosenoic (C20:1)	%	1.47	0.088	1.44	1.38	1.6
EPL	Eicosadienoic (C20:2)	%	0.03	0.002	0.03	0.03	0.03
DLL	Eicosadienoic (C20:2), Eicosatrienoic(C20:3)	%	2.38	0.939	2.54	1.09	3.54
EPL	Behenic (C22:0)	%	0.02	0.002	0.02	0.02	0.02
DLL	Behenic (C22:0)	%	0	0	0	0	0
EPL	Erucic (C22:1)	%	0.06	0.013	0.07	0.04	0.08

DLL	Erucic (C22:1)	%	0	0	0	0	0
EPL	Lignoceric (C24:0)	%	0.07	0.021	0.08	0.04	0.09
DLL	Lignoceric (C24:0)	%	0	0	0	0	0
EPL	Nervonic (C24:1)	%	0.37	0.024	0.37	0.34	0.4
DLL	Nervonic (C24:1)	%	0	0	0	0	0

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories; NA: Not Analyzed; The following fatty acids were below the level of detection for Lab A: Arachidonic (C20:4), Capric (C10:0), Caproic (C6:0), Caprylic (C8:0), Docosadienoic (C22:2), Eicosatrienoic (C20:3), Gamma Linolenic (C18:3), Heneicosanoic (C21:0), Lauric (C12:0), Myristoleic (C14:1), Nonadecanoic (C19:0), Pentadecanoic (C15:0), Pentadecenoic (C15:1), Tricosanoic (C23:0); for Lab B: Arachidonic (C20:4), Docosahexanoic acid (C22:6); Eicosapentaenoic acid (C20:5).

Table 7

CoverCress CS (CCWG-1-$CuSO_4$) Glucosinolates (Sinigrin, 100% dry matter basis)–EPL Bio Analytical Services

			Standard		Range	
Variable	Units	Mean	Deviation	Median	Minimum	Maximum
Sinigrin–MS	µmoles/g	85.7	16.83	90.7	56.2	98.6
Sinigrin–UV	µmoles/g	86.9	23.97	95.7	45	102

Table 8

CCWG-1-$CuSO_4$ Minerals (100% dry matter basis)

Analytical				Standard		Range	
Lab1	**Variable**	**Units**	**Mean**	**Deviation**	**Median**	**Minimum**	**Maximum**
EPL	Calcium	%	0.849	0.079	0.826	0.791	0.982
DLL	Calcium	%	0.72	0.108	0.69	0.6	0.88
EPL	Phosphorus	%	0.991	0.138	1.06	0.84	1.135
DLL	Phosphorus	%	0.7	0.123	0.78	0.56	0.81
EPL	Magnesium	%	0.378	0.039	0.388	0.335	0.428
DLL	Magnesium	%	0.29	0.01	0.3	0.28	0.3
EPL	Potassium	%	0.951	0.073	0.923	0.909	1.08
DLL	Potassium	%	0.74	0.114	0.71	0.63	0.93
EPL	Sulfur	%	1.008	0.23	1.12	0.6	1.14
DLL	Sulfur	%	0.87	0.23	0.98	0.47	1.05
EPL	Sodium	%	0.005	0.003	0.004	0.003	0.009
DLL	Sodium	%	0	0.003	0	0	0.01
EPL	Chloride	ppm	185.1	35.379	186.5	143	238.5
DLL	Chloride	ppm	400	90	500	300	500
EPL	Iron	ppm	102.18	12.35	108.5	83.85	112
DLL	Iron	ppm	40	55.1	29	16	98.5
EPL	Copper	ppm	820.7	17.101	814	806	845.5
DLL	Copper	ppm	808	68.7	811	704	890
EPL	Manganese	ppm	31.15	4.019	29.65	27	37.65
DLL	Manganese	ppm	27	2.6	26	23.5	30
EPL	Zinc	ppm	37.71	2.086	39.2	35.4	39.25
DLL	Zinc	ppm	55	11.4	55	43	72

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories.

Table 9 contains the vitamins as analyzed by EPL for the five lots. Generally, the values for the five lots had symmetric distribution. Nutritionists and feed formulators, as common practice, do not use the vitamin content of feedstuffs in formulating diets due to the variability, stability, low levels in the feed ingredient and the low cost of supplementing vitamins. The Canola Council of Canada in their Canola Feed Guide [21] state, "As is recommended with most natural sources of vitamins in animal feeds, users should not place too much reliance on these values and use supplemental vitamin premixes instead" (Table 9).

Table 9
CCWG-1-$CuSO_4$ Vitamins (100% dry matter basis)–EPL Bio Analytical Services

			Standard		Range	
Variable	Units	Mean	Deviation	Median	Minimum	Maximum
Folic acid	mg/kg	3.3	1.35	3.2	1.8	5.3
Niacin	mg/kg	51.2	10.52	48.6	42.1	69.3
Vitamin B1 (Thiamine)	mg/kg	5.4	0.25	5.3	5.2	5.8
Vitamin B2 (Riboflavin)	mg/kg	2.7	0.54	2.6	2.3	3.6
Vitamin B6 (Pyridoxine)	mg/kg	10.6	1.69	10.3	8.8	13.4
Alpha-Tocopherol	mg/kg	118	10.86	121.5	99	125.5
Beta-Tocopherol	mg/kg	1.8	0.07	1.8	1.7	1.9
Delta-Tocopherol	mg/kg	2.3	0.16	2.3	2.1	2.5
Gamma-Tocopherol	mg/kg	53.4	14.65	48.6	40.3	78.5

Sinapine and mycotoxins: Sinapine, like glucosinolates, is an anti-nutrient found in modern oilseed rape and canola meals. Sinapine is metabolized in animals to trimethylamine, which is further metabolized by trimethyl oxidase. Certain brown egg laying strains of hens have been reported to have lower hepatic trimethyl oxidase activity apparently leading to accumulation of trimethylamine in some brown eggs and an associated "fishy taint". As summarized by Rymer and Short [22], sinapines are present in modern rapeseed at levels of 12-23 g/kg seed [23]. They are converted in the large intestine to trimethylamine, which apparently produces an undesirable fishy odor in the eggs of certain brown egg chickens. Some of these types of birds lack the ability to produce trimethylamine oxidase [24], and as a result the trimethylamine accumulates in the eggs of these birds. This odor in eggs occurs at levels of 0.8 mg/kg diet [25]. The concentrations of sinapine in CCWG-1-$CuSO_4$ were <0.05% DM basis as reported by EPL in all five lots. This is much lower in comparison to canola meal where the Canola Council of Canada [26] sinapine levels of 1.0% as is basis (with average 12% moisture content) or 1.14% on a 100% DM basis. The following mycotoxins were below the limits of detection in all samples from all of the five lots: Aflatoxin B1, B2, G1, G2; T-2 Toxin; Ochratoxin A; Deoxynivalenol (DON), 3- Acetyl-DON; 15-Acetyl-DON; Zearalenone; Fumonisin B1, B2, B3; Ergosine; Ergotamine; Ergocornine; and Ergocryptine. For Ergocristine, which is a natural ergot alkaloid, four lots were below the levels of detection. For one lot, one of the two replicates was below the level of detection and the second had 15.9 ppb on a dry matter basis with level of detection at 1.5 ppb.

Study B-CCWG-2-$CuSO_4$

Proximate analyses: Table 10 contains the results of proximate analyses. Just as with the CCWG-1 samples, it was postulated that Dairyland Laboratories's method extracted more fat from the product than EPL's method. In addition, there was greater variation noted with EPL's fat values than with Dairyland Labs. Fat in the sample may affect the fiber analysis with higher fat resulting in inflated crude fiber, ADF and NDF values. Moisture levels are high due to the addition of the copper sulfate solution to the CoverCress grain. Since the mean and median values are similar for all proximates, the values from the five lots are evenly distributed or symmetrical in distribution (Table 10).

Amino acid analyses: Table 11 contains the amino acid profile of CCWG-2-$CuSO_4$ when expressed on a 100% dry matter basis and Table 12 contains the amino acid profile of CCWG-2-$CuSO_4$ when expressed on a protein basis. The amino acid values from the five lots showed a symmetrical distribution with the means and median values being similar. Dairyland had a higher percentage of total amino acids when total amino acids were expressed as a percent of crude protein (88.1% *vs.* 83.1%) (Tables 11 and 12).

Fatty acid characterization: Tables 13 and 14 contain the fatty acid profile of CCWG-2-$CuSO_4$ when expressed on a 100% dry matter basis and percent of total fatty acids, respectively. In general, there was good agreement between laboratories. The fatty acid values from the five lots showed a symmetrical distribution with the means and median values being similar. The major fatty acids are oleic (~43% of the total fatty acids) followed by linoleic (~32% of the total fatty acids) and linolenic (~18% of the total fatty acids). These three fatty acids comprise over 90% of the fatty acids in CCWG-2-$CuSO_4$. No high polyunsaturated long chain fatty acids such as EPA and DHA were detected. Results confirm that CCWG-2-$CuSO_4$ contains negligible levels of erucic acid. Dairyland Laboratories did not detect it and EPL reported erucic acid to be less than 0.5% of the total fatty acids (Tables 13 and 14).

Glucosinolate characterization and quantification: Sinigrin averaged 105.4 µmoles/g of CCWG-2-$CuSO_4$ on a 100% dry matter basis and was similar among lots (Table 15). Sinigrin was measured using the Ultraviolet method (UV).

Minerals, Sinapine and Mycotoxins: Table 16 contains the results to the mineral analyses. EPL and Dairyland Laboratories results varied. The discrepancy between labs is unexplained. Generally, the values for the five lots had symmetric distribution. The high level of copper is due to the addition of copper sulfate. Target addition of copper was 800 ppm. The analytical results confirm that the target levels were achieved. The concentrations of sinapine in CCWG-2-$CuSO_4$ were <0.05% as reported by EPL in all five lots. This is in comparison to canola meal where the Canola Council of Canada [26] reports sinapine levels of 1.0% as is basis (with average 12% moisture content) or 1.14% on a 100% DM basis. No mycotoxins were detected in the five lots. All mycotoxins were below the limits of detection in all samples from all of the five lots: Aflatoxin B1, B2, G1, G2; T-2 Toxin; Ochratoxin A; Deoxynivalenol (DON), 3-Acetyl-DON; 15-Acetyl-DON; Zearalenone; Fumonisin B1, B2, B3; Ergosine; Ergotamine; Ergocristine; and Ergocornine; and Ergocryptine (Table 16).

Table 10
CoverCress CS (CCWG-2-$CuSO_4$) proximates (100% dry matter basis)

Analytical				Standard		Range	
Lab1	Variable	Units	Mean	Deviation	Median	Minimum	Maximum
EPL	Moisture	%	19.6	0.24	19.6	19.3	19.9
DLL	Moisture	%	16.6	0.38	16.7	16.1	17.1
EPL	Dry matter	%	80.4	0.24	80.5	80.1	80.7
DLL	Dry matter	%	83.4	0.38	83.3	82.9	83.9

EPL	Crude fiber	%	20	2.82	21	15.6	22.6
DLL	Crude fiber	%	12.1	0.71	12.5	10.9	12.5
EPL	Acid detergent fiber	%	25.8	2.73	25.3	22.1	28.7
DLL	Acid detergent fiber	%	17.8	2.04	16.8	15.9	20.2
EPL	Neutral detergent fiber	%	26.9	3.32	27.7	22	30.2
DLL	Neutral detergent fiber	%	22.6	1.48	21.9	21.3	24.4
EPL	Total dietary fiber	%	28.8	1.04	28.7	27.7	30.3
EPL	Crude protein	%	25.4	1.27	25	24.1	27.4
DLL	Crude protein	%	23.9	0.97	24.1	22.5	25.1
EPL	Crude fat	%	32.7	1.62	33	30.4	34.8
DLL	Crude fat	%	37	1.07	37	35.7	38.5
EPL	Carbohydrates	%	36.3	2.12	36.8	32.7	38.1
EPL	Ash	%	5.6	0.45	5.4	5.1	6.2
DLL	Ash	%	6	0.86	6.1	4.6	6.7

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories.

Table 11

CoverCress CS (CCWG-2-$CuSO_4$) Amino acids (100% dry matter basis)

Analytical				Standard		Range	
Lab	Variable	Units	Mean	Deviation	Median	Minimum	Maximum
EPL	Alanine	%	1.13	0.023	1.14	1.11	1.15
DLL	Alanine	%	1	0.034	0.99	0.97	1.06
EPL	Arginine	%	1.39	0.067	1.39	1.3	1.46
DLL	Arginine	%	1.57	0.052	1.55	1.51	1.63
EPL	Aspartic acid	%	1.93	0.054	1.91	1.91	2.03
DLL	Aspartic acid	%	1.92	0.031	1.93	1.88	1.96
EPL	Cystine	%	0.38	0.022	0.38	0.36	0.41
DLL	Cysteine	%	0.38	0.017	0.39	0.36	0.41
EPL	Glutamic acid	%	3.83	0.11	3.81	3.68	3.95
DLL	Glutamic acid	%	3.59	0.133	3.59	3.4	3.75
EPL	Glycine	%	1.38	0.064	1.38	1.3	1.46
DLL	Glycine	%	1.45	0.041	1.45	1.39	1.51
EPL	Histidine	%	0.54	0.022	0.54	0.52	0.57
DLL	Histidine	%	0.47	0.015	0.47	0.45	0.49
EPL	Isoleucine	%	0.93	0.019	0.93	0.9	0.94
DLL	Isoleucine	%	0.73	0.047	0.74	0.68	0.8
EPL	Leucine	%	1.63	0.046	1.63	1.56	1.68
DLL	Leucine	%	1.59	0.059	1.58	1.53	1.68
EPL	Lysine	%	1.28	0.035	1.28	1.24	1.34
DLL	Lysine	%	1.12	0.032	1.13	1.09	1.17
EPL	Methionine	%	0.37	0.029	0.38	0.33	0.41
DLL	Methionine	%	0.33	0.019	0.33	0.31	0.36
EPL	Phenylalanine	%	0.99	0.06	0.98	0.92	1.08
DLL	Phenylalanine	%	1.04	0.033	1.04	0.99	1.08
EPL	Proline	%	1.22	0.043	1.23	1.17	1.27
DLL	Proline	%	1.36	0.02	1.37	1.33	1.38
EPL	Serine	%	0.93	0.035	0.93	0.89	0.99
DLL	Serine	%	0.99	0.019	0.99	0.97	1.02
EPL	Threonine	%	1.03	0.03	1.04	0.99	1.07
DLL	Threonine	%	1.06	0.025	1.05	1.03	1.1
EPL	Tryptophan	%	0.36	0.016	0.37	0.33	0.37
DLL	Tryptophan	%	0.47	0.059	0.47	0.42	0.56
EPL	Tyrosine	%	0.49	0.032	0.49	0.45	0.54
DLL	Tyrosine	%	0.74	0.018	0.74	0.72	0.75
EPL	Valine	%	1.23	0.019	1.23	1.2	1.26
DLL	Valine	%	1.17	0.063	1.17	1.11	1.27

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories.

Table 12
CoverCress CS (CCWG-2-$CuSO_4$) Amino acids as percent of protein

Analytical				Standard		Range	
Lab	Variable	Units	Mean	Deviation	Median	Minimum	Maximum
EPL	Alanine	%	4.46	0.164	4.48	4.2	4.6
DLL	Alanine	%	4.2	0.118	4.19	4.05	4.38
EPL	Arginine	%	5.49	0.16	5.44	5.31	5.7
DLL	Arginine	%	6.59	0.138	6.59	6.43	6.74
EPL	Aspartic acid	%	7.64	0.45	7.73	6.97	8.12
DLL	Aspartic acid	%	8.05	0.22	7.99	7.81	8.33
EPL	Cystine	%	1.5	0.104	1.5	1.41	1.67
DLL	Cysteine	%	1.62	0.076	1.62	1.49	1.69
EPL	Glutamic acid	%	15.13	0.711	15.35	13.9	15.75
DLL	Glutamic acid	%	15.07	0.172	15.09	14.88	15.27
EPL	Glycine	%	5.45	0.094	5.41	5.36	5.56
DLL	Glycine	%	6.09	0.087	6.06	6.01	6.2
EPL	Histidine	%	2.14	0.043	2.14	2.08	2.19
DLL	Histidine	%	1.99	0.027	1.99	1.96	2.02
EPL	Isoleucine	%	3.66	0.124	3.72	3.45	3.74
DLL	Isoleucine	%	3.07	0.125	3.09	2.87	3.19
EPL	Leucine	%	6.42	0.162	6.5	6.13	6.51
DLL	Leucine	%	6.69	0.081	6.71	6.56	6.78
EPL	Lysine	%	5.05	0.33	5.08	4.53	5.35
DLL	Lysine	%	4.71	0.121	4.69	4.55	4.85
EPL	Methionine	%	1.47	0.083	1.49	1.38	1.57
DLL	Methionine	%	1.39	0.05	1.38	1.33	1.45
EPL	Phenylalanine	%	3.89	0.072	3.91	3.8	3.96
DLL	Phenylalanine	%	4.35	0.044	4.38	4.3	4.4
EPL	Proline	%	4.83	0.136	4.87	4.6	4.95
DLL	Proline	%	5.73	0.164	5.71	5.48	5.91
EPL	Serine	%	3.68	0.062	3.69	3.6	3.76
DLL	Serine	%	4.16	0.116	4.13	4.06	4.36
EPL	Threonine	%	4.08	0.103	4.11	3.91	4.18
DLL	Threonine	%	4.44	0.098	4.38	4.36	4.58
EPL	Tryptophan	%	1.41	0.058	1.44	1.34	1.48
DLL	Tryptophan	%	1.98	0.174	1.93	1.8	2.21
EPL	Tyrosine	%	1.93	0.051	1.97	1.87	1.97
DLL	Tyrosine	%	3.09	0.073	3.08	2.99	3.18
EPL	Valine	%	4.85	0.17	4.92	4.56	4.98
DLL	Valine	%	4.89	0.18	4.98	4.59	5.04

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories.

Table 13
CoverCress CS (CCWG-2-$CuSO_4$) Fatty acids (100% dry matter basis)

Analytical				Standard		Range	
Lab	Variable	Units	Mean	Deviation	Median	Minimum	Maximum
EPL	Myristic (C1 4:0)	%	0.02	0.002	0.02	0.01	0.02
DLL	Myristic (C14:0)	%	0	0	0	0	0
EPL	Palmitic (C16:0)	%	0.62	0.039	0.62	0.56	0.67
DLL	Palmitic (C16:0)	%	1.17	0.051	1.16	1.11	1.24
EPL	Palmitoleic (C16:1)	%	0.02	0.002	0.02	0.02	0.03
DLL	Palmitoleic (C16:1)	%	0	0	0	0	0
EPL	Heptadecanoic (C17:0)	%	0.01	0.001	0.01	0.01	0.01
DLL	Heptadecanoic (C17:0)	%	0	0	0	0	0
EPL	Heptadecenoic (C17:1)	%	0	0	0	0	0
DLL	Heptadecenoic (C17:1)	%	NA	NA	NA	NA	NA

EPL	Stearic (C18:0)	%	0.13	0.01	0.13	0.12	0.14
DLL	Stearic (C18:0)	%	0.26	0.017	0.27	0.24	0.28
EPL	Oleic (C18:1)	%	6.75	0.43	6.74	6.17	7.38
DLL	Oleic (C18:1)	%	13.61	0.93	13.84	12.35	14.86
EPL	Linoleic (C18:2)	%	5.16	0.411	5.14	4.77	5.84
DLL	Linoleic (C18:2)	%	9.57	0.733	9.83	8.57	10.44
EPL	Linolenic (C18:3)	%	2.91	0.25	2.83	2.68	3.34
DLL	Linolenic (C18:3)	%	5.16	0.423	5.28	4.72	5.7
EPL	Nonadecenoic (C19:1)	%	0	0	0	0	0
DLL	Nonadecenoic (C19:1)	%	NA	NA	NA	NA	NA
EPL	Arachidic (C20:0)	%	0.02	0.001	0.02	0.02	0.02
DLL	Arachidic (C20:0)	%	0	0	0	0	0
EPL	Eicosenoic (C20:1)	%	0.14	0.009	0.14	0.12	0.14
DLL	Eicosenoic (C20:1)	%	0.23	0.014	0.23	0.21	0.25
EPL	Eicosadienoic (C20:2)	%	0.02	0.003	0.02	0.02	0.03
DLL	Eicosadienoic (C20:2), Eicosatrienoic(C20:3)	%	0	0	0	0	0
EPL	Behenic (C22:0)	%	0	0	0	0	0
DLL	Behenic (C22:0)	%	NA	NA	NA	NA	NA
EPL	Erucic (C22:1)	%	0.07	0.022	0.06	0.05	0.11
DLL	Erucic (C22:1)	%	0	0	0	0	0
EPL	Lignoceric (C24:0)	%	0	0	0	0	0
DLL	Lignoceric (C24:0)	%	0	0	0	0	0
EPL	Nervonic (C24:1)	%	0.05	0.005	0.05	0.04	0.06
DLL	Nervonic (C24:1)	%	0	0	0	0	0

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories; NA: Not Analyzed; The following fatty acids were below the level of detection for Lab EPL: Capric (C10:0), Caproic (C6:0), Caprylic (C8:0), Docosadienoic (C22:2), Docosahexaenoic (C22:6), Eicosatrienoic (C20:3), Eicosapentaenoic (C20:5), Gamma Linolenic (C18:3), Heneicosanoic (C21:0), Heptadecenoic (C17:1), Lauric (C12:0), Myristoleic (C14:1), Nonadecanoic (C19:0), Nonadecenoic (C19:1), Pentadecanoic (C15:0), Pentadecenoic (C15:1), Tricosanoic (C23:0); for Lab DLL: Arachidonic (C20:4), Docosahexanoic acid (C22:6); Eicosapentaenoic acid (C20:5).

Table 14

CoverCress CS (CCWG-2-$CuSO_4$) Fatty acids as a percent of total fatty acids

Analytical				Standard		Range	
Lab	**Variable**	**Units**	**Mean**	**Deviation**	**Median**	**Minimum**	**Maximum**
EPL	Myristic (C14:0)	%	0.1	0.011	0.1	0.09	0.11
DLL	Myristic (C14:0)	%	0	0	0	0	0
EPL	Palmitic (C16:0)	%	3.88	0.042	3.89	3.84	3.95
DLL	Palmitic (C16:0)	%	3.89	0.079	3.91	3.77	3.96
EPL	Palmitoleic (C16:1)	%	0.15	0.018	0.16	0.12	0.17
DLL	Palmitoleic (C16:1)	%	0	0	0	0	0
EPL	Heptadecanoic (C17:0)	%	0.03	0.018	0.03	0	0.05
DLL	Heptadecanoic (C17:0)	%	0	0	0	0	0
EPL	Heptadecenoic (C17:1)	%	0.07	0.011	0.08	0.06	0.09
DLL	Heptadecenoic (C17:1)	%	NA	NA	NA	NA	NA
EPL	Stearic (C18:0)	%	0.84	0.039	0.84	0.77	0.88
DLL	Stearic (C18:0)	%	0.88	0.04	0.87	0.83	0.93
EPL	Oleic (C18:1)	%	42.32	2.261	42.4	39	45.35
DLL	Oleic (C18:1)	%	45.4	2.134	45.34	42.22	48.16
EPL	Linoleic (C18:2)	%	32.42	1.425	32.5	30.25	34.25
DLL	Linoleic (C18:2)	%	31.89	1.431	31.86	29.84	33.87
EPL	Linolenic (C18:3)	%	18.25	0.793	18.15	17.35	19.5
DLL	Linolenic (C18:3)	%	17.18	0.737	17.24	16.44	18.26
EPL	Nonadecenoic (C19:1)	%	0.03	0.018	0.03	0	0.05
DLL	Nonadecenoic (C19:1)	%	NA	NA	NA	NA	NA
EPL	Arachidic (C20:0)	%	0.13	0.013	0.13	0.13	0.016
DLL	Arachidic (C20:0)	%	0	0	0	0	0
EPL	Eicosenoic (C20:1)	%	0.85	0.024	0.84	0.82	0.87
DLL	Eicosenoic (C20:1)	%	0.77	0.042	0.78	0.7	0.82

EPL	Eicosadienoic (C20:2)	%	0.03	0.002	0.03	0.03	0.03
DLL	Eicosadienoic (C20:2), Eicosatrienoic(C20:3)	%	0	0	0	0	0
DLL	Arachidonic (20:4)	%	0.02	0.018	0.02	0	0.05
EPL	Behenic (C22:0)	%	0.06	0.003	0.06	0.06	0.07
DLL	Behenic (C22:0)	%	0	0	0	0	0
EPL	Erucic (C22:1)	%	0.43	0.109	0.38	0.36	0.62
DLL	Erucic (C22:1)	%	0	0	0	0	0
EPL	Lignoceric (C24:0)	%	0.07	0.005	0.07	0.06	0.07
DLL	Lignoceric (C24:0)	%	0	0	0	0	0
EPL	Nervonic (C24:1)	%	0.31	0.025	0.3	0.3	0.36
DLL	Nervonic (C24:1)	%	0	0	0	0	0

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories; NA: Not Analyzed.

Table 15

CoverCress CS (CCWG-2-$CuSO_4$) Glucosinolates (Sinigrin, 100% dry matter basis)-EPL Bio Analytical Services

			Standard		Range	
Variable	**Units**	**Mean**	**Deviation**	**Median**	**Minimum**	**Maximum**
Sinigrin - UV	µmoles/g	105.4	4.21	104.3	101.4	110.7

Table 16

CoverCress CS (CCWG-2-$CuSO_4$) Minerals (100% dry matter basis)

Analytical				**Standard**		**Range**	
Lab1	**Variable**	**Units**	**Mean**	**Deviation**	**Median**	**Minimum**	**Maximum**
EPL	Calcium	%	0.93	0.074	0.95	0.84	1.01
DLL	Calcium	%	1.25	0.154	1.31	0.99	1.39
EPL	Phosphorus	%	0.99	0.135	0.96	0.8	1.14
DLL	Phosphorus	%	0.68	0.134	0.71	0.48	0.81
EPL	Magnesium	%	0.38	0.091	0.37	0.3	0.48
DLL	Magnesium	%	0.35	0.087	0.3	0.27	0.44
EPL	Potassium	%	1.11	0.083	1.05	1.05	1.23
DLL	Potassium	%	1.04	0.117	1.05	0.89	1.17
EPL	Sulfur	%	1.17	0.061	1.15	1.12	1.26
DLL	Sulfur	%	0.94	0.064	0.96	0.86	1.01
EPL	Sodium	%	0	0	0	0	0
DLL	Sodium	%	0.01	0.004	0.01	0.01	0.02
EPL	Chloride	ppm	399.4	85.334	432	275.5	473
DLL	Chloride	ppm	800	25	700	600	1200
EPL	Iron	ppm	107.85	48.471	84.95	63.9	162.5
DLL	Iron	ppm	72	30.7	57	40.5	113
EPL	Copper	ppm	959.7	29.641	955	930.5	1001.5
DLL	Copper	ppm	1052	257.8	1087.5	633	1315
EPL	Manganese	ppm	36.96	3.254	38.3	31.8	39.75
DLL	Manganese	ppm	46	6.5	47.5	39	55
EPL	Zinc	ppm	38.88	4.672	40.2	33.65	45
DLL	Zinc	ppm	46	15.6	43	34	73

Note: Analytical lab: EPL–EPL Bio Analytical Services; DLL–Dairyland Laboratories.

Vitamins: Table 17 contains the vitamins as analyzed by EPL for the five lots. Generally, the values for the five lots had symmetric distribution.

The results of these extensive compositional and nutritional analyses show:

• The composition and nutritional components of CCWG-1-$CuSO_4$ and CCWG-2-$CuSO_4$ lots were generally consistent with very good process control and low inter- lot variability.

• As expected by loss of function of the FAE1 gene, the fatty acid profile of the CCWG-1-$CuSO_4$ and CCWG-2-$CuSO_4$ lots showed negligible erucic acid levels.

• As expected by loss of function of the TT8 gene, mean ADF and crude fibers levels were in acceptable ranges for broiler diets.

• Sinigrin (2-propenyl glucosinolate) was the only detectable glucosinolate consistent with previous published results in field pennycress seed or meals and total glucosinolate concentration in CCWG-1-$CuSO_4$ ranged from 45 to 102 µmoles/g on 100% DM basis.

• Total glucosinolate concentration in CCWG-2-$CuSO_4$ ranged from 101.4

to 110.7 µmoles/g on 100% DM basis.

• Total copper levels achieved target levels of 800 ppm.

• Other anti-nutrients (sinapine) and mycotoxins were below the limit of detection or quantification.

The main purpose of CoverCress whole grain as a feed ingredient in animal diets (e.g. broilers) is as an energy source. Determination of energy value is complex, but is related to the fat, protein, and fiber content. Further, the degree of unsaturation of the fatty acids is a factor in energy. While there are some slight differences in total fat and the fiber profile, the overall nutritional value of CCWG for energy is expected to be similar to that of canola seed in Table 18. Levels of the four key limiting amino acids in broiler diets, methionine, lysine, threonine and valine are similar between CCWG and canola. The low-erucic acid phenotype expected with loss of function of FAE1 was achieved as shown by the low to non-detectable levels in CCWG. The nutritional value in terms of energy (total fat, profile of fatty acids, crude fiber, ADF, NDF) of CCWG-2 is comparable to that of CCWG-1. Crude fiber levels were variable across lots and between CCWG-1 and CCWG-2. This may be due to assay or natural variability within the plants. Levels of the four key limiting amino acids in broiler diets, methionine, lysine, threonine and valine were lower for the CCWG-2 as compared to the CCWG-1. The difference is mostly like due to the lower amino acids as a percent of protein in the CCWG-2 as compared to the CCWG-1 (88.1% *vs.* 97% of the protein for CCWG-2 and CCWG-1, respectively) (Tables 17 and 18).

Table 17

CoverCress CS (CCWG-2-$CuSO_4$) Vitamins (100% dry matter basis)–EPL Bio Analytical Services

			Standard		Range	
Variable	**Units**	**Mean**	**Deviation**	**Median**	**Minimum**	**Maximum**
Folic Acid	mg/kg	5.6	0.67	5.2	5	6.6
Niacin	mg/kg	40.2	2.06	40.6	37.1	42.5
Vitamin B1 (Thiamine)	mg/kg	5.2	0.06	5.2	5.1	5.3
Vitamin B2 (Riboflavin)	mg/kg	4.7	0.29	4.6	4.3	5
Vitamin B6 (Pyridoxine)	mg/kg	6.1	0.17	6.1	5.9	6.3
Alpha-Tocopherol	mg/kg	181.8	24.28	174.5	160.5	218
Beta-Tocopherol	mg/kg	3.1	0.13	3.1	2.9	3.4
Delta-Tocopherol	mg/kg	<1.25		<1.25	<1.25	<1.25
Gamma-Tocopherol	mg/kg	13.4	1.75	12.5	11.9	15.8

Table 18

Key compositional parameters for canola whole grain, CCWG-1 and CCWG-2

Component	Canola	CCWG-1-$CuSO_4$ Mean [range]	CCWG-2-$CuSO_4$ Mean [range]
Fat % DM	39.1	36.3[35.5-36.7]	37[35.7-38.5]
Erucic acid % TFA	<0.1	<0.1	<0.1
Oleic % of TFA	61.4	40.07[38.61-41.06]	45.4[42.22-48.16]
Linoleic % TFA	20.1	34.48[34.17-34.94]	31.89[29.84-33.87]
Linolenic % TFA	9.3	16.55 [16.18-17.67]	17.18 [16.44-18.26]
Total saturated %TFA	7	5	
Total mono- unsaturated %TFA	64.4	41.6	
Total poly-unsaturated % TFA	28.6	53.4	
Protein %DM	24.5	25.5 [22.7-26.7]	23.9 [22.5-25.1]
Methionine % protein	1.93	1.88 [1.74-2.03]	1.39 [1.33-1.45]
Lysine % protein	5.66	5.51 [5.30-5.68]	4.71 [4.55-4.85]
Threonine % protein	3.97	4.91 [4.62-5.26]	4.44 [4.36-4.58]
Valine % protein	4.4	5.69 [5.48-6.14]	4.89 [4.59-5.04]
Crude fiber % DM	13.3	23 [20.9-24.9]	12.1 [10.9-12.5]
ADF	18.1	13.9 [12.1-15.8]	17.8 [15.9-20.2]
NDF	25.7	20.3 [17.3-24.5]	22.6 [21.3-24.4]
Sulfur % DM	0.45 [0.36-0.55]	0.87 [0.47-1.05]	0.94 [0.86-1.01]
Total glucosinolates µmoles/g on DM basis UV method	9.8	86.9 [45-102]	105.4 [101.4-110.7]

Note: Values from dairy one feed Composition Laboratory; means of whole canola seed samples from crop years 2004 – 2020.

CONCLUSION

The composition and nutritional components of CCWG-1-$CuSO_4$ and CCWG-2-$CuSO_4$ lots were generally consistent with very good process control and inter-lot variability. These results will enable eventual development of permissible ranges for key nutritional analytes and guaranteed levels for specific components (i.e., commercial specifications) like total crude protein, crude fiber, crude fat, copper and sulfur. A glucosinolate specification will be needed to ensure safe consumption depending on the level of inclusion in the diet and sensitivity of the animal species. In these lots, the mean level of glucosinolates was slightly higher in CCWG-2 than CCWG-1, but ranges for the two overlapped, indicating the difference is likely due to natural variability. The current study shows that low-erucic acid, lower-fiber pennycress (CoverCress) produces a consistent compositional phenotype that may enable the seed to be consumed as an energy source for various animal species.

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CONFLICT OF INTEREST

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