*Review*

# Lignan Content in Cereals, Buckwheat and Derived Foods

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**Abstract:** Cereal foods are a fundamental part of a balanced diet and several studies have assigned to wholemeal cereal products a protective role in human health, due to their content of bioactive compounds. Within the phytochemicals, lignans are of increasing interest for their potential anticarcinogenic, antioxidant, estrogenic and antiestrogenic activities. The aim of this work is to contribute to the updating of food lignan databases by providing the profile and the amount of lignans in cereals, buckwheat and several cereal based foods commonly consumed in human diets. Values were taken from published papers. Items were divided in different groups, namely *grains*, *brans and flours*, *bread*, *cereal staple foods*, *breakfast cereals* and *other cereal products*, and values for secoisolariciresinol, matairesinol, pinoresinol, lariciresinol are given. For example, the total average values for the mentioned lignans in grains ranged between 23 μg/100 g and 401 μg/100 g dry weight. The contribution of each single lignan molecule to the total value of lignans appears to be different for every cereal species. Lignan content and typology in processed foods depends on the raw materials used, their degree of refinement and on processing conditions.

## 1. Introduction

Cereal food products are a fundamental part of a balanced diet and recently several studies have assigned to cereal grains and to wholemeal cereal products in particular a protective role in human health due to their content of bioactive compounds. Bertram *et al.* [1] conclude that the main protective foods are represented by fiber- and lignan-rich whole-grain cereals, beans, berries, nuts and various seeds.

Within the group of the so called phytochemicals, the phenolic compounds named lignans are attracting the interest of food chemists and nutrition researchers alike. Lignans are vascular plant secondary metabolites, which are attributed a wide range of physiological functions and beneficial properties [2–4].

Lignans belong to the group of diphenolic compounds derived from the combination of two phenylpropanoid C6–C3 units at the β and β′ carbon atoms. They have a chemical structure like the 1,4-diarylbutan. They are derived from the shikimic acid biosynthetic pathway [5–7]. They are optically active compounds and may exist as two enantiomers, *i.e.*, the right- and left-handed forms [8,9]. Numerous structurally different forms of lignans exist, even if their molecular backbone consists only of two phenylpropane units.

Lignans are contained in edible plants where they occur free or bound to sugars [10]. Several hundred lignans have been discovered in different parts of various plants, including wooden parts, roots, leaves, flowers, fruits and seeds. The plant lignans most commonly detected in foods are lariciresinol, matairesinol, pinoresinol and secoisolariciresinol [11,12]. Other lignans such as medioresinol, syringaresinol, sesamin were reported in various kinds of foods [13–16]. However, it is important to point out that all lignans present in all foods have never been analysed in any study so far. The main sources of dietary lignans are oilseeds (e.g., flax, soy, rapeseed and sesame), whole-grain cereals (e.g., wheat, oats, rye and barley), legumes and various vegetables and fruits (particularly berries) [11–16]. Amongst edible products flaxseed and sesame seeds are rich sources of lignans [11,15,17–19], but wood knots in coniferous trees, especially Norway spruce, are the most concentrated lignan sources known so far [20].

Some of the ingested plant lignans are deglycosylated and partly converted to the mammalian lignans enterodiol and enterolactone by colonic bacteria: enterodiol is readily oxidized to enterolactone [21–24]. These metabolites are then absorbed in the colon and conjugated with glucuronic acid or sulfate in the liver. Some of the metabolites may also undergo enterohepatic circulation. Lignans are excreted in bile and urine as conjugated glucuronides and in feces in the unconjugated form [25,26].

Enterodiol and enterolactone, which are generally called enterolignans due to their colonic origin, have a similar structure to the human hormone estrogen and so may have estrogenic/anti-estrogenic effects. Several epidemiological studies have shown a potential protective effect of the enterolignans or of a lignan-rich diet against the development of various diseases, particularly hormone dependent cancer and cardiovascular diseases [27–37]. The health effect of lignans varied depending on the particular lignan type. It is well known that the physiological activities of compounds are affected by their molecular structures.

The knowledge of the dietary intake of lignans is most notably needed to understand the relationship between a lignan-rich diet and probable prevention of various diseases such as hormone-related cancers, heart diseases, menopausal symptoms and osteoporosis. For this reason, a complete and comprehensive database on the content of lignans in foods is needed [38]. However, the available information has some limitations: many studies focused only on a few compounds, the structural diversity of the compounds, the large number of dietary sources, the large variability in content for a given source, the diversity of extraction techniques and analytical methods used, and, in some cases, the lack of suitable analytical methods [39].

Accurate information on dietary lignan in foods is crucial to determine exposure and to investigate health effects *in vivo*. Recently, more analytical data on lignans have become available and they could be used to expand food composition databases [11–16,40–43].

The aim of this work is to contribute to the updating of food lignan databases in general, focusing in particular on cereal grains and cereal based foods by gathering and systematizing available data coming from scientific publications. Our list can be a valuable tool for nutritionists, dietitians, medical doctors and scientists in general to estimate the human dietary exposure to lignans coming from the consumption of cereal based foods and in evaluating the effects of cereals consumption in epidemiological studies. Moreover, it is a document stating the state-of-the-art on this topic.

## 2. Experimental Section

### 2.1. Evaluation and Selection of Available Lignan Data

An extensive bibliographical search was conducted using the following keywords: lignans, secoisolariciresinol, lariciresinol, pinoresinol, matairesinol, medioresinol, syringaresinol, cereals and names of individual cereals, cereals based foods and names of individual foods. Having laboratory experience in the determination of lignans we were also aware that the extraction method from the food matrix is an important issue: acid hydrolysis effectively breaks the ester linkages and the glycosidic bonds, but may also affect the molecular structure, causing interconversions between lignans. On the other hand, alkaline hydrolysis is not effective enough in some instances, particularly in strong matrices such as fiber-rich foods, and can lead to underestimation of matairesinol [4,13].

Therefore, an extraction strategy used to determine the amount of dietary lignan in foods was chosen as preferable and publications using that method were selected in order to assure a fair data comparison. The method by Peñalvo *et al.* [15] that adopts alkaline hydrolysis as the step prior to enzymatic hydrolysis, was chosen. Under alkaline conditions, ester-linked oligomers of lignan are hydrolysed to give the lignan monomer. This method also incorporates isotope dilution to ensure correct accuracy and precision, introducing the utilization of individual stable $^{13}C_3$-labeled lignans.

Analytical values using isotope dilution as internal standards and either gas or liquid chromatography-mass spectrometry [11,13–15,44,45] were considered to be preferable because this was the most sensitive analysis available, having the lowest level of detection. However, values obtained by HPLC were also considered, even if HPLC is less selective and sensitive for the detection of low concentrations of the compounds under study.

*2.2. Database Construction*

For easiness of comparison foods were grouped in seven different categories, namely *grains*, *brans and flours*, *bread*, *cereal staple foods*, *breakfast cereals* and *other cereal products*. Grains included barley (*Hordeum vulgare* L.), buckwheat (*Fagopyrum esculentum* Moench.), durum wheat (*Triticum durum* Desf.), emmer (*Triticum dicoccon* Shrank.), maize (*Zea mais* L.), oat (*Avena sativa* L.), rice (*Oryza sativa* L.), rye (*Secale cereale* L.), soft wheat (*Triticum aestivum* L.), spelt (*Triticum spelta* L.) and triticale (× *Triticosecale* Wittm).

The average and range values were reported for secoisolariciresinol, matairesinol, lariciresinol, pinoresinol, whether the reported values were on a wet or dry basis, together with other useful information such as origin of samples, genetic background, origin, composition and treatment. Despite syringaresinol and medioresinol are present in cereals and cereal based foods, few data on these lignans are available in the literature [13–16], as a consequence, sometimes, of restricted standards availability.

## 3. Results and Discussion

Cereals, whole grain cereals in particular are an important source of lignans in the human diet [11].

The data presented here (Table 1) are a comprehensive and systematized assessment of lignans in cereals and cereal based products for a more accurate determination of exposure to dietary lignans from foods which are commonly consumed by the population in different countries. For ease of consultation, items are grouped in different categories and are listed in each group in alphabetical order.

**Table 1.** Database of lignans (secoisolariciresinol, matairesinol, lariciresinol, pinoresinol) composition in cereals, buckwheat and derived foods *.

| Foods | Seco | Mat | Lari | Pino | Unit | Origin, composition and/or treatment | Reference |
|-------|------|-----|------|------|------|-------------------------------------|-----------|
| *Grains* | | | | | | | |
| Barley | 30 | 3 | 85 | 72 | µg/100 g wet basis | Local markets; dehulled | Penãlvo *et al.* [15] |
| Barley | 28 | n.d. | 132 | 45 | µg/100 g dry weight | Italian farms; 2 cultivars; dehulled | Durazzo *et al.* [40] |
| Buckwheat | 131 | 1 | 362 | 92 | µg/100 g wet basis | Local markets | Penãlvo *et al.* [15] |
| Durum wheat | n.d. | n.d. | 76 | n.d. | µg/100 g dry weight | Italian farms; 2 cultivars | Durazzo *et al.* [40] |
| Emmer | 29 | n.d. | 104 | n.d. | µg/100 g dry weight | Italian farms; 2 cultivars | Durazzo *et al.* [40] |
| Maize | 12 | n.d. | 11 | 0 | µg/100 g dry weight | Italian farms; 3 cultivars | Durazzo *et al.* [40] |
| Millet | 67 | 3 | 20 | 85 | µg/100 g wet basis | Local markets | Penãlvo *et al.* [15] |
| Oat | 19 | 71 | 183 | 194 | µg/100 g wet basis | Local markets | Penãlvo *et al.* [15] |
| Oat | n.d. | n.d. | 97 | 304 | µg/100 g dry weight | Italian farms; 2 cultivars; dehulled | Durazzo *et al.* [40] |
| Oat | 6–13 | 0–104 | 340–599 | 214–683 | µg/100 g wet basis | Fifty-five spring oat samples of 5 different cultivars | Smeds *et al.* [14] |
| Rice | 15 | n.d. | 128 | 29 | µg/100 g dry weight | Italian farms; 3 cultivars | Durazzo *et al.* [40] |
| Rye | 38 | 27 | 324 | 381 | µg/100 g wet basis | Local markets | Penãlvo *et al.* [15] |
| Rye | 25 | n.d. | 100 | n.d. | µg/100 g dry weight | Italian farms; 2 cultivars | Durazzo *et al.* [40] |
| Rye | 10–29 | 18–45 | 76–177 | 176–313 | µg/100 g wet basis | Twenty-eight winter rye samples of 6 different cultivars | Smeds *et al.* [14] |
| Soft wheat | n.d. | n.d. | 58 | n.d. | µg/100 g dry weight | Italian farms; 2 cultivars | Durazzo *et al.* [40] |

**Table 1.** *Cont.*

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Soft Wheat | 35 | 3 | 62 | 37 | µg/100 g wet basis | Local markets | Peñalvo *et al.* [15] |
| Soft Wheat | 20–43 | n.d. | 45–95 | 53–83 | µg/100 g wet basis | Seventy-three spring wheat samples of 9 different cultivars | Smeds *et al.* [14] |
| Spelt | 26 | n.d. | 83 | n.d. | µg/100 g dry weight | Italian farms; 2 cultivars | Durazzo *et al.* [40] |
| Triticale | n.d. | n.d. | 58 | n.d. | µg/100 g dry weight | Italian farms; 2 cultivars | Durazzo *et al.* [40] |
| *Brans and flours* | | | | | | | |
| Durum wheat bran | n.d. | n.d. | 220 | 181 | µg/100 g dry weight | Two cultivars | Durazzo *et al.* [41] |
| Soft wheat bran | 370 | n.d. | 459 | 386 | µg/100 g dry weight | One cultivar | Durazzo *et al.* [41] |
| Soft wheat | 31 | 0 | 140 | 38 | µg/100 g wet basis | Supermarkets; wholemeal | Milder *et al.* [11] |
| Soft wheat | 0 | 0 | 18 | 9 | µg/100 g wet basis | Supermarkets; whiteflour | Milder *et al.* [11] |
| Soft wheat | 16 | n.d. | 34 | n.d. | µg/100 g dry weight | Supermarkets; whiteflour | Durazzo *et al.* [43] |
| *Bread* | | | | | | | |
| Currant/raisin | 9 | 7 | 79 | 9 | µg/100 g wet basis | Two supermarkets and a local bakery | Milder *et al.* [11] |
| Flaxseed (whole) | 11,845 | 26 | 220 | 383 | µg/100 g wet basis | Two supermarkets and a local bakery | Milder *et al.* [11] |
| Flaxseed | 7208 | 0 | 29 | 2 | µg/100 g wet basis | Dempsters; pre-sliced | Thompson *et al.* [12] |
| Multi-grains | 6163 | 19 | 185 | 377 | µg/100 g wet basis | Two supermarkets and a local bakery | Milder *et al.* [11] |
| Multi-grains | 4770 | 1 | 10 | 4 | µg/100 g wet basis | Dempsters; pre-sliced | Thompson *et al.* [12] |
| Oat | 7 | 0 | 4 | 11 | µg/100 g wet basis | Wheat and oats with honey; pre-sliced | Thompson *et al.* [12] |
| Rye (dark type) | 13 | 14 | 122 | 172 | µg/100 g wet basis | Two supermarkets and a local bakery | Milder *et al.* [11] |
| Rye (light type) | 16 | 12 | 111 | 163 | µg/100 g wet basis | Two supermarkets and a local bakery | Milder *et al.* [11] |
| Rye | 122 | 0 | 11 | 9 | µg/100 g wet basis | Jagdschnitten hunter style, Dimpflmeier; pre-sliced | Thomson *et al.* [12] |
| Rye | 33 | 4 | 47 | 44 | µg/100 g wet basis | Local markets in Tokio; (50% rye) | Peñalvo *et al.* [16] |
| Rye | 7 | 1 | 18 | 16 | µg/100 g wet basis | Local markets in Tokio; (30% rye) | Peñalvo *et al.* [16] |
| Sesame | 3 | 0 | 8 | 42 | µg/100 g wet basis | Dempsters; pre-sliced | Thompson *et al.* [12] |
| Wheat (whole type) | 3 | 0 | 5 | 1 | µg/100 g wet basis | Original 100%, Dempsters; pre-sliced | Thompson *et al.* [12] |
| Wheat (whole type) | 15 | 0 | 73 | 33 | µg/100 g wet basis | Two supermarkets and a local bakery | Milder *et al.* [11] |
| Wheat (refined type) | 17 | 0 | 38 | 28 | µg/100 g wet basis | Two supermarkets and a local bakery | Milder *et al.* [11] |
| Wheat (white type) | 0 | 0 | 11 | 7 | µg/100 g wet basis | Two supermarkets and a local bakery | Milder *et al.* [11] |
| Wheat (white type) | 1 | 0 | 2 | 1 | µg/100 g wet basis | Enriched, Wonder; pre-sliced | Thompson *et al.* [12] |
| *Cereals staple foods* | | | | | | | |
| Couscous (cooked) | 2 | n.d. | 0 | n.d. | µg/100 g wet basis | President's choice; cooked in water | Thompson *et al.* [12] |
| Macaroni (cooked) | 4 | 0 | 7 | 5 | µg/100 g wet basis | White, boiled | Milder *et al.* [11] |

**Table 1.** *Cont.*

| | Seco | Mat | Lari | Pino | | | |
|---|---|---|---|---|---|---|---|
| Rice (cooked) | 3 | 2 | 28 | 7 | µg/100 g wet basis | Supermarket; whole grain, boiled | Milder *et al.* [11] |
| Rice (cooked) | 0 | 0 | 7 | 0 | µg/100 g wet basis | Supermarket; white, boiled | Milder *et al.* [11] |
| Rice (cooked) | 0 | 0 | 3 | 1 | µg/100 g wet basis | White, converted long grain, Uncle Ben's; cooked in water | Thompson *et al.* [12] |
| Semolina pasta (raw) | 22 | n.d. | 26 | 27 | µg/100 g dry weight | Market; three different brands | Durazzo *et al.* [41] |
| *Breakfast cereals* | | | | | | | |
| *Brand 1* | 7 | n.d. | 79 | 69 | µg/100 g dry weight | Market; cereals 48.4% (whole oat flour 35.8%; maize flour), wheat germ | Durazzo *et al.* [41] |
| *Brand 2* | 20 | n.d. | 97 | 131 | µg/100 g dry weight | Market; whole cereals (54%) (flour of whole oat, whole rice, whole wheat), cereal agglomerate (19%), oat bran, barley malt | Durazzo *et al.* [41] |
| *Brand 3* | n.d. | n.d. | 99 | 187 | µg/100 g dry weight | Market; cornflakes and bran (31.5%), toasted oatmeal (30%), rice aggregate and bran (25%), sugar-coated barley flakes (9%), almonds (4.5%) | Durazzo *et al.* [41] |
| Cheerios | 9 | 1 | 3 | 0 | µg/100 g wet basis | General Mills | Thompson *et al.* [12] |
| *Muesli* | 17 | 0 | 250 | 497 | µg/100 g wet basis | Jordans, crunchy | Milder *et al.* [11] |
| *Muesli* | 13 | 0 | 120 | 210 | µg/100 g wet basis | Albert Heijn, basic | Milder *et al.* [11] |
| *Muesli* | 17 | 0 | 63 | 129 | µg/100 g wet basis | Edah, crunchy | Milder *et al.* [11] |
| *Oatmeal* | 1 | 0 | 4 | 2 | µg/100 g wet basis | Dempsters; quick cooking, boiled in water | Thompson *et al.* [12] |
| *Raisin Bran* | 15 | 0 | 17 | 1 | µg/100 g wet basis | Kellogg's | Thompson *et al.* [12] |
| *Other cereal products* | | | | | | | |
| *Compressed puffed rice* | 23 | n.d. | 82 | 22 | µg/100 g dry weight | Market; white rice and dehulled rice | Durazzo *et al.* [41] |
| *Puffed barley* | 26 | n.d. | 143 | 48 | µg/100 g dry weight | Market; whole barley | Durazzo *et al.* [41] |
| *Wholegrain biscuits* | 28 | n.d. | 25 | 23 | µg/100 g dry weight | Market; wheat flour (51%), barley flakes (3%), rye flakes (1.8%), rice flour (1.7%), oatmeal (1.3%), maize flour (1.2%), wheat malt | Durazzo *et al.* [41] |
| *Granola bar* | 3 | 2 | 8 | 14 | µg/100 g wet basis | Nature Valley, with almond | Thompson *et al.* [12] |

\* Seco = Secoisolariciresinol; Mat = Matairesinol; Lari = Lariciresinol; Pino = Pinoresinol; n.d. = not detectable.

Among grains, Durazzo *et al.* [40] showed that dehulled oat and barley reached the highest values (by summing up the analysed lignans) amongst the 10 reported cereal species, 401 and 206 µg/100 g dry weight, respectively. A great variability was observed with regard to lignan typology and content also within the same species.

In fact, the content of some lignans and the degree of esterification of the same lignan glycosides may vary within the same cereal species as a consequence of different growing conditions, geographic location, climate, and genetic characteristics [11,13,14]. In fact, agronomic, environmental and post-harvest factors influence, in different ways, not only different classes of chemical compounds but also structurally different compounds belonging to the same chemical subgroup [46].

However, in most of the studied grains the predominant compound amongst the reported lignans was lariciresinol [14,15,40].

Many grains are consumed daily in a number of products from around the world. The health benefits of cereal products are an emergent part of the health related food market. Grains undergo different kinds of processing to obtain desirable products with optimized flavor, color, texture and appearance as well as shelf life. Few results are reported in the literature regarding the effects of cereal processing technologies such as milling, baking, extrusion, etc. on lignans content in most foods.

Regarding flours, considering that lignans are mainly located in the grain outer layers [13,47,48], it is understandable that wholemeal flour is richer in lignans than refined flours. The same difference was observed in whole wheat bread with respect to refined wheat bread in both the investigations of Milder *et al.* [11] and Thompson *et al.* [12].

Miur and Westcott [49] reported that secoisolariciresinol diglucoside was stable in the bread making process. In particular, it could withstand the higher temperatures in the core during baking. Simbalista *et al.* [50], by investigating the effect of bread making on a product containing flaxseed, have shown that, after baking, 89% of the original lignan content was kept in bread.

Among bakery products, besides those containing flaxseed and multi-grains, rye bread represents a good source of all different lignans [11,12,16].

Regarding breakfast cereals, Milder *et al.* [11] found a range between 209 and 764 μg/100 g wet basis considering the sum of lariciresinol, secoisolariciresinol and pinoresinol. Durazzo *et al.* [41] found a range of total lignan content (same as above) from 154 to 286 μg/100 g dry weight. Lariciresinol and pinoresinol were found at higher concentrations with respect to secoisolariciresinol in most of the items. Obviously, the different raw materials used and their degree of refinement are mainly responsible for the different lignan concentrations in breakfast cereals but, in general, they are a good source of lignans.

As regards the cereals staple foods group, pasta is recognized all over the world as an ingredient of traditional meals, especially in the Mediterranean regions [51]. Recent statistics indicate that 26 kg/person of pasta are yearly consumed in Italy [52]. In raw Italian semolina pasta, total lignan content (*i.e.*, the sum of secoisolariciresinol, lariciresinol and pinoresinol) was reported to be 76 μg/100 g dry weight [41]. The concentration of lignans in pasta is relevant considering that pasta is a staple food in the diet of some populations and it is consumed daily.

Pasta undergoes cooking before consumption so it is also important to consider the influence of domestic cooking on the lignans present in the raw pasta. Milder *et al.* [11] reported for cooked macaroni, cooked white rice and cooked whole rice values of total lignan content of 16, 7 and 40 μg/100 g wet basis, respectively.

As regards *other cereal products*, puffed barley represents a good source of lignans and the most representative component amongst the identified lignans is lariciresinol [41]. The level of total lignans (*i.e.*, the sum of secoisolariciresinol, lariciresinol and matairesinol) in puffed barley matched that observed in dehulled barley grains. So, again, the raw material and its degree of refining determines mainly the amount of bioactive substances, lignans in particular, which are found in raw processed foods.

This database, which is limited and can be updated as new data become available, can nevertheless for the time being be useful for several purposes such as understanding the potential effects of specific

lignans in epidemiological studies or estimating the human dietary exposure to lignans coming from cereal based foods.

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## Conflict of Interest

The authors declare no conflict of interest.

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