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Dietary Alkylresorcinols and Lignans in the Spanish Diet: Development of the Alignia Database

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ABSTRACT: The intake of alkylresorcinols and lignans in Spain is unknown due to the lack of information on the content of these compounds in particular foods. This paper describes the development of the first alkylresorcinol and lignan database adapted to the Spanish diet, including foods items especially relevant for this population. The values of alkylresorcinols and lignans in common foods and beverages were collected from scientific publications in refereed journals, and other foods particularly consumed in Spain, for which values were not available, were analyzed by standardized protocols and included into the database. The Alignia database presents the content of alkylresorcinols in 88 food items and the lignan content of 593 foods and beverages. Using the database, the intake of lignans in Spain, calculated using data from the Food Composition Panel based on household consumption, was estimated to be 0.76 mg/day.

KEYWORDS: alkylresorcinols, lignans, phytoestrogens, database, intake, food composition

INTRODUCTION

The prevalence of cardiovascular disease (CVD) in occidental societies increases steadily,[1] and its association with inappropriate food habits has been largely proved.[2] This is of special relevance to the Mediterranean countries, where traditional dietary patterns are nowadays displaced by Westernized lifestyle habits.[3] Energy balance, together with saturated fat and cholesterol intake, are surely the major determinants of CVD, but there are other nutrients and diet-derived compounds that are also related with cardiovascular risk modulation. There is a large body of evidence concerning the protective role of a cereal-rich diet on the development of CVD risk factors. However, the molecular mechanisms underlying this effect have not been yet fully identified. Dietary fiber seems to play a relevant role in this association, and it has been recently hypothesized that minor compounds in the fiber complex can be partly responsible for this effect.[4]

Epidemiological studies showed that regular consumption of whole grains may protect against CVD, and different bioactive compounds, particularly those present in the bran fraction, are currently acknowledged to participate in this effect.[4] Alkylresorcinols (AR) are amphiphilic phenolic compounds deriving from 1,3-dihydroxybenzene with an odd-numbered alkyl chain at position 5 (5-*n*-alkylresorcinols). The length of this string defines six AR homologues (Figure 1): C15:0, C17:0, C19:0, C21:0, C23:0, and C25:0, C17:0 and C21:0 being the most abundant.[5] High amounts of AR are found only in whole grain wheat and rye, mostly in the bran fraction,[6] although much lower levels can also be found in other cereals such as barley and corn, but not in rice. Once ingested, AR are incorporated into biological membranes that may affect their permeability and stability.[7] In vitro, AR lack antioxidant power but, as components of biological membranes, prevent peroxidation of phospholipids[8] and autoxidation of triglycerides and fatty acids.[9]

Also abundantly present in whole grains, lignans (LG) are diphenolic compounds widely distributed in the diet as part of the fiber complex, partly integrated into the lignin polymer.[10] In Figure 1 the chemical structures of the most abundant dietary LG are presented. Dietary LG are also present in oilseeds, legumes, and cruciferous vegetables.[11] Once ingested, LG can be partially absorbed[12] or further metabolized to enterolactone (ENL), the main LG metabolite. ENL and its immediate precursor, enterodiol (END), are formed by microbial fermentation of the nonabsorbed fraction of the LG in the colon. Because of its plant origin, the urinary levels of ENL correlate with dietary fiber intake,[13] and consequently its use as a biomarker of this intake has been proposed, although this hypothesis has not been proved to date. Moreover, the presence of ENL in plasma has been inversely and dose-dependently associated with the risk of myocardial infarction,[14] coronary heart disease mortality,[15] plasmatic concentration of F2-isoprostanes,[16] plasma lipids,[17] and arterial pressure.[18]

The intake of AR has been estimated in the United Kingdom and Sweden to be 12−17 mg/day, using household questionnaires.[19] Daily intake estimations have also been calculated for LG in The

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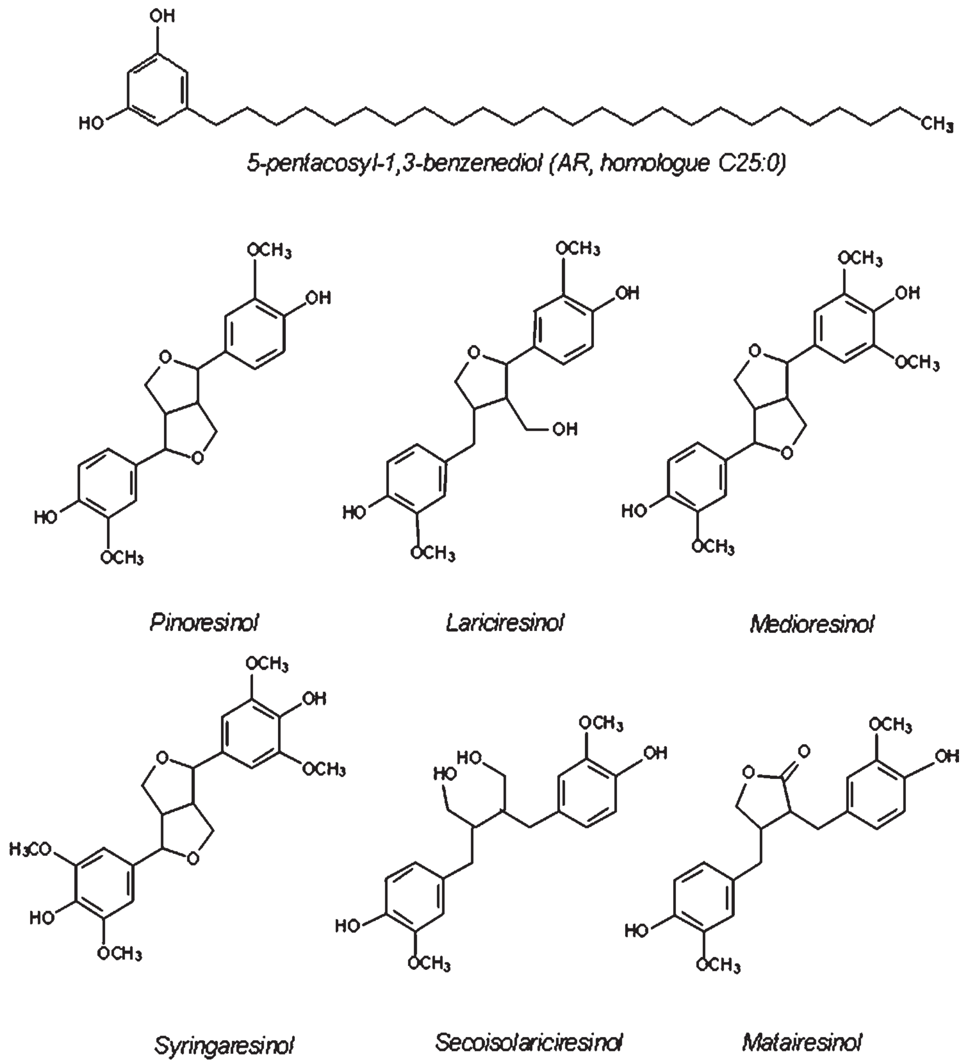

Figure 1. Chemical structures of alkylresorcinols (homologue C25:0) and the most common dietary lignans.

Netherlands (1.24 mg/day) and Canada (0.85 mg/day)[20,21] on the basis of food frequency questionnaires. To assist in the calculation of these intakes in Spain and further the association with CVD end points in epidemiological studies, this paper describes the development of a custom database for AR and LG content in foods.

MATERIALS AND METHODS

The development of the database consisted of consecutive steps: literature search, data compilation, quality evaluation, additional food analyses, data aggregation, and exportation to an accessible database.

Literature Search and Data Compilation. Systematic searches were carried out in PubMed, WOK, Scifinder, and Scirus scientific databases from 1996 to 2010 using the following terms: acetoxypinoresinol* or alkylresorcinol* or hydroxymatairesinol* or isolariciresinol* or lariciresinol* or lignans* or matairesinol* or medioresinol* or pinoresinol* or secoisolariciresinol* or sesamin* or syringaresinol*. References for values considered in already available databases, especially those contained into the Phenol-Explorer database, were also pulled for consideration.[22,23] The references containing quantitative information were identified by reviewing the abstract, and full papers were collected. References were subsequently reviewed by pairs and pulled for data extraction if they met minimum quality criteria consisting of (1) article written in English, (2) analytical method used based on gas or liquid chromatography, (3) values preferentially expressed in wet weight or moisture content available, and (4) duplicate analyses.

Quality Evaluation. Although a primary standard for data quality was established before the literature search, several entries for the same food item and a wide variation in the data were anticipated. On the basis of previously used criteria for similar compounds in foods,[22,24] a system for classification according to data quality was developed (Table 1): Analytical method, in relation to the use of appropriate extraction techniques, reporting of validation parameters, and limits of detection, the number of samples and their origin, and the impact factor of the journal in which data were published were the main criteria considered.

Incorporation of Additional Food Items. The database was cross-checked with the data on food consumption in households and commercial catering facilities and workplaces in Spain, based on the Food Consumption Panel survey conducted by the Spanish Ministry of the Environment and Rural and Marine Affairs (in Spanish, MARM).[25] Monthly data during the year 2009 were retrieved, and only food items exceeding 15% of household buyers (food's market penetration) were considered for additional analyses. Additionally, food frequency questionnaires from two large epidemiological studies designed for the characterization of Spanish dietary habits[26,27] were reviewed for the identification of food items not currently

Table 1. Confidence Codes and Criteria To Evaluate Analytical Data

quality index	analytical method	sampling	journal impact factor
0	none	not reported	not reported
1	not reported	no. of samples: 1−4	0−2
2	modified and published	no. of samples: 5−9 handling documented non-European origin	2−4
3	appropriate methodor prior database[a]	no. of samples: ≥10 handling documented European origin	4−8

sum of scores	confidence code (explanation)	proportion (% of data) LG	proportion (% of data) AR
9−7 points	A (confidence in the mean value)	83	64
6−4 points	B (some confidence in the mean value)	17	34
0−3 points	C (low confidence in the main value, only an estimate)	0	2

[a] Should include sample pretreatment (hydrolysis to aglycone), use of internal standards.

Table 2. Maximum and Minimum Values of Total Lignans in Different Food Groups

food group	maximum (μg/100g wet weight)	minimum (μg/100g wet weight)
vegetables		
vegetables and vegetable-based products	artichokes (3883.6)	new potatoes (1.0)
legumes and legume-based products	carob bean (16742.5)	soybean sprouts (0.9)
soy products and meat substitutes	edamame (509.2)	miso soup (2.8)
soy-added dishes	canned chili (32.4)	buns (English muffins) (0.0)
fruits	avocado (1046.8)	Elstar apple (1.0)
herbs and spices	basil (548.7)	watercress (15.0)
others	black licorice (415.1)	chocolate cake (1.5)
grains		
breads	flaxseed bread, whole grain (12091.0)	wheat bread white (3.8)
breakfast cereals	muesli, extra fruit (381.0)	puffed rice (4.0)
biscuits and snacks	crackers (481.5)	chocolate cookies (1.9)
cereal grains, brans, germs, and flour type foods	rye (10377.0)	sweet corn, tinned (1.0)
pasta and noodles	stuffed pasta with meat (116.5)	noodles, chicken soup (0.1)
oilseeds and nuts	flaxseed (1265860.0)	poppy seed (10.0)
animal		
formulas	baby formulas (35.0)	NA
cheese	Cheshire cheese (41.0)	feta cheese (5.0)
egg and egg products	egg yolk, raw (12.0)	egg whites, raw (2.0)
fish and seafood	prawns, frozen (3.0)	tuna, canned (1.0)
honey	honey (38.9)	NA
ice cream and desserts	trifle cake (17.0)	chocolate mousse (4.0)
meat	lamb liver, grilled (23.0)	ham (0.6)
milk and related products	cream UHT for coffee (57.0)	cow's milk (1.0)
fats		
animal	butter, slightly salted (5.0)	butter, unsalted (1.0)
vegetable	sesame oil, white sesame seeds (1860000.0)	extra virgin olive oil, Picual (10.0)
drinks		
alcoholic beverages	red wine, Tempranillo (145.0)	beer, bitter, best/premium (1.0)
coffee	coffee, instant powder (920.0)	coffee, grounded (3.9)
tea	chamomile tea, dry leaves (5959.3)	chamomile tea, brewed (1.0)
other	packet soup (183.9)	horchata (tigernut beverage) (34.6)

Table 3. Maximum and Minimum Values of Total Alkylresorcinols in Different Food Groups

food group	maximum (μg/g wet weight)	minimum (μg/g wet weight)
barley		
grain	barley (103.1)	barley (3.5)
bran, germ, and flour	barley flour, whole grain (32.0)	barley flour, whole grain (7.1)
rye		
grain	rye (1444.0)	rye (120.0)
bran, germ, and flour	rye flour (2034.0)	rye bran, spring Profilic (17.0)
bread, crackers	rye, softbread, whole grain (1007.0)	rye bread (61.0)
pasta and noodles	pasta with rye bran (262.0)	NA
breakfast cereals	whole grain rye flakes (721.0)	rye breakfast cereals (683.9)
triticale		
grain	triticale (950.0)	triticale (439.0)
bran, germ, and flour	triticale flour (2710.0)	triticale bran, spring (6.0)
bread, crackers	triticale whole grain bread (80.0)	NA
wheat		
grain	wheat (1480.0)	wheat (45.9)
bran, germ, and flour	wheat flour, cookies, and crackers (2700.0)	wheat bran (0.1)
bread, crackers	whole grain wheat crackers (6085.0)	whole grain mixed wheat/rye bread (25.9)
breakfast cereals	whole wheat, rye, flax breakfast cereal (1784.0)	wheat breakfast cereals (53.0)
pasta and noodles	wheat pasta, refined (435.5)	pasta, wheat (32.1)
other cereal product		
	whole grain bread (508.0)	wholegrain couscous (15.1)

Table 4. Lignan Content[a] in Selected Food Products

	μg/100g wet basis						
food	SECO	MAT	LAR	PIN	SYR	MED	total
carob bean (*Ceratonia siliqua* L.)	1266.51	108.41	1770.74	294.99	12965.7	336.08	16742.4
chamomile tea (dry leaves)	440.67	0.00	0.00	2798.51	2444.09	276.00	5959.28
pennyroyal tea (dry leaves)	26.31	0.00	977.31	2057.59	812.08	297.23	4170.52
artichokes	171.45	0.00	153.76	3479.71	21.89	56.65	3883.47
gofio (Canary Islands' toasted cereal flour)	25.09	0.00	68.89	48.38	1108.51	14.72	1265.59
lentil (*Lens culinaris* L. armuña)	1.38	245.17	233.24	86.93	196.63	17.74	781.10
bean (*Phaseolus vulgaris* L. carilla)	240.02	9.30	422.45	20.85	16.98	2.83	712.43
broad bean (*Phaseolus vulgaris* L. granja)	240.39	34.89	319.23	24.67	57.34	4.77	681.29
bean (*Phaseolus vulgaris* L. pola)	153.20	19.46	218.24	38.87	186.57	20.81	637.15
Bean (*Phaseolus vulgaris* L. plancheta)	140.47	10.89	248.01	33.43	157.70	19.80	610.31
crackers	38.71	5.26	79.85	244.17	107.02	6.44	481.45
pea (*Pisum sativum*)	2.73	6.79	150.59	79.81	175.36	24.20	439.48
bean (*Phaseolus vulgaris* L. bolos)	139.15	29.00	92.79	48.86	69.51	19.12	398.45
baby purees, five cereals	21.02	0.00	52.31	40.97	268.02	7.61	389.92
toasted corn	14.46	0.00	15.33	0.00	331.55	3.01	364.35
cereal bars	25.53	1.42	47.95	142.32	106.91	4.90	329.04
bean (*Phaseolus vulgaris* L. canela)	92.99	21.03	88.27	47.39	31.53	15.90	297.11
bean (*Phaseolus vulgaris* L. garrafons)	167.85	11.70	32.02	2.90	72.26	2.41	289.14
almorta (*Lathyrus sativus* L.)	61.37	18.30	134.89	5.21	60.83	3.89	284.49
breadsticks (whole flour)	19.44	0.00	32.48	23.37	195.59	6.28	277.16
cereal bars with chocolate	22.25	1.90	31.71	41.29	145.04	6.03	248.22
chickpea (*Cicer arietum* L. lechoso)	2.61	87.75	133.75	8.22	1.81	0.00	234.14
loquats	0.28	0.00	6.90	179.99	23.43	9.62	220.21
polvorón (Spanish Christmas shortbread)	29.43	0.00	26.07	24.89	110.55	4.12	195.06
chickpea (*Cicer arietum* L. castellano)	1.15	98.82	83.73	7.11	1.82	0.00	192.63
baby purees, eight cereals	10.25	1.94	23.11	16.90	132.52	2.86	187.57

Table 4. Continued

food	μg/100g wet basis						
	SECO	MAT	LAR	PIN	SYR	MED	total
turrón (Spanish Christmas almond paste)	110.17	0.00	52.11	18.55	5.24	0.49	186.55
packet soup	37.92	0.00	22.83	29.16	91.14	2.92	183.96
savory snacks	19.07	0.00	11.18	0.00	143.28	2.77	176.30
flat peach (*Prunus persica* platycarpa)	3.67	0.00	9.67	138.05	0.97	1.51	153.87
white bread	7.44	0.00	14.75	9.02	108.60	2.87	142.68
parboiled rice	8.44	0.00	59.20	21.07	44.25	3.25	136.21
tea biscuits	40.42	0.00	12.26	6.45	70.38	2.02	131.53
marmalade	32.15	0.00	14.91	51.01	24.74	1.31	124.12
breadsticks	8.56	0.00	14.21	11.47	85.83	2.86	122.93
croissant	33.10	0.00	9.99	0.00	73.57	1.89	118.56
stuffed pasta with meat	9.53	0.00	16.92	7.69	80.31	2.05	116.48
Marie (rich tea cookies)	18.20	0.00	13.50	5.62	73.46	1.75	112.54
marzipan	54.11	0.00	32.32	17.24	6.03	0.23	109.92
churros (spanish doughnut)	4.86	0.00	21.35	8.29	69.07	2.16	105.73
stuffed pasta with cheese	9.06	0.00	18.14	8.40	63.21	1.98	100.79
Ribera red wine	39.58	3.06	21.89	8.15	22.89	1.08	96.66
dark chocolate	17.42	0.00	24.34	28.74	22.87	0.00	93.37
Rioja red wine	42.54	3.13	21.62	6.69	18.30	0.95	93.24
gazpacho (Spanish vegetable soup)	12.70	0.00	56.18	13.93	6.64	0.76	90.21
baby purees, gluten free	8.98	0.00	10.94	5.43	56.79	0.00	82.13
puff pastry	33.45	0.00	4.57	0.00	42.43	1.38	81.83
almond chocolate	32.77	0.00	25.78	11.70	8.21	0.00	78.46
pastries	21.41	0.00	12.26	0.00	42.18	1.38	77.23
pennyroyal tea, brewed	0.00	0.00	18.16	39.92	11.43	4.14	73.65
chamomile tea, brewed	3.67	0.00	13.00	22.85	22.56	2.29	64.37
honey	8.51	0.00	10.93	14.63	4.61	0.23	38.91
little cakes	5.84	0.00	4.40	6.20	20.87	0.68	37.99
horchata (tigernut-based beverage)	1.63	11.93	2.96	1.14	16.64	0.44	34.74
cava (Spanish sparkling wine)	20.82	2.23	8.30	0.00	0.00	0.00	31.35
sponge cake	4.36	0.00	2.92	0.00	22.77	0.00	30.05
Muscat white wine	11.04	1.48	8.69	1.79	3.58	0.00	26.58
cereal yogurt	1.30	0.00	3.90	2.94	16.94	0.64	25.72
pickles	9.26	0.00	8.59	5.15	0.52	0.31	23.82
milk and juice beverage	5.65	0.00	2.34	6.21	8.40	0.25	22.84
fruit yogurt	5.06	0.00	3.87	10.96	1.86	0.00	21.75
Rueda red wine	12.73	1.27	3.61	2.31	1.61	0.00	21.54
Albariño white wine	9.81	1.86	4.78	2.43	0.00	0.00	18.87
finos (Spanish sherry)	5.20	0.00	0.83	0.00	1.36	0.00	7.38
rice pudding	1.16	0.00	0.58	0.00	3.97	0.32	6.03
curd	0.00	0.00	0.00	0.00	0.00	0.00	0.00
custard and cream caramel	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[a] Lignan content of composite (three different samples of the same food item) samples. Results were accepted if variation within analytical replicates was <15%.

present in the scientific literature. All relevant AR-containing foods were described in the literature, and further analyses were not considered to be necessary. For LG, a total of 67 food items with a high consumption in Spain lacking information on LG content were identified. Foods were purchased in supermarkets of the Madrid area, in at least three different locations and three different brands. Samples were then combined, homogenized, and freeze-dried before storage and shipment to the Folkhälsan Institute for Preventive Medicine, Nutrition and Cancer, Helsinki, Finland, where analyses were carried out according to a previously reported protocol capable of simultaneously analyzing the main dietary lignans, for example, secoisolariciresinol (SECO), matairesinol (MAT), lariciresinol (LAR), pinoresinol (PIN), syringaresinol (SYR), and medioresinol (MED).[28] Briefly, composite samples were added with individual C^{13}-labeled internal standards (School of Chemistry, University of St. Andrews) to ensure correct accuracy and precision. Samples were then submitted to alkaline and overnight enzymatic (β-glucuronidase) hydrolysis, further extracted by solid-phase extraction (C18 cartridges, Waters, Milford, MA), purified on ion-exchange chromatography (DEAE-Sephadex, Pharmacia Biotech AB, Uppsala, Sweden), and

Table 5. Estimated Consumption of Total Lignans According to Data from the Food Composition Panel (2009) of the Spanish Ministry of Environment and Rural and Marine Affairs (MARM)

		lignan intake (μg/day)	
	total food intake (g/day)	median	IQR
rice	13.0	0.9	0.6−11.0
pasta	12.5	0.6	0.2−1.3
bread	125.8	110.7	14.9−247.2
pastries/cakes/biscuits/cereal	40.3	6.4	2.5−27.7
fruits and vegetables	519.1	233.6	51.9−617.8
potatoes	98.1	1.0	0.9−2.8
legumes	10.5	2.4	0.6−16.7
oils and fats	49.3	254.2	92.5−1715.4
milk and related products	350.7	31.5	17.5−49.1
eggs	29.4	0.5	0.6−1.4
meat and meat product	167.1	5.0	3.1−8.3
fish and seafood	94.1	0.4	0.0−1.6
sweets	24.2	1.5	8.9−15.6
wine and beer	183.1	78.0	42.6−167.5
distilled beverages	11.8	2.0	0.3−3.8
nonalcoholic beverages	226.1	24.8	11.7−46.6
total		**761.7**	**242.1−2934**

derivatized to be subsequently injected into the gas chromatographic system coupled with a Fisons MD 1000 mass spectrometer (Fisons Instrumentation, Inc., Manchester, U.K.).[28] Control samples were included at the end of each series, and data were accepted when the coefficient of variation values for the controls differed <15%.[28] The limits of detection for each analyte ranged from 6.16 (SECO) to 16.1 (PIN) μg/100 g (dry basis). Samples were analyzed in duplicate, and mean values were again accepted when the CV was <15%. The accuracy of the method was guaranteed by the use of the isotope dilution technique by which any possible loss during sample pretreatment is automatically corrected.

Data Aggregation and Export. The Microsoft Access data were exported to a MySQL database, and a wed application on PHP/AJAX/jQuery was developed to improve the user experience when querying the data. The publically accessible database runs on Apache 2.2 for Linux LFS on the following address: www.alignia.org.

RESULTS AND DISCUSSION

The Alignia database is the first comprehensive compilation of values for AR and LG publically accessible. In its development, quality data assurance was one of the main objectives. Many factors may affect the quality of the data, one of them being the analytical method used for the quantification of these compounds. Analytical values using isotope dilution as internal standards and either gas or liquid chromatography−mass spectrometry were considered to be preferable because this was the most sensitive analysis available, having the lowest level of detection.[29] Values obtained by HPLC were also considered if no values by MS were available, as HPLC is less sensitive to the detection of low concentrations of the compounds. Another highly relevant aspect to consider is the extraction method used in the literature. Acid hydrolysis effectively breaks the ester linkages and the glycosidic bonds, but also may affect the molecular structure, causing interconversions between LG.[30] On the other hand, alkaline hydrolysis is not effective enough in some instances, particularly in strong matrices such as fiber-rich foods, leading to underestimation of MAT in particular.[30] According to the criteria described, 59 scientific papers containing LG and AR levels in food were identified to meet our standards. All new food items analyzed for LG levels were scored A, as a standardized protocol was used for their quantification.[28] The general quality assessment of this database, based on the sum of the quality indices, shows that an elevated proportion of the data resulted in confidence codes A (83% LG and 64% AR) and B (17% LG and 34% AR). Only 2% of the data belonging to the AR database are present in confidence C (Table 1).

The Alignia database contains information of 5 different AR homologues (AR17, AR18, AR21, AR23, and AR25), as well as information on a total of 13 dietary lignans, 6 of them (SECO, MAT, LAR, PIN, SYR, and MED) commonly found in the literature, plus the less common secoisolariciresinol sesquilignan, 7-hydroxymatairesinol, 7-oxomatairesinol, acetoxypinoresinol, and sesamin, and the two enterolignans (ENL and END) found only in animal food items. The database contains 565 entries for AR in 88 different foods divided into 5 categories: barley (2), rye (14), triticale (4), wheat (39), and other cereal products (29). Each food includes name, variety/cultivar (when available), country, preparation method, moisture, AR homologue composition (%), total AR content (μg/g wet weight), quality index (score), and references. For LG, the database contains 1390 entries corresponding to 593 foods and beverages divided into 5 categories, that is, vegetables (263), grains (183), animal products (113), beverages (26), and fats (8). All entries for LG contained values for SECO and MAT, and from this 343 had values for PIN and LAR and 96 contained also values for SYR and MED. Values for ENL and END were found for 104 animal products. Each entry describes name and variety/cultivar (when available), preparation method, moisture, content of individual and total lignans (μg/100 g wet weight), quality index (score), and references.

Items are sorted alphabetically within their corresponding group. As different cooking techniques affect the levels,[31] in those cases when that information was available, data on the preparation/processing were included. Otherwise, food was untreated. Units were chosen to allow for comparison with other published values.[32] Both AR and LG content in foods fluctuate significantly as can be seen in Tables 2 and 3, where data are shown as maximum and minimum values. The lower limits of the interval of AR and LG values for the different groups of foods are zero or nearly zero. In Table 4 the LG content of 67 foods highly consumed in Spain is presented.

The database presented in this paper contains a large number foods resulting from a comprehensive review and compilation from scientific papers in refereed journals, including the papers we considered to be most relevant in the field of dietary LG research.[11,30,33−35] These data were complemented with additional analyses of LG in food items not previously quantified.

The Alignia database contains a systematic collection of data on the content of AR and LG, including those foods particularly relevant to the Spanish diet. It is especially important due to the lack of data on the intake of these compounds in Spain, where the consumption of foods rich in LG and AR, such as cereals and legumes, is relatively high. As an example of its potential application, the estimated consumption of LG in Spain calculated using data from the Food Composition Panel based on household consumption[22] was 0.76 mg/day (Table 5). This estimation is low compared with the intake previously reported for some European countries such as The Netherlands[20] and France,[36] which were calculated using more accurate dietary assessment tools, that is, food frequency questionnaires. In our estimations, the major contributors to LG intake are oils and fats (33%), fruits and vegetables (30%), bread (14%), and wine and beer (10%). Accurate estimations for AR were not possible due to the high degree of aggregation of the data, not differentiating between whole grain and refined cereal products.

Despite the good data quality of the database, an important limitation observed is the lack of a complete LG profile in many of the literature values compiled in which only SECO and MAT values are reported. Another limitation implicit in most food composition databases is the variability in the composition of foods from different countries, crops, varieties, or brands.

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Author Contributions

B.M.-F. interpreted the data and wrote the manuscript. A.G.-G., A.M.-B., E.I.-G., and N.U. carried out the food sampling and contributed to database development; L.M.-N. contributed to database development and quality cross-check; H.A. supervised the analysis of food items and revised the manuscript; J.L.P. designed the study and wrote and revised the manuscript. All authors read and approved the final version of the manuscript.

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ABBREVIATIONS USED

AR, alkylresorcinols; CVD, cardiovascular disease; END, enterodiol; ENL, enterolactone; LAR, lariciresinol; LG, lignans; MAT, matairesinol; MED, medioresinol; PIN, pinoresinol; SECO, secoisolariciresinol; SYR, syringaresinol; WOK, Web of Knowledge.

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