

Association Between Lignan Intake from Different Types of Plant-Based Foods and Obesity Indicators in the Netherlands

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Abstract This study aimed to assess whether lignan intake is associated with lower body mass index (BMI) and waist circumference in a Dutch population. Data on lignan content of foods was extracted from a lignan database of Dutch plant-based foods and complemented with three other references to estimate lignan intake in 1012 Dutch men and women participating in the NQ-plus prospective cohort study. The association between lignan intake and BMI and waist circumference was assessed using linear regression analysis. Three multivariate models were used to investigate the association of BMI and waist circumference with total lignan intake. Model 1 included adjustments for lifestyle variables, in Model 2 adjustments were made for energy intake and nutrients, and in Model 3 these adjustments were combined. The median lignan intake was 3226 µg/day (mean 4763 µg/day, SD 5386 µg/day). Lignan intake was strongly skewed towards higher values, ranging from 40-50500 µg/day. The major sources of lignans were bread, which contributed 52%, nuts, seeds, and snacks (21%), and vegetables (12%) to the lignan intake. After adjustments, lignan intake was associated with a lower waist circumference (-0.93 cm, 95% CI: -0.88; -1.00). No association between BMI and lignan intake was observed. A higher lignan intake is significantly associated with a smaller waist circumference in Dutch adults. To what extent a high lignan intake can reduce waist circumference in obese patients or prevent the onset of abdominal obesity remains to be tested in future intervention studies.

Keywords: body mass index, waist circumference, NQ-Plus data

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1. Introduction

The global obesity epidemic has tripled rapidly in various populations and all age groups. Obesity increases the risk of chronic diseases such as type 2 diabetes, cardiovascular diseases, certain cancers, dyslipidemia, poor mental health, and osteoarthritis [1]. Furthermore, obesity is one of the main factors for respiratory tract infections and functional capacity, impacting pulmonary function due to specific inflammation and immunological conditions. In addition, novel findings indicate that visceral obesity and characteristics of impaired metabolic health such as hyperglycemia, hypertension, and subclinical inflammation are strong and independently associated with a high risk of morbidity and mortality from severe SARS-CoV-2 infection/COVID-19 [2].

Lignans are plant-derived diphenolic compounds that belong to the phytoestrogen class and are structurally similar to the estrogen hormone 17-estradiol [3]. They

occur in edible plants [4] and are abundantly found in flax and sesame seeds [5]. Oilseeds, nuts, cereals, vegetables (Brassica species), fruits, and beverages (tea, coffee, beer, and wine) are the major sources of lignans in the European diet [6]. Secoisolariciresinol (SECO) is the most abundant lignan, whereas matairesinol (MATA), pinoresinol (PINO), and lariciresinol (LARI) occur as minor components [7]. Intestinal bacteria can convert some plant lignans to enterolignan metabolites: enterodiol (END) and enterolactone (EL), under strictly anaerobic conditions. These metabolites are inversely related to weight loss [8]. Studies on lignans have tried to explain the mechanisms responsible for weight reduction and their relation to lipid metabolism [9].

A study involving 3438 young Spaniards between 2–24 years old investigating the prevalence of obesity-related to lignan intake found a strong association between dietary lignan intake and prevalent obesity for boys, with an odds ratio of 0.34 (95 % CI, 0.17–0.70) in the highest versus lowest quartile of lignan intake (10). Similarly, a 10-year prospective cohort study on weight change of U.S. women

observed that the annual weight change rate among women in the highest quartile of total lignans intake was 0.20 kg less (95 % CI: -0.36, -0.04) than that among women in the lowest quartile [11]. Previously, Milder et al. performed a study to estimate the intake of lignans in a large, representative Dutch population sample using the National Food Consumption Survey 1997-1998 [12] by using the lignan database of Dutch plant foods containing 83 solid foods and 26 beverages. In brief, the study showed that the amount of lignan intake in the population had previously been underestimated [13]. The survey was conducted in 1998.

Nevertheless, there are some limitations of the aforementioned studies, which only involved young participants aged 2-24 [10] or women [11], while the study from by Milder was conducted more than ten years ago and only included 109 foods and beverages [12]. Hence, to estimate current intakes, our study aimed to assess lignan intake from plant-based foods in a Dutch population aged 20-70 years using an updated database, the Nutrition Questionnaires Plus (NQ-plus) study conducted between 2011 to 2013. Additionally, the association between lignan intake, body mass index, and waist circumference was assessed as indicators of obesity.

2. Material and Methods

2.1. Design and Study Population

The NQ-plus study is a prospective cohort study initiated by researchers of the Division of Human Nutrition of Wageningen University. This study started in May 2011 to pinpoint the specific dietary factors responsible for obesity and adverse cardiometabolic health outcomes. 1012 men and women aged 20-70 years living in Wageningen, Ede, Renkum, and Arnhem, the Netherlands, were included [14,15].

Baseline measurements consisted of the assessment of dietary intake by multiple telephone-based 24-h recalls (24hR), a physical examination, including measurement of anthropometrics (e.g., weight, height, blood pressure), and general and lifestyle questionnaires (education, health, and smoking habits). This study was conducted according to the guidelines laid down in the Declaration of Helsinki. All procedures involving human participants were approved by the Medical Ethics Committee of Wageningen University and Research. Written informed consent was obtained from each participant [15].

2.1.1. Dietary and Lignan Assessment

Multiple, telephone-based 24-h recalls (24hR) were administered by trained dietitians using the five-step, multiple-pass method, which is a validated technique to increase accuracy [16,17,18]. Dates were randomly selected evenly across the year and days of the week. The foods recorded on the recalls were translated into food codes and food groups using the 2011 Dutch Food Composition Table. All participants with at least two 24hR were included in this study. The record days were equally distributed over the seven days of the week. Average daily dietary intakes were calculated by multiplying the consumption frequency by the portion size

and nutrient content in grams [15]. Out of 2082 reported food items for the 24hR, 290 foods were with known lignan content and were thus selected for inclusion in this analysis. The lignan data was extracted from a lignan content database of Dutch plant-based foods 6 and complemented with data from three published lignan databases from the United Kingdom, Canada, and Japan [19,20,21]. Foods that contained no lignans (0.0 µg), unknown lignan content, or composition were excluded from the calculation. For each person, lignan intake was calculated by multiplying the consumed amount of each food with its lignan content (µg/g) for each recorded day.

2.1.2. Anthropometrics

Height was measured with a stadiometer (SECA, Germany) to the nearest 0.1 cm, and weight was assessed with a digital scale (SECA) to the nearest 0.1 kg. Body mass index (BMI, kg/m²) was calculated as a person's weight in kilograms divided by the square of height in meters. Participants were categorised as normal weight (BMI < 25 kg/m²), overweight (BMI ≥ 25 kg/m²), and obese (BMI > 30 kg/m²) [22]. Waist circumference was measured using a measuring tape (SECA 201) to the nearest 0.5 cm.

2.1.3. Demographic, Lifestyle, and General Health

The general and lifestyle questionnaires included demographics, education, work status, smoking status, and physical activity. Most of these questions were derived from the general questionnaires of the Lifelines study [23]. The education status was divided into three groups which were low, intermediate, and high. Participants with no education or primary or lower vocational education as the highest completed education were classified as low. Meanwhile, lower secondary or intermediate vocational education participants were classified as intermediate education. Participants with a high education level completed higher secondary education, higher vocational education, or university. Smoking status was classified into three categories: non, current, and former smoker. Information about the participants' usual physical activity was obtained using the Short QUestionnaire to ASsess Health enhancing physical activity (SQUASH) [24]. The SQUASH contains questions evaluating the participants' compliance to the Dutch physical activity guidelines, specifically, a physical activity pattern including at least 30 min of moderate-intensity physical activity on ≥ 5 days/week [25].

2.1.4. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics version 25 software (IBM Corp). The initial sample consisted of 7437 participants having the required information. We excluded participants who did not have complete information on all nutrients. Then, we eliminated participants who only had one 24hR record. One participant was excluded from the analyses since she/he provided only nutrient information. Thus, the complete data on all nutrient intake variables with at least 2 days of 24hR were available for 1012 participants. The generated dataset was checked for duplicates and missing values for BMI, waist circumference, education, smoking

status, and physical activity. Automatically generated values replaced all the missing observations in the confounding database through multiple imputations. All the variables were entered in the imputation model, and five imputations were carried out with 10 iterations under a fully conditional specification imputation method. The missing observation represented 5.6 % out of the entire data. Pooled data was used for further analysis [26]. The study population consisted of 1012 participants: 534 men and 478 women. Participant characteristics were reported as means with standard deviation (mean + S.D.), median (IQR), or n (%). ANOVA tests were performed for normally distributed continuous variables, Kruskal-Wallis tests were performed for skewed continuous variables, and chi-square tests were performed for categorical variables to compare the baseline characteristics over tertiles of total lignan intake. The energy intake was based on participants' total dietary intake, and the value was used for the energy adjustment.

The contribution of individual foods and food groups to the mean lignan intake was calculated, and the percentage of users of each food or food group was determined. Mean lignan intakes for men and women, adjusted for age, and intakes in age categories adjusted for gender were compared using analysis of covariance after log transformation of the individual lignan intakes. Similarly, mean lignan intakes stratified by other selected lifestyle characteristics were adjusted for age and gender.

In addition, three multiple regression models were used to investigate the association between BMI and waist circumference and total lignan intake. The waist circumference was used as an outcome variable as it is the simplest, most practical, and accurate measure of abdominal obesity for practice in public health research [27,28]. We applied the Z-score calculation to standardize the variables with a 1-SD increase in intakes of total lignan. The model with crude (unadjusted energy) and energy-adjusted results were compared with three multiple regression models. A list of potential confounders was selected from published research on lignan intake to

obesity. Ethanol intake, physical activity, and education are listed as potential risk factors for obesity and may be correlated with lignan intake. Smokers have greater oxidative stress than non-smokers; thus, the lignans' antioxidant effects might be more marked in smokers. In addition, dietary fiber intake may influence the lignan bioavailability, affecting intestinal transit time [29]. Model 1 included adjustments to the lifestyle variable: age, sex, education, smoking status, ethanol consumption, and physical activity with energy-adjusted. In model 2, adjustments were made for macronutrients, and fiber with energy adjusted. Model 3 (full model) was the adjustment variables of models 1 and 2. The residual method was used to adjust for energy intake. P-values were considered significant if $P \leq 0.05$.

3. Result and Discussion

3.1. Lignan Intake

Mean lignan intake of the study population was 4763 $\mu\text{g/day}$ (ranging from 40 to 50500 $\mu\text{g/day}$) on the average days surveyed, and was strongly skewed towards higher values (Figure. 1). The correlation of lignan intake between the two non-consecutive days of recalls was low ($r = -0.009$, $P = 0.69$), indicating a large day-to-day variation.

There was no significant difference in total lignan intake between men and women in this population (Table 1). Our finding is by the study of Milder et al. [12], reporting no significant difference in lignan intake according to gender. In contrast, in a Finnish study total lignan intake was shown to be higher in men than in women [30]. Also, no differences according to age category, educational level, smoking, or BMI were observed for all participants (data not shown). Participants in the highest tertile of total lignan intake had a lower waist circumference than those in the lowest tertile ($P = 0.008$) (Table 1). There was no significant difference in other selected characteristics across the tertiles.

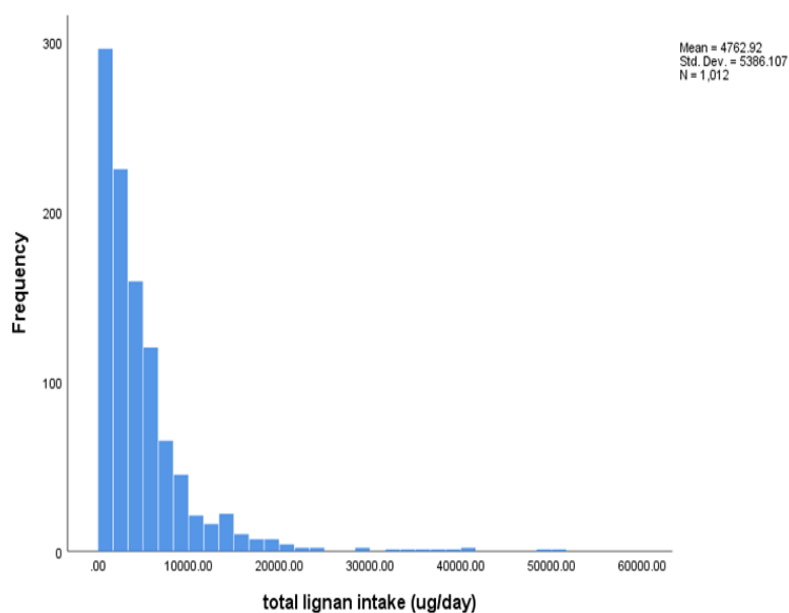


Figure 1. Distribution of total lignan intake among 1012 participants in the NQ-Plus study

Table 1. Selected baseline characteristics and nutrients by tertile of lignan intake among 1012 participants in the NQ-Plus study

Tertile	Total	T1 (low)	T2	T3 (high)	P [†]
<i>n</i>	1012	338	336	338	
Lignan intake, µg/day [‡]	3226 (1369-5948)	996 (726-1372)	3226 (2574-3971)	7674 (5943-11351)	
Men	2877 (2642 - 3126)				0.16
Women	3140 (2870 - 3428)				
Sex, men (%)	534 (52.8)	194 (57.4)	159 (47.3)	181 (53.6)	0.03
Age, years [‡]	55 (45-62)	56 (46-63)	54 (45- 61)	52 (44 – 62)	0.09
<i>Age, years (%)</i>					
19-29	61 (6.0)	24 (7.1)	16 (4.8)	21 (6.2)	0.58
30-49	290 (28.7)	88 (26.0)	105 (31.3)	97 (28.7)	
50-69	651 (64.3)	223 (66.0)	213 (63.4)	215 (63.6)	
≥70	10 (1.0)	3 (0.9)	2 (0.6)	5 (1.5)	
BMI, kg/m ^{2†}	25.2 (23.1-28.0)	25.5 (23.4-28.1)	25.1 (23.1-27.9)	25.3 (23.1-27.9)	0.77
<i>BMI category, kg/m² (%)</i>					
<25	461 (45.6)	148 (43.8)	162 (48.2)	151 (44.7)	0.57
25-30	411 (40.6)	147 (43.5)	125 (37.2)	139 (41.1)	
>30	140 (13.8)	43 (12.7)	49 (14.6)	48 (14.2)	
Waist circumference (cm) [‡]	90.5 (82.7-99.0)	92.9 (83.4-99.8)	89.4 (81.6-98.5)	89.5 (82.5-98.5)	0.008
<i>Smoking status, n (%)</i>					
Non	554 (54.7)	172 (50.9)	186 (55.4)	196 (58.0)	0.17
Current	375 (37.1)	136 (40.2)	117 (34.8)	122 (36.1)	
Former	83 (8.2)	30 (8.9)	33 (9.8)	20 (5.9)	
Total Physical activity level, minutes per week [‡]	2212 (1373-2784)	2185 (1211-2805)	2233 (1451-2772)	2216 (1457-2785)	0.39
<i>Education, n (%)</i>					
Low	65 (6.4)	20 (5.9)	25 (7.4)	20 (5.9)	0.36
Intermediate	301 (29.7)	92 (27.2)	111 (33.0)	98 (29.0)	
High	646 (63.8)	226 (66.9)	200 (59.5)	220 (65.1)	
<i>Dietary intake</i>					
Energy, kcal/day [‡]	2064 (1778-2354)	2093 (1797-2363)	2038 (1752-2332)	2039 (1788-2364)	0.17
Dietary fiber, g/day [‡]	22.3 (18.1-26.8)	21.9 (18.0-26.9)	22.4 (17.8-26.7)	22.6 (18.3-26.9)	0.65
Protein, g/day	80.3 (69.0-92.2)	80.9 (69.8-92.9)	79.9 (68.2-94.1)	80.2 (69.3-91.6)	0.78
Fat, g/day [‡]	77.4 (64.1-94.4)	77.5 (65.1-94.0)	76.5 (63.4-95.0)	78.3 (63.9-94.5)	0.60
Carbohydrate/ day [‡]	219.9 (184.3-261.5)	219.5 (184.2-264.7)	218.0 (185.1-256.7)	224.7 (183.8-260.4)	0.37
Ethanol consumption (g) [‡]	8.8 (0.1-18.4)	9.8 (0.0-20.4)	7.2 (0.3-16.6)	9.1 (0.1-18.4)	0.22

*To compare baseline characteristics over tertiles of total lignan intake, ANOVA tests were performed for the mean of normally distributed continuous variables, Kruskal-Wallis tests were performed for a median of skewed continuous variables, chi-square tests were performed for categorical variables. ‡Mean + S.D. (all such values), †Median, IQR in parentheses (all such values).

Milder et al. studied the lignan intake and major food sources of lignans using the Dutch Food Composition Survey from 1997 to 1998 [12]. She reported a mean intake of lignan of only 1241 µg/day, which was far lower than our findings. This may be partly since they accounted for 109 foods while we included lignan intake for 290 foods. Moreover, we included multigrain bread, as this food was reported by our study population in more recent years (2011-2013). As the lignan composition of this food relatively high, this may well account for the higher level of intake we observed.

It concluded that the large variation of the lignan intake in the Dutch population over the 10 years is due to the healthy diet transition to plant-based food. More food in the study contributed to high lignan content, e.g.; flaxseed and multigrain bread. In addition, more lignan food data is available, thus increasing the accuracy of lignan intake.

Furthermore, we examined 102 participants with more than 10,000 µg/day of lignan intake to identify which foods contribute to this high intake level. Moreover, we thoroughly checked the raw data but found no incorrect

code or unusual values in the dataset. Multigrain bread/roll/bun with seeds was an important source for these 102 participants, with an average intake of 110 g/day. Also, flaxseed bread, flaxseed, tea, broccoli, sesame seeds, kale curly boiled, Brussel sprouts boiled, sesame paste tahin, contributed to the high lignan intake. The energy intake of participants with high lignan intake (> 10000 µg/day) ranged from 1076 to 4410 kcal/day. The highest intake of bread and flaxseed were 490 g/day and 18 g/day, respectively (data not shown). We compared the food group intake of participants who consumed more than 10,000 g per day to that of all participants. The high lignan group consumed more flaxseed and multigrain bread than the general population.

The primary source of lignans intake was bread, which contributed 51.6 % of the total lignan intake in this population. The contribution was mainly from multigrain bread with seeds, contributing 48.5 % (Table 2). The second primary source of lignan was the nuts, seeds, and snacks group (21 %), where flaxseed provided the highest lignan mean intake (19.6 %), although the seeds were

consumed only by a small part of the population. The vegetable group was in third place of the total lignan intake, contributing 11.9 %. Boiled kale curly was the major vegetable source of lignan (3.3 %), followed by boiled broccoli, 2.8 %. Tea contributed a similar amount as boiled kale curly, and was the beverage providing the largest contribution to total lignan intake (3.3 %). Fruits contributed to 4.3 % of the lignan intake, and berries were the major lignan fruit source with a contribution of 1.0 %.

Table 2. Full list of total lignan intake and % contribution of food items

Food items	total lignan intake	% contribution	Rank
bread	5065095	51.6	
Bread/roll/bun multigrain average with seeds	4760328	48.5	1
Bread/baguette/roll brown/wholemeal average	100804	1.0	
Crispbread sesame	71250	0.7	
Fruits	418586	4.3	
berries & currants	94045	1.0	9
Pear	58083	0.6	
Avocado	36175	0.4	
Vegetables	1169898	11.9	
Kale curly boiled	322271	3.3	3
Broccoli boiled	270780	2.8	5
Beans French/runner/mangetout boiled	102389	1.0	8
Nuts, seeds & snacks*	2062362	21.0	
Flaxseed	1921095	19.6	2
Sesame seeds	55179	0.6	
Soy product	16811	0.2	
Legumes	5080	0.1	
Cereal	34358	0.4	
Potatoes	30961	0.3	
Herbs & spice	1807	0.0	
Savoury	150896	1.5	
Sesame paste tahin	141902	1.4	6
Pastry, cakes, and biscuits	99266	1.0	10
Sugary product	19045	0.2	
Fat & oil	40366	0.4	
Soup	30511	0.3	
Composite food	57786	0.6	
Milk & milk product	8510.01	0.1	
Miscellaneous	1788	0.0	
Beverages	607647	6.2	
Tea prepared	324193	3.3	4
Coffee prepared	107062	1.1	7
Wine red/port wine	62555	0.6	
Beer	50304	0.5	

* Snack is part of the group, the contribution was lower than 0.1%.

Another cross-sectional study of 301 Dutch women aged 60–75 years reported a lignan intake ranging from 650 ug/day to 2300 ug/day for the lowest and highest quartile [31]. The most common lignan classes were SECO, MATA, PINO, and LARI. In this study, only SECO and MATA were considered, while we and Milder et al. included four individual lignans (SECO, MATA, PINO and LARI). However, PINO and LARI only contribute small amounts to total lignan intake [12], thus we can compare these findings.

Other recent studies report a large range of lignan intake as well. For instance, low mean lignan intake was reported in France (200 µg/day) in a study conducted from 2006 to 2007 (HELENA study) [32]. Similarly, EPIC cohorts observed a low lignan intake in Italy (700 µg/day). Limited information was provided on the lignan content of the products consumed, such as various types of coffee and herbal tea. Also, this estimate was based on a single 24-h recall and the variation includes within-person variation [33].

Meanwhile, the Latvian population generally had a high lignan intake, with the estimated mean lignan intake being 4300 µg/day. This could be explained by a high intake of grain products (86 %), including seed breads which were most commonly consumed [34]. Additionally, the highest lignan intake (9100 µg/day) was reported in a vegetarian/vegan UK population consuming mainly plant-based foods [33].

Our reported total lignan intake was in the range of the Latvian population. Despite study variances, the existence of large multi-center studies such as the European Prospective Investigation into Cancer and Nutrition (EPIC) and the Healthy Lifestyle in Europe by Nutrition in Adolescents (HELENA) permits assessment of lignan intakes across Europe using comparable methods [32,33,35]. However, differences in estimated lignan intake can be due to differences in foods available over the years, population composition, and the lignan food database used. We filled the data gaps in the existing older Dutch database with lignan values with data from three published lignan databases from the United Kingdom, Canada, and Japan [19,20,21], hence we had a few missing values.

The lignan sources in our study were similar to those found in a previous study of women in the Netherlands and Germany, in which bread, nuts, and seeds contributed the most to lignan intake [36]. We observed that flaxseed, multigrain bread, and seeded buns contributed significantly to this population's lignan intake, similar to the main lignan food sources in northern European countries, including Scandinavian and Baltic countries including Latvia [37]. Moreover, in our study, Brassica vegetables such as broccoli, kale curly, and Brussel sprouts were among the sources and contributed more to lignan intake than Milder's previous study. In addition, tea and coffee also contributed to total lignan intake.

Cereals were the major lignans source in most Western countries because of their regular daily consumption [38]. Furthermore, the study by Tetens concluded that cereals and grain products are important contributors to lignan intake in all Scandinavian countries [35]. Other findings showed that the total lignan intake varies among countries due to the different dietary habits [39].

3.1. Association of BMI and Waist Circumference with Total Lignan Intake

We next investigated the association between BMI and lignan intake adjusted for lifestyle and nutrient variables (Table 3). A higher total lignan intake was significantly associated with a lower BMI in unadjusted analysis and model 2 ($P < 0.05$). No significant association was observed when adjusting for lifestyle confounders (model

1) and in the full model. All models significantly associated a higher total lignan intake with a lower waist circumference (Table 3). Moreover, men are significantly associated with a higher total lignan intake with a lower waist circumference in a lifestyle-adjusted and full model. The regression coefficient adjusting for all potential confounders amounts to -0.93 (95 % CI: -0.88; -1.00), indicating that with a 1SD higher lignan intake waist was 0.93 SD lower.

So far, few studies have investigated the relationship between lignan intake and obesity. An observational study of 115 postmenopausal women in Canada showed that the high dietary lignan intake group had a significantly lower BMI and total body fat mass than women in the low lignan intake group [40]. One cross-sectional study indicated that higher lignan intake was associated with less abdominal fat mass [41]. Similarly, a Spanish study observed a strong association between dietary lignan intake and reduced prevalence of obesity for 2 to 24-year-old Spaniards boys [10]. Overall, the aforementioned studies were in line with our findings. They support the notion that increased lignan consumption might potentially lead to less weight gain and reduced waist circumference, an indicator of abdominal obesity.

Although the exact underlying biological mechanisms are not completely clear, several studies have suggested that the enterolignans' estrogenic effects contribute to weight reduction [9]. Lignans have been shown to suppress adipose tissue growth, inhibit differentiation of preadipocytes, stimulate lipolysis, and induce apoptosis of existing adipocytes, thus reducing adipose tissue mass in the cell [42]. In addition, it has been shown that the intestinal microbiota is responsible for metabolizing lignans to enterolignans [43], and this may be one of the pathways through which they affect body weight and fat mass [44].

The present study results should be considered in light of some limitations. We did not assess the habitual intake since at least participants with 2 days of 24HR were included. Although no adjustment for within-person variation was made, the means of the lignan intake remain valid. Residual confounding due to unknown or unmeasured factors and confounding due to other dietary constituents cannot be completely excluded. In addition, lignan intake was estimated by matching daily food consumption and its lignan content obtained from a database, which may not reflect the actual amount of the compounds reaching the target organs after digestion, absorption, and metabolism, and as usual in this type of observational studies, metabolic conversion in the body was not taken into account. Research on the impact of different food matrices and the synergy between various foods in determining bioavailability will be relevant for future studies.

An important strength of our study was that we used a Dutch lignan database [13] that contained lignan data for more than 90 % of our selected foods, and this database was exclusively developed to study the Dutch population. The dataset included all major plant foods in the Netherlands, habitually processed and prepared. On top of that, all values in this database were obtained using the validated LC-MS-MS lignan analysis method [45] with identical sample preparation for all food items.

Table 3. Association of BMI and waist circumference according to intake of lignans among participants in the NQ-Plus study, per 1-SD increase

Total lignan intake B (95 % CI)	P-value	Total lignan intake, B (95 % CI)	P-value	Total lignan intake, B (95 % CI)	P-value
Total population		Men		Women	
BMI (kg/m²)					
Crude (energy unadjusted)					
-0.92 (-0.87; -0.98)	0.01	-0.95 (-0.85;1.04)	0.20	1.04 (-0.95;1.11)	0.37
Energy adjusted					
-0.93 (-0.87; -0.98)	0.01	-0.95 (-0.85;1.04)	0.20	1.04 (-0.96;1.12)	0.38
Model 1					
-0.95 (-0.89;1.04)	0.07	-0.94 (-0.83;1.03)	0.15	1.06 (-0.97;1.11)	0.22
Model 2					
-0.91 (-0.85;- 0.96)	0.00	-0.94 (-0.84;1.04)	0.24	1.10 (-0.96;1.13)	0.35
Full model					
-0.96 (-0.91;1.02)	0.21	-0.93 (-0.83;1.03)	0.17	1.07 (-0.97;1.15)	0.20
Waist circumference (cm)					
Crude (energy unadjusted)					
-0.90 (-0.85; -0.96)	0.00	-0.92 (-0.98;1.00)	0.06	1.00 (-0.92;1.11)	0.87
Energy adjusted					
-0.89 (-0.84; -0.95)	<0.00	-0.92 (-0.98;1.00)	0.06	1.01 (-0.92;1.11)	0.80
Model 1					
-0.92 (-0.86; -0.98)	0.01	-0.90 (-0.98;1.00)	0.03	1.05 (-0.95;1.16)	0.35
Model 2					
-0.88 (-0.83; -0.94)	<0.00	-0.92 (-0.98;1.00)	0.08	1.01 (-0.92;1.11)	0.78
Full model					
-0.93 (-0.88; -1.00)	0.04	-0.91 (-0.98;-1.00)	0.04	1.05 (-0.95;1.12)	0.31

Model 1: age, sex, education, smoking status, ethanol consumption, physical activity, energy intake

Model 2: energy intake, fat, protein, fibre, carbohydrate

Full model: model 1+ model 2

4. Conclusions

In conclusion, the present study results add further evidence to earlier observations of an association between a higher lignan intake and less obesity, as we observed an associated decreased waist circumference in a Dutch population. Future studies, including a prospective design and randomised controlled trials, are warranted to confirm our results and provide additional information about the optimal dietary intake of lignans required to achieve the expected positive health outcomes. Further investigation of the metabolism of lignans to enterolignans by gut microbiota in the colon will also be useful.

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