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Legume flours: Nutritionally important sources of protein and dietary fiber

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Summary

Vegetarian and vegan nutrition have become fashionable. Some consumers now see themselves as partial vegetarians and greatly restrict their consumption of animal products. This has led to an increase in the demand for alternative sources of protein, in the form of legumes and their processed products. Proteins enhance the feeling of fullness and can contribute to lowering blood pressure. Moreover, plant proteins have a favorable effect on lipid metabolism. For this reason, legume flours are important sources of plant protein.

Flours from soya, lupin, chickpea and green pea have been studied. The highest content of protein was found in soya and lupin, which both contained ca. 35 g protein per 100 g. Lupin flour had the highest content of kernel fiber, corresponding to 35 g/100 g soluble kernel fiber. In addition, lupin and soya flour only had a low content of easily digestible carbohydrates: ca. 8–10 g/100 g.

Cereal flour had a high content of starch and a low content of protein and is used in making bread, cakes and pastries; one possibility would be to replace 10–20% of this with legume flour. The amino acids contained in the legume flour would enhance the nutritional value of the cereal protein.

The fat content in legume flours other than soya flour was clearly under 10 g/100 g. The omega-6/omega-3 ratio in lupin and green pea flour was in accordance with the recommended maximal ratio of 5:1. Most legume flours are a good source of magnesium, iron and zinc, as well as of vitamin E, the B vitamins, and carotenoids. Aside from their nutritional and physiological benefits, legume flours are cheaper than protein and fiber extracts from legumes.

For ecological and nutritional/physiological reasons, only plant protein should be used to enrich protein relative to fats and carbohydrates. Lupin is an interesting alternative to soya beans in Europe, as it has a high content of protein. Legume flour can be used to enrich bread, cakes or pastries, or meat products. It supports good health and is easy to process.

Keywords: legume flour, pulses, plant protein, dietary fiber, protein quality, fat quality, carotenoids, vitamins, trace elements

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Introduction

Demand is increasing for grain legumes, such as pea, lupin, beans, and lentils. An increase in the content of grain legumes in food would support sustainable agriculture and nutrition, and would be good for health. The use of grain legumes in Europe needs to be developed. This is why both scientists and politicians are attempting to promote human consumption of these valuable foods. One result has been that the area in Germany under cultivation for pea and broad beans doubled in 2015 relative to the previous year. Highly processed foods are now consumed in large quantities, but have a lower content of protein than conventionally produced foods. "Tasty", cheap, and energy dense components are deliberately selected for processing and manufacturing, with the consequence that the proportions of carbohydrate and fat increases at the expense of protein. Analysis of the nutrient supply in the USA be-

For ecological and nutritional/physiological reasons, protein content of foods should be enriched with legumes: lentils, beans, chickpea or green pea (not depicted) are suitable sources of plant proteins.

tween 1971 and 2006 found that the protein fraction decreased by 1 energy percent (En%) and the carbohydrate and fat fraction increased by 8 En% [1]. Other studies too have indicated "protein dilution" in highly processed food. This leads to an imbalance, which is evident in increased energy uptake from carbohydrates and fat and decreased energy uptake from proteins. Although the German Nutrition Society (DGE) specifies a reference value of 15 En% from protein, there are demands to increase this to 30 En% [2].

For ecological reasons, any increase in protein supply should be exclusively due to additional plant proteins, although 30 En% is certainly too high. This demand is based on the protein leverage hypothesis [3], which assumes that protein appetite exerts a "leverage effect". The hypothesis postulates that the feeling of satiation is mainly determined by the quantity of protein consumed. The proportion of nutritional protein is negatively associated with total energy uptake (F = 6.9; $p < 0.0001$), unrelated to whether the protein is diluted by carbohydrate or by fat [4]. LEE et al. [5] showed that the decrease in the study participants' plasma levels of ghrelin and their feeling of fullness were both much greater after eating a breakfast roll with added lupin flour rather than with a roll of pure wheat flour. Moreover, the calorigenic effect (specific dynamic effect) for protein is 20–30 En%, for carbohydrates 5–15 En%, and for fats 0–3 En% [6].

In addition, in Western countries, there has been a marked trend in recent years towards the development of nutrition which is more plant-based, as this reflects the wish for greater environmental compatibility and sustainability [7]. In animal husbandry (swine or poultry), about 3 kg of plant protein are needed to give 1 kg meat protein. Thus, 2 kg plant protein is lost when 1 kg animal protein is consumed. Aside from this ecological aspect, pro-vegetarian nutritional habits, with a lot of vegetables, fruits, legumes, and nuts, can also reduce the risk of cardiovascular diseases. For example, this has been confirmed by the PREDIMED study, a randomized, controlled clinical study with more than 7,000 volunteers [8]. If the intake of plant protein is increased in isocaloric exchange with carbohydrate or animal protein, this is associated with lower mortality from coronary heart disease, as has been shown, for example, in the Iowa Women´s Health Study [9].

Sources of plant protein, such as soya bean, lupin, chickpea, lentils or kidney bean, are of particular interest in the context of pro-vegetarian nutritional habits. The present studies exclusively employed flours from European culture.

Materials & methods

Materials

Flours from the following manufacturers were used for these studies:

1. 5 soya flours (W. Schoenenberger, Magstadt; Vantastic foods, Nabburg; Bauck, Rosche; Spielberger, Brackenheim; L.I. Frank, Twello/the Netherlands)
2. 4 chickpea flours (Naturawerk, Hannover; TRS Wholesale, Southall/UK; Global Foods Trading, Biebesheim; Bauck, Rosche)
3. 5 lupin flours (Gesund & Leben, Stockach; Prolupin, Grimmen; purvegan, Ramsen with 2 batches; L.I. Frank, Twello/the Netherlands)
4. 1 green pea flour (Müller's Mühle, Gelsenkirchen)

Methods

Protein content was determined by the Kjeldahl method (N factor 5.8). Fat content was determined by Soxhlet extraction after HCl digestion. Amino acid concentrations were determined with an amino acid analyzer (Biochrom 30; Laborservice Onken, Gründau).

Total fiber was determined by Bioquant (Merck Darmstadt; in accordance with L.00.00–18 § 35 LFBG [Lebensmittel- und Futtermittelgesetzbuch, German Food and Consumer Goods Act]). After acid digestion of the ash under pressure, bulk and trace elements were determined using the following techniques: calcium, phosphorus, sulphur, magnesium, potassium, iron, copper, zinc, and manganese with ICP-AES; selenium with hydride-AAS. To determine the content of carotenoids and vitamin E, the flours were extracted with methanol/tetrahydrofuran (1+1, v/v). Prior to the quantitative solvent extraction of the carotenoids, the flours were softened with water. HPLC analysis of carotenoids was performed with a C30 column [10], and of vitamin E isomers with a diol column [11].

Results

The content of dry matter in the individual legume flours varied between 90 and 95 g/100 g. The highest protein content – ca. 35 g/100 g – was found in soya and lupin flour; chickpea and green pea contained less than 20 g/100 g (◆ Table 1). The highest content of fat was found in soya flour, with > 20 g/100 g. The content of fiber was greatest in lupin flour, at 35 g/100 g. Although soya and chickpea only exhibited a low content of carbohydrates, a very high content of carbohydrates – > 50 g/100 g – was found in pea flour. The ash content of flour was 3–4 g/100 g. In soya and chickpea, the content of sulphur amino acids was ca. 3% of total protein. The content in lupin and green pea was clearly lower with more than 2% (◆ Table 2). The lysine content of the two sorts of pea was ca. 7%, which was higher than the values for soya (6%) and for lupin (5%). The high arginine content of lupin flour was striking, at ca. 11%, while the corresponding value was under 8% in soya flour. Lupin flour exhibited a high content of simple unsaturated fatty acids (◆ Table 3). In general, the lipids in the legume flours contained few saturated fatty acids. Soya and chickpea flour were rich in polyunsaturated fatty acids (ca. 60%). The omega-6/omega-3 ratio (n6/n3) reached the very high value of 22 in soya flour, but was only 5 in lupin and green pea (◆ Table 3). One striking result was that lupin contained more than 2% of C22:0.

After correction for the high absolute content of fatty acids, soya flour contained the highest proportion of n3 fatty acids (1.4 g/100 g). However, the proportion of n6 fatty acids is high too (◆ Table 4). Because of the narrow n6/n3 ratio, lupin is a better source of n3 fatty acids than soya.

Soya and lupin flour are rich in calcium (◆ Table 5). Soya flour contained the highest content of magnesium. All the flours examined were rich in iron. Soya flour had a relatively high selenium content of almost 20 µg/100 g.

The legume flours contained lutein. Nutritionally relevant concentrations of zeaxanthin were only found in chickpea and lupin flour (◆ Table 6). The content of carotenes was negligible in all flours. The principle component of vitamin E was γ-tocopherol, although soya flour also had a relatively high content of α-tocopherol. Soya flour also had a relevant content of δ-tocopherol, and lupin flour a corresponding content of γ-tocotrienol.

	Total protein	Total fat	Total fiber	Ash	Digestible carbohydrates (estimated difference)
Soya	35.6 ± 0.6	22.8 ± 2.3	22.6 ± 6.8	3.6	ca. 10
Chickpea	18.6 ± 1.4	5.8 ± 0.1	15.4 ± 4.5	3.5	ca. 45
Lupin	35.0 ± 1.8	8.8 ± 2.1	35.1 ± 3.7	4.3	ca. 8
Green pea	19.4	1.3	10.2	3.1	> 50

Tab. 1: **Total protein, total fat and total fiber content of the legume flours** (g/100 g original substance)

Discussion

The "land consumed" for the preparation of the food consumed in Germany can be calculated from the results of the National Consumption Study II (NVS II) and reaches 2,365 m^2 per person per year [12]. This means that each inhabitant of Germany "uses up" more agricultural area than is available to the overall population (1,920 m^2 per person per year). 69% of the area is needed for the production of animal products. The most important step in achieving a balance would be to decrease the import of soya beans as animal fodder. An important precondition in achieving this objective would be to cultivate domestic legumes and use them directly in human nutrition.

Protein

In order to fully exploit the satiety effect of protein, several authors (e.g. [2]) have recommended to considerably increase its current proportion of ca. 15 En%. For ecological reasons, an increase in the proportion of protein in food should be exclusively attained with plant protein. For a variety of nutritional, physiological and technological reasons, the first choice would be increased consumption of legumes. Our own studies have concentrated on lupin proteins. A human intervention study was performed in which 25 g lupin protein daily was added to food; there was a favorable effect on plasma lipids [13]. The effect was particularly favorable if lupin kernel fibers were administe-

	Soya	Chickpea	Lupin	Green pea
Cystine	1.5 ± 0.1	1.7 ± 0.1	1.4 ± 0.2	1.4
Methionine	1.4 ± 0.1	1.6 ± 0.1	0.7 ± 0.1	0.9
Threonine	4.1 ± 0.1	3.9 ± 0.2	4.2 ± 0.6	4.2
Valine	4.4 ± 0.4	4.2 ± 0.2	3.8 ± 0.3	4.4
Isoleucine	4.2 ± 0.2	4.1 ± 0.2	4.0 ± 0.4	3.9
Leucine	7.7 ± 0.4	7.7 ± 0.3	7.3 ± 0.7	7.1
Tyrosine	4.0 ± 0.5	2.7 ± 0.2	4.3 ± 0.9	3.6
Phenylalanine	5.0 ± 0.2	5.9 ± 0.4	4.0 ± 0.4	4.9
Lysine	6.0 ± 0.1	7.0 ± 0.3	4.9 ± 0.4	7.2
Tryptophan	1.5 ± 0.1	1.4 ± 0.1	1.0 ± 0.3	0.7
Asparaginic acid/ Asparagine	11.8 ± 0.1	12.1 ± 0.4	10.7 ± 0.7	12.2
Serine	5.5 ± 0.2	5.6 ± 0.2	5.6 ± 0.4	5.6
Glutaminic acid/ Glutamine	18.2 ± 0.4	17.1 ± 0.4	21.5 ± 1.6	19.7
Glycine	4.4 ± 0.2	4.3 ± 0.1	4.4 ± 0.5	4.8
Alanine	4.7 ± 0.2	4.5 ± 0.1	3.8 ± 0.5	4.4
Histidine	2.7 ± 0.2	2.7 ± 0.1	2.8 ± 0.5	2.5
Arginine	7.8 ± 0.2	9.2 ± 0.5	11.2 ± 1.1	8.6
Proline	5.3 ± 0.8	4.4 ± 0.4	4.4 ± 0.5	3.9

Tab. 2: **Amino acid content of the examined legume flours** (% total protein)

red; this had a favorable effect on blood lipids in volunteers with hypercholesterolemia [14].

Even though these studies were performed separately either with legume protein or with legume kernel fibers, most legume flours may also be used directly to enrich foods such as bread, rolls, sausages, meat paste etc. The peeling of the seeds (e.g. lupin seeds) before producing the flour leads to an additional protein enrichment and changes in the fiber components resulting in an increase of nutritionally important soluble fibers.

As regards the amino acid distribution, soya and pea protein contain at least 6% lysine, while lupin protein contain ca. 5% lysine (◆ Table 2). When lupin flour is used e.g. in flour mixtures the low lysine level is partially compensated by its high protein content. On the other hand, lupin protein is very high in arginine (ca. 11%). Clinical studies with lupin flour have found significant reductions in systolic blood pressure, sometimes accompanied by favorable effects on lipid metabolism. These changes are thought to be largely linked to the high content of arginine in lupin protein. A current study has demonstrated that a milk protein diet enriched with arginine leads to reductions in total and LDL cholesterol, like the lupin protein diet itself [15]. Arginine seems to function as an NO donor and thus not only helps to reduce blood pressure, but influences lipid metabolism by modulating the genes of lipid homeostasis [16]. The hypotensive activity of lupin proteins may also be influenced by bioactive peptides (e.g. ACE inhibitors) released during digestion [17]. Thus, just as with soya, lupin protein can be exchanged for carbohydrates and then exert a favorable effect on cardiovascular risk factors [13, 15, 18, 19].

In this context, it should be pointed out that the fraction conglutin γ is often absent from lupin protein isolates. As conglutin γ is particularly active in reducing cholesterol levels [20], total protein extracts should be used in food production.

Several publications have pointed out that individual legumes may be highly allergenic. Our own studies have found essentially no differences between the tested legumes and peanuts – a known allergen – in subjects with or without atopic allergy (◆ Table 7). Even though most allergic reactions to soya beans in-

	Soya	Chickpea	Lupin	Green pea
SFA	15.3 ± 4.2	13.6 ± 0.3	17.6 ± 3.6	17.5
MUFA	23.0 ± 3.6	27.7 ± 4.6	47.8 ± 15.3	26.2
PUFA	59.7 ± 4.5	58.7 ± 4.6	34.6 ± 12.0	56.6
Σ n3	6.6 ± 1.1	2.6 ± 0.2	7.5 ± 2.3	8.5
Σ n6	53.1 ± 3.5	56.2 ± 4.4	27.1 ± 13.9	47.8
n6/n3	**8.2**	**21.8**	**4.6**	**5.7**
C16:0	10.8 ± 0.5	10.5 ± 0.3	9.9 ± 2.6	12.6
C18:1 c9	21.4 ± 3.4	25.7 ± 4.6	42.0 ± 11.4	25.0
C18:1 c11	1.2 ± 0.1	1.3 ± 0.1	1.8 ± 0.9	0.5
C18:2 c9,12	53.1 ± 3.5	56.1 ± 4.4	26.8 ± 14.1	47.7
C18:3 c9,12,15	6.6 ± 1.1	2.6 ± 0.2	7.4 ± 2.3	8.3
C22:0	0.4 ± 0.0	0.3 ± 0.0	2.3 ± 1.1	0.2

Tab. 3: **Fatty acid distribution of the examined legume flours (% of the FAME), with the n6/n3 ratio (in bold)**
FAME = fatty acid methyl esters; MUFA = monounsaturated fatty acids; n3 = omega-3 fatty acids; n6 = omega-6 fatty acids; PUFA = polyunsaturated fatty acids; SFA = saturated fatty acids

	Soya	Chickpea	Lupin	Green pea
SFA	3.3	0.7	1.5	0.2
MUFA	5.0	1.5	4.0	0.3
PUFA	12.9	3.2	2.9	0.7
Σ n3	1.4	0.1	0.6	0.1
Σ n6	11.5	3.1	2.3	0.6
C16:0	2.3	0.6	0.8	0.2
C18:1 c9	4.6	1.4	3.5	0.3
C18:1 c11	0.3	0.1	0.2	0.0
C18:2 c9,12	11.5	3.1	2.2	0.6
C18:3 c9,12,15	1.4	0.1	0.6	0.1

Tab. 4: **Mean fatty acid content of the examined legume flours** (g/100 g)
MUFA = monounsaturated fatty acids; n3 = omega-3 fatty acids; n6 = omega-6 fatty acids; PUFA = polyunsaturated fatty acids; SFA = saturated fatty acids

	Soya	Chickpea	Lupin	Green pea
Calcium	221 ± 37	86 ± 48	220 ± 34	47
Phosphorus	594 ± 48	370 ± 23	407 ± 108	417
Magnesium	231 ± 14	127 ± 11	162 ± 30	96
Potassium	1,764 ± 114	1,040 ± 70	1,156 ± 189	1,030
Sulphur	389 ± 25	219 ± 14	280 ± 49	158
Iron	7.7 ± 3.0	5.9 ± 1.1	4.6 ± 1.7	4.3
Zinc	4.1 ± 0.6	3.1 ± 0.3	3.7 ± 0.4	2.5
Manganese	2.8 ± 0.4	2.6 ± 0.8	4.8 ± 5.2	1.2
Copper	1.3 ± 0.2	0.7 ± 0.1	0.5 ± 0.1	0.6
Selenium (µg/100 g)	19.1 ± 12.3	6.2 ± 5.7	4.7 ± 2.5	1.6

Tab. 5: **Content of bulk and trace elements in the examined legume flours** (mg/100 g; selenium µg/100 g)

volve only mild symptoms, there is evidence that allergic reactions to lupin are often accompanied by systemic reactions, about as severe as in peanut allergy [22]. Although this requires further investigation, it should not lead to any restriction in the use of lupin in food production.

Carbohydrates and fibers

As lupin and soya flours contain large fractions of proteins and fibers, they have correspondingly low fractions of carbohydrates (less than 10 g/100 g). Moreover, lupin and soya flour contain small fractions of easily soluble fibers which reduce postprandial glycaemia [23]. Conversely, pea contains smaller fractions of protein and fiber and larger fractions of carbohydrates (more than 50 g/100 g). Before the introduction of the potato, the pea was an important source of starch in Central Europe. It follows that the growing desire for de-energization would be better met by lupin or soya than by the pea.
In the kernel fibers of legumes, 50–80% of total fibers are soluble. This fraction is highest in lupin kernel fibers and lowest in pea fibers [24]. High content of fibers with low fractions of easily digestible carbohydrates lead to low postprandial glycaemia after consumption, due to delayed bioavailability. An according favorable nutrition reduces the level of body fat, even after *ad-libitum* consumption [25]. Diets containing increased levels of protein and carbohydrates of low glycemic index favor the maintenance of body weight (after weight loss) and improve the risk markers of inflammation, type 2 diabetes mellitus, and cardiovascular diseases.
Legume fibers exhibit several other advantages over cereal fibers. Legume fibers had a higher content of soluble components leading to enhanced formation of volatile fatty acids (acetic acid, propionic acid, and butyric acid). Volatile fatty acids inhibit cholesterol synthesis [14] and butyric acid can reduce the risk of colorectal cancer [26]. Moreover current studies show that acetic acid enhances the feeling of satiation from fibers by influencing central homeostatic mechanisms, as well as through the known action on the baroreceptors in the gastrointestinal tract [27].

	Soya	Chickpea	Lupin	Green pea
(*all-E*)-lutein	0.64 ± 0.27	0.47 ± 0.06	0.56 ± 0.25	0.75
(*all-E*)-zeaxanthin	0.07 ± 0.01	0.43 ± 0.08	0.21 ± 0.04	0.08
(*all-E*)-α-carotene	n. n.	< 0.06	< 0.06	< 0.06
(*all-E*)-β-carotene	n. n.	n. n.	< 0.06	n. n.
(*9Z*)-β-carotene	n. n.	n. n.	n. n.	n. n.
(*13Z*)-β-carotene	n. n.	n. n.	0.08 ± 0.03	n. n.
α-tocopherol	6.4 ± 1.5	2.2 ± 0.2	1.1 ± 1.7	0.11
β-tocopherol	0.44 ± 0.24	< 0.15	n. n.	n. n.
γ-tocopherol	23.0 ± 3.5	11.5 ± 2.3	15.3 ± 1.5	5.0
δ-tocopherol	7.0 ± 3.3	0.74 ± 0.32	0.47 ± 0.19	0.15
β-tocotrienol	n. n.	< 0.15	n. n.	n. n.
γ-tocotrienol	n. n.	< 0.15	0.41 ± 0.47	n. n.

Tab. 6: **Content of carotenoids and tocopherols/tocotrienols in the examined legume flours** (mg/100 g)
n. n. = undetectable

	Soya bean	Peanut	Lupin	Green pea
Non-atopic	3.3	2.2	2.2	2.2
Atopic	7.0	4.2	5.6	14.1

Tab. 7: **Fraction of positive reactions to legumes (%) in the skin prick test on 183 volunteers (81 atopic, 102 non-atopic)** [21]

Fats

The lipid fraction in legumes is only of secondary importance. Relatively high fat content (> 20 g/100 g) was only found in soya flours. Correspondingly, soya flour contained the highest content of n6 fatty acids (ca. half the fat content) (◆ Table 4). In accordance with the requirements of the DGE, the n6/n3 ratio should have a maximal value of 5:1; however, in the present case it is as high as 7:1 to 10:1 (◆ Table 3). The reference values of 5:1 are only fulfilled by lupin and pea flours. Chickpea fat is particularly unfavorable. Almost half of lupin fat consists of the monounsaturated fatty acids. Moreover, together with green pea, it has the greatest fraction of the n3 fatty acid α-linolenic acid (◆ Table 3). Thus, if wheat or rye flour in food is to be partially replaced, it would be desirable to use lupin flour, as this contains only a little additional fat, albeit of high quality.

Trace elements and vitamins

The fractions of iron and zinc are of the order of 4–8 mg/100 g and 2–4 mg/100 g, respectively. These values are of relevance for nutritional physiology (◆ Table 4). 50 g lupin flour could then cover between one fifth and one quarter of the recommended daily intake of these elements. The phytate content in domestic legumes is less than 2% (soya: 2–5%). The phytate content of lupin is particularly low. In contrast to soya, lupin products will hardly influence zinc absorption [28].

The tocopherol content in legume flour (α-tocopherol: 0.1–6.4 mg/100 g, γ-tocopherol: 5.0–23.0 mg/100 g) present a similar pattern to linseed [10]. 50 g soya bean flour can provide the recommended intake of vitamin E (tocopherol equivalents) of 12–15 mg/day. Lupin and chickpea can also make an important contribution to tocopherol intake.

The legume flours contained 0.5–0.8 mg/100 g (*all-E*)-lutein; this was of the same order as for durum wheats, yellow wheats or maize, and much higher than for soft wheats, spelt, rye or oats [29]. In recent years, there has been increasing interest in using lutein and zeaxanthin to support the therapy of macular degeneration [30]. Moreover, legumes are rich in vitamin B_1 (ca. 0.5 mg/100 g), vitamin B_2 (0.3–0.5 mg/100 g), and folate (200–400 μg/100 g) [31, 32].

Technological and functional properties

If legume flours are to be widely used in food production, they must possess various technological properties. These include good solubility, ability to form emulsions, foam or gels, and water binding capacity. Current studies have shown that legume flours are partially superior to wheat flour in this respect. Raikos et al. [33] demonstrated the following sequence for water binding properties:

lupin > broad beans > green pea > wheat.

Bread enriched with pea flour exhibits a lower glycemic index than control, together with significantly better dough properties and reduced bread consistency [34].

Studies have shown that 10% substitution of wheat flour with lupin flour improves bread quality [35]. This improvement is due to crosslinks in lupin and wheat protein, as well as the fibers' high water binding capacity. Substitution of more than 10% reduces bread quality, as lupin protein is less elastic, and gluten structure is impaired by the greater fiber content. Few studies have been performed on the baking characteristics of legume-enriched cereal flours. In particular, more investigations must be performed on the technological and functional effects of different protein compositions.

Conflict of Interest

Prof. Jahreis is chairman of the UFOP commission Human Nutrition (*Union zur Förderung von Öl- und Proteinpflanzen e. V.* = Union for the Promotion of Oil and Protein Plants e. V.). Furthermore, the authors declare no conflict of interest.

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