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Article

Soybean versus other food grain legumes: A critical appraisal of the United Nations International Year of Pulses 2016

Sojabohne versus Körnerleguminosen: Eine kritische Würdigung des Internationalen Jahres der Körnerleguminosen 2016 der Vereinten Nationen

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Summary

The United Nations have declared 2016 as the International Year of Pulses, which aims at communicating the various benefits of legume cropping and legume-protein-based food consumption. As the term "pulses" is inherently excluding soybean from other grain legumes, this review aims at challenging the scientific justification of this separation from both historical and crop science perspectives toward a better understanding of grain legumes and their contributions to food security. An analysis of the historical development and uses of the term "pulses" reveals that it is not used unambiguously throughout the recent scientific literature, and that the separation of soybean from other grain legumes occurred rather recently. Soybean, while being extensively used as an oilseed and animal feedstuff in some parts of the world, is an important protein crop species in other regions with a seed protein content of 40% and outstanding nutritional and food health properties as compared to most other grain legumes. Owing to similar agronomic features such as symbiotic nitrogen fixation and comparable seed protein properties, it does not seem scientifically justified to separate soybean from other food legumes. Therefore, focusing on "grain legumes" rather than "pulses" would better support food security and nutritional quality goals.

Keywords: Food grain legumes, seed protein content, food security, nutritional quality

Zusammenfassung

Die Vereinten Nationen haben 2016 zum Jahr der Körnerleguminosen („Pulses") erklärt, um die Vorzüge der Leguminosen für Landwirtschaft und Ernährung besser in das öffentliche Bewusstsein zu rufen. Da Sojabohnen jedoch als Ölsaaten angesehen und nicht zur Gruppe der „Pulses" gezählt werden, wird hier der wissenschaftliche Hintergrund dieser Trennung untersucht, um das Verständnis für Körnerleguminosen und deren wertvolle Beiträge zur Ernährungssicherheit zu verbessern. Historisch betrachtet existiert diese Abgrenzung erst seit Beginn des 20. Jahrhunderts, und der Begriff „Pulses" wird in der wisssenschaftlichen Literatur uneindeutig verwendet. Dazu kommt, dass Sojabohnen wohl als Ölsaaten und zur Futtermittelproduktion eingesetzt werden, in Asien, Afrika und Europa aber als Proteinpflanze mit sehr hohem Proteingehalt und großem ernährungsphysiologischen Wert Verwendung finden. Auch pflanzenbauliche Merkmale der Sojabohne und diverse Proteineigenschaften sind nicht grundsätzlich verschieden von jenen anderer Leguminosen, sodass die Trennung zwischen Sojabohnen und anderen Körnerleguminosen (Gruppe der „Pulses") wissenschaftlich nicht haltbar erscheint. Daher wird vorgeschlagen, anstatt von „Pulses" von „Grain legumes" (Körnerleguminosen) zu sprechen, um dadurch besser den Zielen der Ernährungssicherheit und der Nahrungsmittelqualität zu entsprechen.

Schlagworte: Körnerleguminosen, Proteingehalt, Ernährungssicherung, Nahrungsmittelqualität

1. Introduction

In December 2013, the General Assembly of the United Nations has adopted a resolution (A/RES/68/231) in which the year 2016 has been declared the International Year of Pulses (United Nations, 2014). This initiative of promoting food and feed grain legumes is greeted warmly from standpoints of agronomic field crop production, biodiversity, food security, and nutritional quality because it aims at underlining the various positive effects of both legume cropping and consumption. The resolution especially emphasizes the important role of legume crops as healthy, plant-based protein sources in human nutrition, their critical function in sustainable food production and food security, and their positive ecosystems effects because of their capability of symbiotic nitrogen fixation. Unfortunately, however, the resolution appears to be flawed in several respects related to the definition of the group of grain legume crops termed "pulses." In the long term, this might have a negative impact on both plant-based protein supply and nutritional quality caused by missing some of the multiple benefits of food legumes. Thus, the future development of legume strategies, national and international policies, and administrative procedures such as setting of research priorities and subsequent public calls for research grants might be hampered by some content of the resolution. In particular, the inherent exclusion of soybean from the list of protein crop species to be recognized by the United Nations resolution A/RES/68/231 may serve as an example to illustrate the frequent misunderstandings associated with the use of the term "pulses." While soybean has the highest protein production per unit area among all major food crops (Hartman et al., 2011), it is considered as an oilseed rather than a protein crop by the United Nations similar to peanut.

Therefore, in correspondence with the resolution mentioned earlier, this review is intended to highlight and analyze

i. the present uses of the term "pulses,"
ii. its historical development,
iii. the comparative nutritional features, and
iv. agronomic characteristics of legume crops.

These issues are addressed in order to challenge the scientific justification for separating grain legumes into pulses and soybeans (i.e., oilseeds). Thus, the objective of the present contribution is to clarify the conception of "pulses" from both historical and crop science standpoints in order to stimulate further discussion toward a more precise view and improved understanding of grain legumes and their multifaceted benefits in nutrition and food security as well as for agroecosystems, which would better support the goals of the United Nations (2014) resolution.

2. Present uses of the term "pulses"

Both in popular and scientific contexts, pulses is most often used to summarize classical grain legumes such as the different species of phaseolus beans, pea, lentil, chickpea, cowpea, mungbean, faba bean, and some others, when dry seed is harvested for human food or livestock feed purposes. A number of crops are commonly excluded from the term pulses, that is, soybean and peanut, which are widely considered oil crops; immaturely harvested green beans, peas, or soybeans, which are considered vegetables; and grains used for sowing only such as seed of clovers, alfalfa, and other forage legumes (Asif et al., 2013; Wikipedia, 2015).

While the United Nations resolution A/RES/68/231 is following the common use of the term pulses as outlined earlier, it is restricting the term to grain legumes yielding between "1 and 12 grains or seeds" per pod only. Apart from appearing bureaucratic rather than biological, this definition is lacking scientific reasoning, as it does not entirely consider the possibility of biological variation in that character. In particular, the description is faulty with respect to mungbean (*Vigna radiata* (L.) Wilczek), which may contain more than 20 seeds per individual pod. Moreover, different accessions of mungbean genetic resources have been described by several authors with an average number of more than 12 and up to 15 seeds per pod (Bisht et al., 1998; Hakim, 2008; Schafleitner et al., 2015; Yimram et al., 2009). Thus, the mungbean appears to be excluded unintentionally from the group of pulse crops by the definition of the United Nations (2014) resolution.

Similar to what has been described earlier, the Food and Agriculture Organization of the United Nations (FAO) uses the term pulses in its publications such as the widely used FAOSTAT (2015) statistical database: Most of the grain legumes are traditionally aggregated as pulses, while soybean and peanut (groundnut) are aggregated to the group of oil crops. In total, 10 primary pulses are recognized in the FAOSTAT (2015) database, that is, dry beans (including both *Phaseolus* and *Vigna* species), dry peas, dry broad beans, dry cowpea, chickpea, lentil, pigeon pea, bambara groundnut, common vetch and lupins; in addition, at least seven other species are aggregated to the group of minor pulses.

In clear contrast to the use of the term "pulses" as discussed so far, soybeans (*Glycine max* [L.] Merr.) are as well considered as pulses in a number of recent publications in different scientific disciplines. In a monograph addressing the nutraceutical properties and health benefits associated with the consumption of cereals and pulses (Yu et al., 2012), two chapters are devoted to soybean: The chapter on soybean isoflavones and bone health (Tsao, 2012) highlights the biosynthesis of isoflavones, the chemical analysis and separation of individual components, and isoflavone-mediated bone health effects, whereas the chapter on dietary soybean for cardiovascular disease prevention (Whent and Slavin, 2012) focuses on the potential hypocholesterolemic compounds such as soy proteins reducing LDL cholesterol in the human blood serum. These chapters are serving as perfect examples why grain legumes should not be separated into pulses, soybeans, and other species: While Whent and Slavin (2012) emphasized the growing popularity of soyfoods because of their health effects, the same applies to other grain legume species as well. Soybean contains isoflavones in physiologically relevant amounts, but isoflavones and other healthy phenolic compounds and other similarly bioactive ingredients are present in pea, bean, chickpea, faba bean, lentil, or lupins as well (Bouchenak and Lamri-Senhadji, 2013; Sánchez-Chino et al., 2015); the same applies to physiologically active soybean proteins that might also be present in other grain legumes. Thus, other grain legumes can benefit from the advances made in soybean isoflavone research. On the other hand, soybean research in the fields of plant breeding and food science can greatly benefit from the knowledge gained in various other legumes with respect to dietary fibers, carbohydrates, allergens, or antinutritional substances such as protease inhibitors or lectins typically present in most of the grain legume crops. This holds true particularly for molecular genetics applications such as functional genomics and quantitative trait loci (QTL) mapping in marker-assisted selection, where the same candidate genes controlling seed quality, grain yield, or resistance traits can be identified and used across related species such as chickpea, pigeon pea, cowpea, common bean, and soybean (Kumar et al., 2011).

Soybeans are also treated as pulses in agronomic research literature: Miller et al. (2002) reviewed pulse crops such as soybean [*sic!*], dry pea, lentil, dry bean, and chickpea as compared to spring wheat with respect to their adaptation to the Canadian and United States northern Great Plains region; with the exception of maturity requirements, which are higher for soybean than for the other grain legumes, soybean did not differ from other species in input parameters such as rainfall or average maximum temperature during critical growing periods, grain yield performance, water use efficiency, and crop rotation effects on subsequent wheat crops. In a further paper on pulse crops for the northern Great Plains region (Cutforth et al., 2007), strategies of climate change adaptation were discussed for pulse crops including soybean, dry pea, lentil, and chickpea.

The examples of present day uses of the term "pulses" in the scientific literature as given earlier illustrate that the term is not applied consistently. In contrast to the term "grain legumes," pulses is not referring to taxonomic, botanical, or agronomic characteristics of crops but is merely applied to separate soybean and peanut from other grain legumes based on their oil content or oil usage. As demonstrated here, soybean is included in the group of pulses in some publications which—although possibly confusing traditional readership—appears scientifically well justified in the context of scientific disciplines such as plant taxonomy, general botany, agronomy, plant breeding, molecular genetics, as well as food and nutrition science. As the English term pulses is not used in many other languages for differentiating between particular grain legume species, its translation is adding to the inconsistency described earlier: As an example, in the official German version of United Nations resolution A/RES/68/231, the term "pulses" is translated as "Hülsenfrüchte" (literally translatable as "fruits from pods"), which clearly denotes grain legumes. Both in the classical (e.g., Fruwirth, 1921) and modern (e.g., Keller et al., 1999) German agronomic standard literature, however, soybean is treated among the grain legume crops, and no differentiation between soybean and other grain legumes is made.

Thus, the term "pulses" as used in the United Nations resolution A/RES/68/231 and other publications is an ill-fated expression for summarizing a particular group of crop species, whereas the term "grain legumes" appears as a much more appropriate alternative because of its unambiguous and concise use in present-day scientific literature (e.g., Summerfield and Roberts, 1985; De Ron, 2015).

3. Linguistic and historical perspectives

The term "pulse" is derived from a Latin word (*puls*, *pultis*; Asif et al., 2013), which is probably originating from ancient Greek (πόλτος, poltos; see Wikipedia, 2015), describing a thick porridge-like slurry or soup. In the English language, pulse was used since the late 13th century in Middle English for summarizing the then-known old-world grain food legumes such as peas, beans, and lentils (Online Etymology Dictionary, 2015). As soybean was unknown to the western world until the year 1712 when the German botanist Engelbert Kaempfer for the first time described it in full botanical detail (Kaempfer, 1712; Hymowitz and Newell, 1981), it had never been counted among the pulse crops which all were well established since ancient times in the Proto-Indo-European languages (Mikić, 2012).

Historically and in traditional Asian soy-food preparations, soybean has not been used as an oilseed; it was only in the early 20th century that industrial separation of soybean into oil and protein fractions was developed for separate utilization of oil and defatted meal in various food and feed industry applications (Hymowitz and Newell, 1981). This development was initiated after the wars between China and Japan (1894–1895) and between Russia and Japan (1904), when soybean production had been increased in Manchuria to secure food supply of Japanese troops. After the end of hostilities and withdrawal of troops, continuing soybean planting resulted in overproduction, and international markets were opened for soybean surpluses (Smith, 1995). As a consequence, significant soybean exports to Europe were taking place from 1907 on, when a processor in Liverpool found out that soybeans were a suitable source of oil for soap manufacturing and the high-protein meal could be used in livestock feeding (Probst and Judd, 1973). A shortage of cottonseed and linseed in Europe by 1908 might have been an additional impetus for increased soybean exports from Manchuria to Europe between 1907 and 1911 (Shurtleff and Aoyagi, 2015). By 1910, soybean oil was also successfully used for margarine production in England replacing coconut oil (Shurtleff and Aoyagi, 2015). Thus, the perception of soybean continually became that of an oilseed crop rather than a legume in western countries. An additional reason for promoting soybean to be considered an oilseed might have been the fact that in several European countries, oilseeds could be imported free of taxes, whereas beans were subject to an import tax (Shurtleff and Aoyagi, 2015). Nevertheless, soybean oil content is about 20% only, which is low as compared to other oilseeds reaching 40–50%.

4. Nutritional composition of legume crops

The United Nations (2014) resolution A/RES/68/231 on pulses is particularly stressing the important role of legumes as critical sources of plant-based protein as well as health effects associated with the consumption of grain legume foods. Therefore, the approximate chemical composition of major legume crops is summarized in Table 1 for further consideration.

Owing to symbiotic nitrogen fixation of legumes, they all are higher in seed protein content as compared to cereal crops or nonlegume oilseeds. Most of the grain legumes classified as pulses have a protein content between 20% and 30% (Table 1); they are low in oil and high in carbohydrates, particularly in starch (Asif et al., 2013). Lupins are the only pulses that may reach a seed protein content of more than 40%. Soybeans, which are excluded from the pulses group of legumes, are high in protein and have a significant oil content but are lower in carbohydrates, being totally devoid of starch, which makes their major difference to pulses. Soybean seed oil content is commonly found in the range between 14% and 24% (Table 1), which is much lower than in other annual oilseeds such as rapeseed, sunflower, or linseed reaching between 40% and 50%. Remarkably, the Andean lupin (*Lupinus mutabilis* Sweet) has a seed composition similar to soybean (Haq, 1993), but in contrast to soybean, the Andean lupin is classified as a pulse crop by the FAO (FAOSTAT, 2015), which is another inconsistency associated to the usage of the term "pulses."

Apparently, while aiming at critical sources of plant-based protein supply for both humans and livestock, the United Nations resolution is clearly missing the highest-potential protein source by their exclusion of soybean, as most pulses are considerably lower in protein content than soybean and synthesizing starch instead. Moreover, owing to both its high-protein content and a well-developed agronomic performance, average protein yields of soybean are more than 900 $kg \cdot ha^{-1}$, while protein yields of other legumes, oil crops, and most cereals are ranging between 200 and 600 $kg \cdot ha^{-1}$ of raw protein on an average (Hartman et al., 2011). In addition to the protein yield per unit area, soybean protein has an outstandingly high biological value based on the true ileal digestible protein concept (Boisen, 1997) because of its high concentration of lysine and other amino acids.

In the United Nations resolution A/RES/68/231, crop species are excluded if they are mainly used for oil extraction. Undoubtedly, this applies to soybean in both North and South America, where soybean oil is a major target of production apart from protein-rich meal. Here, considerable plant breeding and genetic research has been undertaken to improve soybean oil properties and to adapt the fatty acid composition to different processing needs (e.g., Cober et al., 2009). However, in many regions of Asia, Africa, and Europe, soybean is primarily grown for its highprotein content and as a food crop. In Asia, soybean is a traditional staple food in many countries, and both fermented and nonfermented soyfoods are a major source of protein and healthy bioactive compounds to the human diet (Chen et al., 2012). In Africa, soybean is still a minor and new crop continuously growing in acreage with 1.7 mio ha harvested in 2013, particularly in Nigeria and South Africa (FAOSTAT, 2015). Regions suitable for soybean production in Africa have been identified (Sinclair et al., 2014), and soybean has the potential of a sustainable and local source of protein in smallholder farms for livestock feed production and human food preparation (Mpepereki et al., 2000). In Europe, annual soybean production has reached more than 3.2 mio ha (2013) over the past 10 years, which is a similar acreage as used for pulses (FAOSTAT, 2015). Recently, European soybean production has been recognized as an important option to reduce the gap in domestic protein supply for the European livestock feed industry (Schreuder and de Visser, 2014). While soybean grown in Europe is primarily used for feeding animals, growing amounts of soybean are used in human food production, and research in food-grade soybeans with a protein content of more than 45% has been initiated (Sato et al., 2014). These examples illustrate that soybean is not primarily considered as an oilseed crop in many regions of the world but as a rich source of high-quality vegetable protein for human food production and feeding.

In addition to their macronutritional composition, all food grain legume species contain various bioactive compounds adding a health-protecting functional component to legume-based foods. Thus, legume consumption contributes to cardiometabolic risk prevention through protecting against coronary heart disease, diabetes, high blood pressure, inflammation, hyperlipidemia, and other disorders, which has similarly been confirmed for soybean (Anderson et al., 1995; Messina, 2010) as for other food legumes (Arnoldi et al., 2015; Bouchenak and Lamri-Senhadji, 2013). Moreover, the chemopreventive properties of food legumes in lowering the risk of carcinogenesis are well documented (Sánchez-Chino et al., 2015).

Table 1. Seed composition of grain legumes (major parameters)
Tabelle 1. Inhaltsstoffe von Körnerleguminosen (wesentliche Parameter)

Crop species	Protein (%)	Oil (%)	Carbohydrates (%)	Fiber (%)
Dry pea (*Pisum sativum*)[a]	25.7	1.6	68.6	1.6
Broad bean (*Vicia faba*)[a]	26.7	2.3	64.0	7.2
Chickpea (*Cicer arietinum*)[a]	22.7	5.0	66.3	3.0
Garden bean (*Phaseolus vulgaris*)[a]	24.1	1.8	65.2	4.5
Mungbean (*Vigna radiata*) [a]	27.2	1.3	66.6	0.9
Black gram (*Vigna mungo*)[a]	26.9	1.6	66.9	1.9
Lentil (*Lens culinaris*)[a]	28.6	0.8	67.3	0.8
Cowpea (*Vigna unguiculata*)[b]	27	5	62	n.d.
Pigeon pea (*Cajanus cajan*)[b]	27	5	62	n.d.
Peanut (*Arachis hypogea*)[b]	30	50	14	n.d.
White lupin (*Lupinus albus*)[c]	34–45	9–15	n.d.	3–10
Blue lupin (*Lupinus angustifolius*)[c]	28–38	5–7	n.d.	13–17
Andean lupin (*Lupinus mutabilis*)[c]	32–46	13–23	n.d.	7–11
Soybean (*Glycine max*)[d]	35–52	14–24	34–41	n.d.

[a]Asif et al. (2013).
[b]Sinclair and Vadez (2012).
[c]Haq (1993).
[d]Wilson (2004).
n.d.: no data given.

5. Agronomic adaptation and dinitrogen fixation

Food legumes are adapted to a diversity of environmental conditions from arid to moist and from warm to cool climates. Phaseolus beans, soybean, peanut, and few others are classified as warm or tropical season legumes, while most others are considered cool season food legumes (Toker and Mutlu, 2011) playing particularly important roles in Mediterranean agriculture (Howieson et al., 2000). Cool season legumes have a lower minimum germination temperature, are less susceptible to frost, and are generally grown under rainfed conditions as compared to warm season legumes. However, agronomic adaptation is highly site specific: In Europe, for instance, cool season legumes such as dry peas are grown in warm regions of South Europe such as Spain, while soybean is produced in cooler Central European regions under rainfed conditions (FAOSTAT, 2015; Schreuder and De Visser, 2014). Moreover, both warm and cool season legumes are similarly affected by drought in terms of yield reduction (Toker and Mutlu, 2011). Other features of adaptation are comparable as well between the major warm and cool season grain legume species (Miller et al., 2002), and specific adaptation differences might be further mitigated by climate change progress in particular growing regions (Cutworth et al., 2007). At least there is no obvious reason to separate soybean from the other grain legumes with view to environmental adaptation.

Symbiotic nitrogen fixation of legumes is a unique crop feature recognized in the United Nations (2014) resolution contributing to both high seed protein content and increased soil fertility of the cropping system. Nitrogen fertilizers are a major source of greenhouse gases, and higher energy costs for manufacturing mineral nitrogen fertilizers have contributed to increased fertilizer prices; consequently, the importance of leguminous nitrogen fixation is growing in agricultural systems worldwide (Sinclair and Vadez, 2012), as legume cropping might lower carbon dioxide and nitrous oxide emissions while reducing the need for fossil energy input in food production (Jensen et al., 2012). Therefore, recently discussed strategies such as reduced feedback control of nitrogen fixation or better drought tolerance of the fixation process are considered primary targets of research for increasing N fixation rates of grain legumes (Sinclair and Vadez, 2012). Quantitatively, average nitrogen fixation rates have been estimated to range between 30 and 120 kg $N \cdot ha^{-1} \cdot year^{-1}$; fixation rates are differing between the grain legume species, but there is no apparent difference between cool season (pulse crops) and warm season legumes (Herridge et al., 2008). In overall, about 40–80% of grain legume nitrogen uptake is estimated to originate from nitrogen fixation (%Ndfa), while the remainder is taken up from soil N sources (Herridge et al., 2008). In soybean, for instance, N balance was negative for 80% of cases in a large data set (Salvagiotti et al., 2008), and while the balance might be better for other grain legume species, it underlines the urgent research need for improving symbiotic N fixation.

6. Concluding considerations

On the basis of sound scientific evidence discussed here, soybean has to be considered as a grain legume crop with competitive agronomic performance, high protein content, favorable protein quality for human nutrition and livestock feeding, as well as bioactive ingredients contributing to consumer health. Thus, despite the historical development outlined earlier, soybean is clearly a protein crop rather than an oilseed. However, socioeconomic and nutritional developments during the past 50 years such as a nutrition transition toward consuming higher amounts of bovine, pig, or poultry meat and vegetable oils in some regions of the world have various negative impacts on the environment (Gill et al., 2015) and are partly associated with the extension of soybean growing areas in the Americas, because soybean is a major feed ingredient for meat production. Owing to these developments, a considerable protein production imbalance has developed with South America and the United States as major soybean exporters and China and Europe as importers (Hartman et al., 2011). The extension of soybean acreage for meat production has contributed to deforestation in the Brazilian Amazon and is causing largely increased greenhouse gas emissions (Gill et al., 2015). While this type of land grabbing for food commodity production is associated with losses of a functional biodiversity, it also causes local food insecurity in regions of Latin America where farmland is increasingly used for export feed and fuel production (Tscharntke et al., 2012).

In the light of these considerations, the United Nations International Year of Pulses 2016 appears as an important occasion for communicating the urgent need for policy changes and a change in consumer attitude toward regional protein production and consumption. Instead of excluding soybean from the group of protein grain legumes through the ill-defined term “pulses,” the unambiguous and concisely used term “grain legumes” might better be applied to gain the utmost benefit of growing and consuming the wide range of food legumes. Moreover, a considerable body of science-based knowledge of various kinds has been accumulated for legumes such as pea or soybean, while other grain legumes are representing orphan species because of their regional importance permitting limited research activities only. Consequently, overcoming that separation within the group of grain legumes might be beneficial for crop research, agricultural production, and nutritional uses of all grain legume species, thus better serving the higher goals of the United Nations (2014) resolution.

Conflict of interest statement

The author has no conflict of interest to declare.

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