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Soybean management for seed composition: The perspective of U.S. farmers

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Abstract

The soybean [*Glycine max* (L.) Merr.] compositional quality is mainly provided by the seed concentration of protein and oil. These traits are critical for sustaining global use, and although there is demand for high protein soybean, no mechanism to differentiate production is in place. At the opposite end of the supply chain, farmers are remunerated on a mass basis without having any incentive regarding seed composition. This study evaluated farmers' perspectives and knowledge on soybean quality and their propensity to adopt quality improvement technologies. Farmers from the main U.S. producing regions ($n = 271$) were investigated with a self-administrated survey containing 21 questions during 2020 and 2021. Our results show that 84% are unaware of the current protein and oil levels from their own production. A small portion (1.4%) make management decisions (e.g., choice of genotypes or monitor quality) based on the implications on seed quality. However, practices already in place are likely to enhance the quality of seed, namely N nutrition (via rhizobia [12.9%] or fertilizer [5.9%]) and late-season crop protection (17.1%). If farmers are financially rewarded by US$0.50 per bushel, a mindset change may occur. Based on these results, we concluded that shifts in the U.S. production system targeting protein or oil markets are possible, and the constraints are mainly related to on-farm management. However, the challenges for improving the U.S. soybean competitiveness in global or niche markets also rely upon other segments of the production chain, specifically breeders, technology suppliers, and logistical structure.

1 | INTRODUCTION

Soybean is the dominant oilseed crop in the world trade with global consumption of 350 Tg annually (FAOSTAT, 2021). The United States led global soybean production from the early 1970s to 2010 (De Maria et al., 2020), but since 2012 the country has competed for the top position with Brazil, both contributing roughly 30–35% of the world production (Salin & Somwaru, 2014). International soybean trade displayed a threefold increase over the past 30 yr, accompanied by a reduction of the U.S. market share from 70 to 80% in 1992 to 40–45% from 2012 onward (Salin & Somwaru, 2014). The decline in U.S. competitiveness is the result of an intricate combination of geopolitics (De Maria et al., 2020; Tiwari et al., 2021), tariff wars (Cowley, 2020), land and oceanic freight prices (Salin & Somwaru, 2014), and the influence of changes in soybean seed quality (Durham, 2003). A remarkable characteristic of the global soybean and derivatives (meal and crude oil) trade is that 65% of production is bought by a single country, China (De Maria et al., 2020; Gale et al., 2019). In the face of global competition challenges and the engulfment of soybean trade in geopolitical disputes, opening new markets via seed quality differentiation is an alternative strategy for increasing global competitiveness of U.S. soybean.

Soybean demand is mainly driven by its seed quality, with roughly 70–75% of the current soybean seed production crushed (Brack et al., 2016; Marowka et al., 2020) into 79% meal and 18% crude oil (USSEC, 2015). The main component of soymeal is protein, which is used in the animal feed industry (Brack et al., 2016; Wilson, 2004). Seed protein and oil concentrations are quantitative traits (Van & McHale, 2017), strongly controlled by a complex genetic–environmental interrelation (Krishnan & Jez, 2018; Panthee et al., 2006). Unfortunately, the average seed protein concentration of the U.S. production is lower than Brazilian and Argentinean soybean (Park & Hurburgh, 2002) resulting in a meal with less value (Thakur & Hurburgh, 2007). Although the reasons for that are not fully understood, the geographic variability of protein concentration within the U.S. regions was estimated to be 70% controlled by environmental conditions (Assefa et al., 2019). From this regional focus, the U.S. mid-southern and southeastern have historically produced soybean with high protein concentration (≥38%) then north-central regions (Assefa et al., 2019; Durham, 2003; Rotundo et al., 2016). Farmers could influence soybean seed quality by changes in relevant crop management decisions such as cultivar selection, planting date (Assefa et al., 2019), level of N fertilization (Ham et al., 1975), and water availability (Rotundo & Westgate, 2009). Therefore, there is an emerging opportunity to explore spatio-temporal variations and farming practices to improve seed quality, offering a superior product to the crushing and animal industry, ultimately strengthening the U.S. soybean production chain relative to their global competitors.

The scenario of targeting quality could require a mindset change in the perspective of soybean farmers. Instead of producing a commodity, farmers could become producers of soybean oil and protein. Although it may seem only a semantic alternative, it is a structural change in the production system. It would require updating the decision-making process of crop management, the development of new trading mechanisms, and adoption of new technologies, to name only a few. Production of high-quality protein increases the overall complexity of the farming system (Wu et al., 2014) and benefits must outweigh costs (Dwyer et al., 2007). A successful framework for changing farmers' behavior must provide information and promote not only willingness but also ability to change (Moss, 2019). Lessons can also be learned from other crop commodities (e.g., wheat [*Triticum aestivum* L.], barley [*Hordeum vulgare* L.], and cotton [*Gossypium hirsutum* L.]), which successfully implemented a framework for segregating production based on intrinsic quality. However, for conceiving any future framework strategy intending to improve soybean seed quality, we first need to provide foundational knowledge of the current state of perception and willingness to change on the part of U.S. soybean farmers.

The main aim of this research was to assess the current perspective and knowledge of U.S. farmers regarding soybean seed composition via implementation of a survey instrument. The goal of this research is to better understand the growing conditions and current management practices as they relate to current levels of both seed protein and oil concentrations for U.S. soybean production. Our hypothesis is that a few agronomic and management practices favoring seed quality are already operationalized in U.S. soybean systems but are currently focused on yield improvement only. Additionally, the findings of the survey instrument provide practical information on the perception from farmers on the economic advantage to stimulate the adoption of technologies targeting on-farm characterization of soybean seed composition.

2 | MATERIAL AND METHODS

A qualitative research inquiry was developed containing 21 open and closed questions targeted to assess knowledge and intended behavior changes of farmers related to soybean production and seed quality (Table 1). The scope of this inquiry concerned on-farm economic indexes, crop management aspects, and exploration of a theoretical concept of a differential payment system to soybean production. The farmers were invited to participate during field days, technical workshops, and other crop-related meetings promoted by several university extension services and relevant extension stakeholders during both 2020 and 2021. On the occasion of the approach and invitation, the farmers were briefly apprised of the research objective, promoting entities, and the confidentiality of personal data. Most questionnaires were given in-person but some were completed in online events.

Core Ideas

- Crop management linked to seed compositional quality is already carried out in soybean systems.
- Farmers relate improvement of seed composition mainly with crop nutrition.
- Less than 13% of the participants are aware of their levels of protein and oil.
- Premium prices over seed quality can stimulate adoption of new technologies.
- A US$0.50 per bushel premium would justify on-farm investments targeting quality.

Once a farmer agreed to participate, completing the survey instrument was self-instructed without the influence or assistance of any extension or research staff. Both methods, the hard copy (paper format) and the online form, were

TABLE 1 Identification number for all 21 questions and number of responses recorded using the survey instrument targeting U.S. soybean farmers during 2020 and 2021

ID	Question	Type	No. of answers
1	Number of acres planted to soybeans, average of past 5 years?	Open	267
2	What was your five-year average soybean yield, including the 2019 season?	Open	267
3	Do you know the current oil levels in your harvested soybean seed?	Closed	267
4	Do you know the current protein levels in your harvested soybean seed?	Closed	263
5	What are the percent oil levels in your harvested soybean seed?	Open	28
6	What are the percent protein levels in your harvested soybean seed?	Open	30
7	When you select a variety, which factors do you consider	Open	258
8	Please select any of the following practices that you have used on your farm to improve yield.	Closed	252
9	Do you apply nitrogen fertilizer to increase soybean protein?	Closed	257
10	Are crude protein levels in soybean important to you relative to yield?	Closed	248
11	In your opinion, crude protein levels of U.S. soybean are trending:	Closed	244
12	Has your soybean buyer/seller/crop consultant/agronomist ever talked to you about oil or protein levels in the seed you buy or grain you sell?	Closed	249
13	Would you like to know more about how you could manage your soybean crop to increase protein concentration?	Closed	246
14	What management factors do you think will be relevant to manage your crop to increase protein?	Open	234
15	Would protein levels be important to you if you could receive a price differential?	Closed	248
16	If so, what should the amount be per bushel?	Open	235
17	If there is a premium for protein, would you be interested on investing in technology for characterizing the within-field variability for protein?	Closed	244
18	State of production	Open	257
19	What nitrogen product do you apply to increase soybean protein?	Open	11
20	When do you apply nitrogen fertilizer to increase soybean protein?	Open	12
21	At what rate do you apply nitrogen fertilizer to increase soybean protein?	Open	11

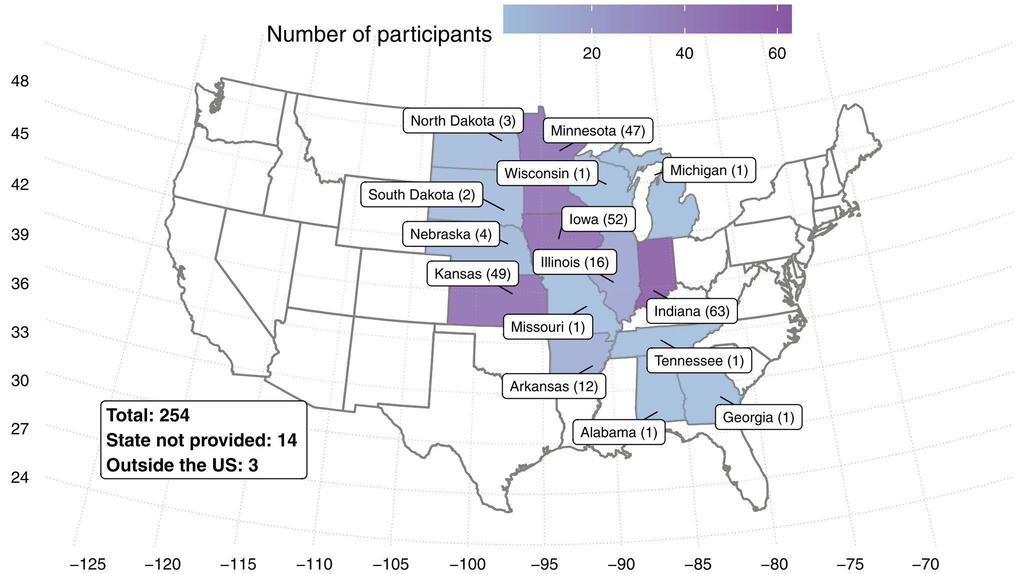

FIGURE 1 Number of participants (farmers) by U.S. states (displayed within parentheses for each state) completing the survey for the characterization of soybean seed composition

available at all events. The participant was never required to provide their name or any personal data. The participant could choose to avoid responding to any of the questions, selecting to opt out on providing any information. When the inquiry was answered in a hard copy form, a support team transcribed the information to the online system so the entire database could be stored in a secure cloud network. Participation was entirely voluntary without any kind of compensation for the completion of this survey instrument.

The inquiry was promoted in the following U.S. states: Arkansas, Kansas, Iowa, Illinois, Indiana, North Dakota, South Dakota, and Minnesota. Nevertheless, growers from 15 U.S. states participated in the survey (Figure 1). The states with the largest entry numbers were Indiana, Iowa, Kansas, and Minnesota. Some important producers from other relevant states such as Ohio, Michigan, Louisiana, Kentucky, and those from the Northeast and Southeast did not participate, but will be a potential focus in the future to complete a national database on the topic.

All forms (and their responses) were converted for numerical data and wrangled using the R project software (R Core Team, 2019). The data were cleaned from invalid entries, and figures were produced using the ggplot2 package (Wickham, 2016).

3 | RESULTS

Among respondents, the average soybean operation size was about 200 ha with the overall size ranging from 81 to 400 ha, but with a large proportion (~55%) of all responses growing less than 200 ha (Figure 2a). Soybean operation size greater than 500 ha was provided only by 20 participants, representing 7% of the overall number of participants. From the total number of farmers, 131 reported an average (considering the last 5 yr) seed yield ranging from 3.7 to 4.7 Mg ha^{-1}, followed by 102 farmers recording yields ranging from 2.7 to 3.7 Mg ha^{-1} (Figure 2b). Only 21 participants reported yields below 2.7 Mg ha^{-1} and 13 farmers reported yields above 4.7 Mg ha^{-1}.

In contrast to yield, only a small proportion of the surveyed farmers declared awareness about soybean seed compositional quality. For example, out of 271 participants, only 34 farmers (for oil) and 35 (for protein) knew the compositional quality of their harvested seed (Figure 3a,b). For those familiar with their oil levels, the range reported by those farmers ranged from 150 to 200 g kg^{-1} ($n = 15$), whereas protein concentration was dominated ($n = 22$) in the range from 300 to 400 g kg^{-1} (Figure 3c,d). Only one participant reported oil concentrations below 150 g kg^{-1} and two farmers declared protein concentrations below 300 g kg^{-1}.

Farmers presented a more complete set of responses about the critical factors supporting their decision regarding variety selection and management practices aiming for yield improvement. For variety selection, yield potential (29%), maturity group (related to season length, 27%), and tolerance to crop diseases (22%) were the most important factors (Figure 4a). Conversely, the genetic background was only mentioned on less than 2% of the responses. Regarding achieving high yield, seed treatment (with fungicides and insecticides) and early planting date were the most highly ranked factors (roughly 22% each; Figure 4b). Crop protection during seed filling and narrow row spacing were also

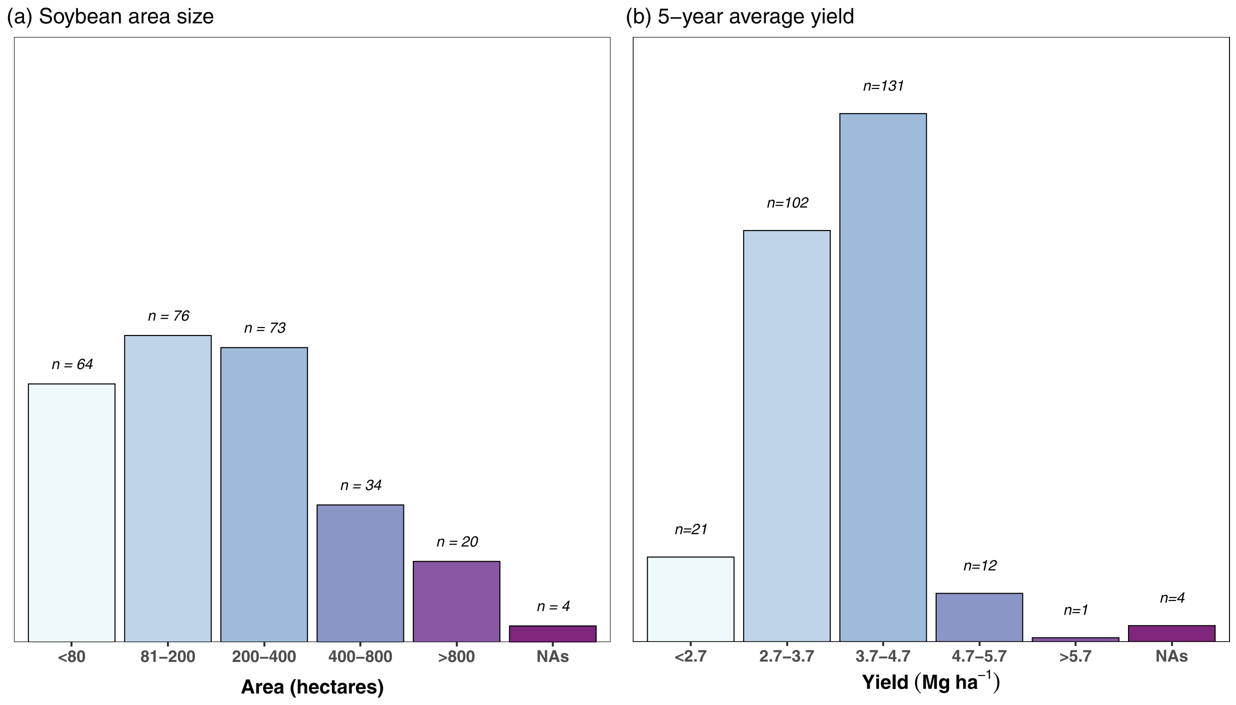

FIGURE 2 Surveyed farmer profile (all recorded responses) related to (a) soybean area size expressed in ha, and (b) average soybean yield as the average of the last 5 yr expressed in Mg ha^{-1}. NAs, number of absent answers

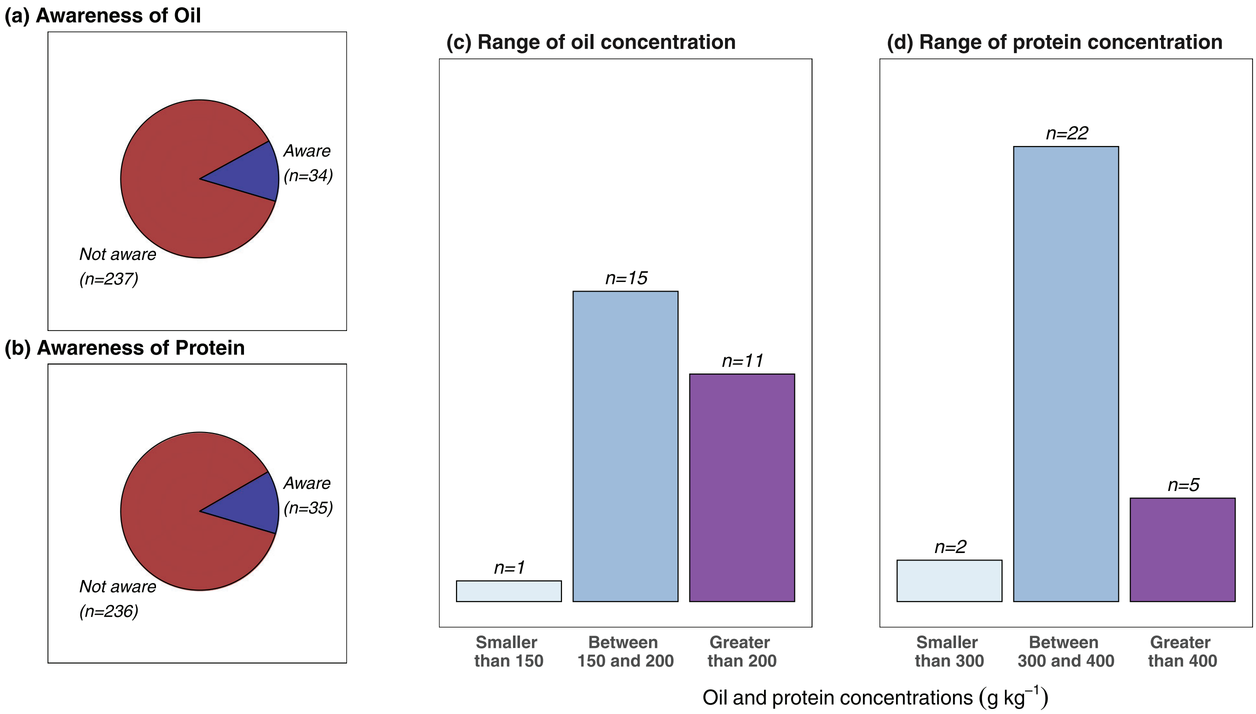

FIGURE 3 Knowledge and level of awareness of soybean seed compositional quality (both oil and protein) obtained from direct responses from farmers using a survey instrument. Awareness of (a) oil and (b) protein concentrations of harvested soybeans, and range of (c) oil and (d) protein concentrations (expressed in g kg^{-1})

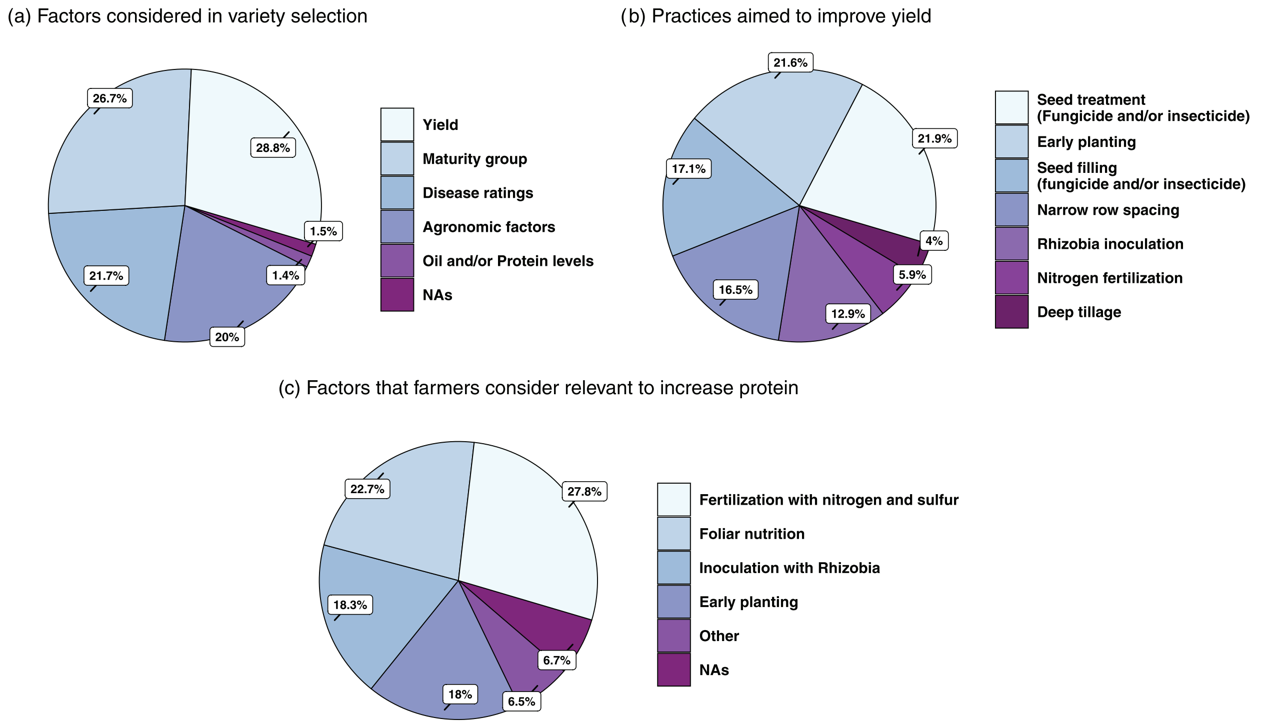

FIGURE 4 Technology adoption and management practices. The factors associated with (a) variety selection, (b) practices aimed to increase yield, and (c) factors considered relevant to increase seed protein concentration. NAs, number of absent answers

associated with high yields. The least recurrent practices related to yield were fertilizer N application (6%) and deep tillage (4%; Figure 4b).

Among the factors that farmers consider affecting yields, the fertilization with N and S was mentioned by 22% of all responses, followed by foliar nutrition with 23% and rhizobia seed inoculation and early planting with 18% each. In addition, 88% ($n = 238$) of the respondents declared that they do not apply N fertilizers to increase protein or oil concentrations, with only 7% ($n = 19$) providing a positive response on this factor. For this small set of farmers, most reported that they use ammonium sulfate or urea at pre-plant or planting ($n = 5$) or during reproductive stages ($n = 3$) at rates below 56 kg N ha^{-1} (data not shown). Regardless of whether in the near future the market will reward protein levels or not, 65% of the farmers declared interest in understanding and acquiring knowledge on how to manage crops in order to increase seed protein concentration (data not shown).

Farmers perceived that protein levels are stable ($n = 141$) or even increasing ($n = 28$) in U.S. production in the past years. Only 75 of the total respondents declared that they were aware of a decrease in soybean protein concentration (Figure 5a). Most respondents (92%) were not aware of their soybean seed quality, without having any other relevant player of the production chain (e.g., buyers, elevator, seed provider, or consultant agronomist) discussing this topic (data not shown). In the current market scenario, only 20% of the respondents considered protein level as an important soybean trait (data not shown). However, a remarkable change in this perception would be expected if farmers were to be rewarded for seed protein concentration. According to the survey, 243 farmers responded that they would consider their protein level if a premium price was guaranteed (Figure 5b). Additionally, 202 (75%) respondents declared a potential willingness to acquire technology for characterizing within-field variability of protein. Finally, a premium price of US$0.50 per bushel was considered as a sufficient incentive for farmers to focus more on improving seed quality (Figure 5c).

4 | DISCUSSION

This study reflected that soybean protein and oil concentrations are not yet a relevant topic for many U.S. farmers, but it provided new insights that this could evolve quite rapidly if a proper economic incentive is provided. Although our sample size was relatively small compared with the total number of farmers in the main U.S. soybean-producing region, the survey instrument successfully encompassed a large geographical area. This study provides unique evidence on the overall perspectives of U.S. soybean farmers relative to seed quality with the goal of developing new strategies to build a refocused value chain for the U.S. soybean farming system.

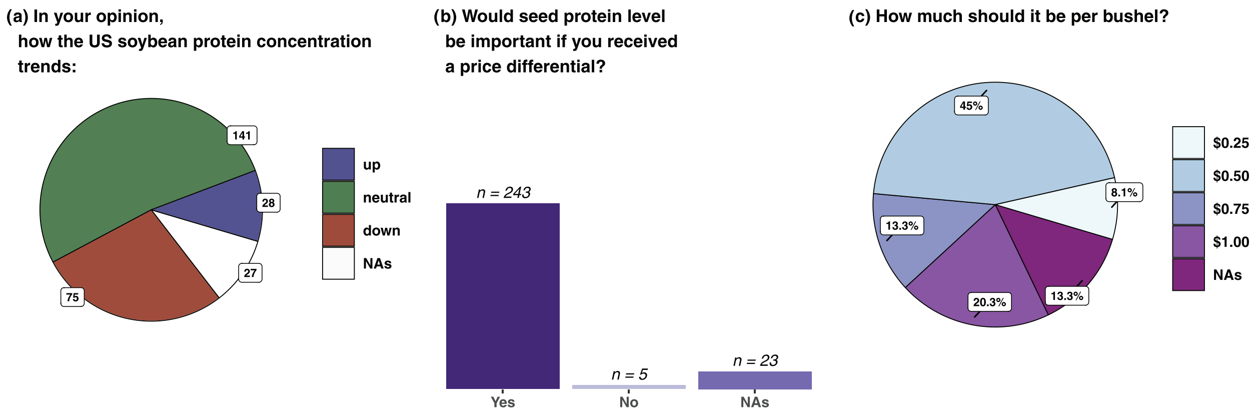

FIGURE 5 Farmers' outlook regarding a prospective market rewarding high protein levels. Perspective of farmers relative to (a) the overall U.S. soybean protein concentration, (b) potential for receiving a price differential in developing such market, and (c) overall additional price per bushel to be considered as attractive for soybean farmers. NAs, number of absent answers

The farmers' answers depicted an association between N or S fertilization with the increment of seed protein; however, this relationship may be valid for only a few environments. Although early research described the positive relationship of nutrient status and seed quality (Ham et al., 1975; Sexton et al., 1998, 2002), recent field results demonstrated a strong environmental control leading to erratic responses (de Borja Reis et al., 2021). Specifically, seed protein concentration may increase after S fertilization during the early season (vegetative) or late season (reproductive), but it depends on soil organic matter levels (de Borja Reis et al., 2021; Kaiser & Kim, 2013). Similar consideration must be outlined regarding rhizobia inoculation. In a recent study, de Borja Reis et al. (2022) observed responses on seed protein concentration due to rhizobia inoculation in only two out of 25 site-years, depicting a relatively low probability of responses across U.S. regions. In contrast, the association between protein concentration and foliar nutrition is not strongly grounded. Under extreme limiting conditions, any nutritional intervention may affect yield and seed composition (Assefa et al., 2019; Vrataric et al., 2006), but prophylactic foliar fertilizers did not change seed composition (Matcham et al., 2021). Interestingly, the growers did not mention variety selection as a potential alternative for increasing protein or oil concentration. This lack of association might be linked to limited options currently available on commercial varieties offering high seed quality levels. High protein genotypes exist, but without representing a significant portion of the market share (Alaswad et al., 2021; Mian et al., 2017). In summary, farmers demonstrated some degree of knowledge of management aspects linked to superior seed quality, but local agronomic validation and, even more importantly, market development will be critical for the success of high seed quality soybean production and, consequently, differentiation for U.S. soybeans.

Technologies for gauging on-farm management and support decisions are currently available. On-combine sensors measure seed mass protein concentration during harvesting based on spectral reflectance or transmittance and present relatively high accuracy (Taylor & Whelan, 2007). Despite this technology being available since the late 1990s (Engel et al., 1997), it has been used only in a few crops (e.g., wheat) and has never been broadly implemented in soybean systems. A complete solution for sensing and segregating grains or oilseeds is not yet available. Distinctly, off-combine proximal and remote sensing technologies allow harvest planning by predicting concentration during seed filling (Song et al., 2017; Wang et al., 2014; Xue et al., 2007). This method is less accurate than the on-combine sensor, but farmers could segregate and trade the production once areas of the field are identified with differential seed quality levels (Lilienthal, 2020). On-combine and off-combine technologies are not exclusive and may be used as complementary strategies. However, the challenge of sensing and segregating seed quality on-farm is proceeded by the even greater complexity of keeping the product segregated during the following steps of transportation and storage until the industrial processing.

The premium price of $0.50, considered by most farmers as attractive for stimulating investment, is smaller than the premium prices paid in other commodity markets. For instance, the spread between hard red spring wheat (~13.5% protein) and hard red winter wheat (~11% protein) averaged between 2010 and 2019 was $0.63 per bushel with peaks above to $2.00 (Bekkerman, 2018). In practice, the high protein wheat price may reach up to $1.25 per bushel (NWGG, 2021). Malting barley (containing higher protein than feeding barley) had an average premium price of $1.31 per bushel compared with feed barley from 1997 to 2020 (USDA, 2021). Price incentives are justified by the raw material providing superior quality down the production chain. In the case of soybean, there is a growing market for high protein soybean meal currently made from dehulled seeds, which could benefit from an increased protein concentration seed (Banaszkiewicz, 2011). High protein meal increases feeding efficiency and growing performance of livestock (Baker et al., 2014; Pangeni et al., 2017). Such benefit could substantiate demand and price differentiation for high protein soybean (Lilienthal, 2020).

In summary, this survey revealed that the challenges concerning managing soybean for seed quality are realizable if there is economic motivation. Future assessment should evaluate how feasible it is to unify the goals of high yield potential and high seed quality (mainly protein levels) within the same variety (Cober & Voldeng, 2000). Backlash on yield due to improved seed composition may hinder use. A major challenge may be related to a segregated product logistic (Sobolevsky et al., 2005), although regional differentiation due to climatic conditions is already reported (Assefa et al., 2019; Durham, 2003) and would require a less complex implementation. Future regional specialization of soybean production could be relevant to expanded opportunities and increased overall value of U.S. soybean markets. Finally, the tireless pursuit of adding value to an agricultural commodity is a complex but a desirable endeavor aiming to increase U.S. soybean competitiveness in future international markets.

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AUTHOR CONTRIBUTIONS

Andre F. Borja Reis: Data curation; Formal analysis; Writing – original draft. Luiz Rosso: Data curation; Formal analysis; Writing – original draft. Dan Davidson: Data curation; Writing – review & editing. Péter Kovács: Data curation; Writing – review & editing. Larry C. Purcell: Conceptualization; Writing – review & editing. Frederick E. Below: Data curation; Writing – review & editing. Shaun Casteel: Data curation; Writing – review & editing. Hans J. Kandel: Data curation; Writing – review & editing. Seth Naeve: Data curation; Writing – review & editing. Sotirios V. Archontoulis: Data curation; Writing – review & editing. Ignacio A. Ciampitti: Conceptualization; Data curation; Funding acquisition; Writing – original draft; Writing – review & editing.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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