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Stability Evaluation for Main Quality Traits of Soybean in the Northeast and Huang-Huai-Hai Regions

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Abstract: The content of protein and oil in soybeans is an important trait for evaluating quality and is regulated by genetic and environmental factors, lacking comprehensive identification under a variety of ecological conditions. Therefore, evaluating the stability of soybean quality traits under different environmental conditions has great significance for various applications. In this study, we compare 150 soybean varieties from Northeast China (Group A and Group B) and the Huang-Huai-Hai region (Group C). As the release time progressed, the oil content in the soybean varieties showed an upward trend in both Northeast China and the Huang-Huai-Hai region, while the protein content showed a downward trend. Additionally, the oil contents were negatively correlated with the protein contents and the sum of protein and oil contents, while the protein contents were positively correlated with the sum of protein and oil contents, with the correlation becoming stronger as the latitude decreased. Moreover, there were obvious variations in quality stability among different varieties. Hefeng 45, Jilinxiaolidou 4, and Zhonghuang 19 had relatively high protein contents and exhibited good stability across different environments, while Kenjiandou 25, Changnong 17, Dongnong 46, Kennong 17, Liaodou 14, and GR8836 had relatively high oil contents with good stability performance in varying environments.

Keywords: soybean; quality traits; oil content; protein content; stability analysis

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1. Introduction

Soybean (*Glycine max* (L.) Merr.), originating in China, stands as a pivotal oil crop and a vital source of plant-based protein for human consumption worldwide [1–3]. The enhancement of protein and oil content is of growing importance. Soybean seeds boast a high concentration of fats and proteins, serving dual roles as a nutrient reservoir for the growth of seedlings and as a key raw material for the extraction of soy protein and oil in the food processing industry [4–6]. Consequently, the improvement in soybean quality, particularly focusing on its protein and oil content, has garnered significant interest. Extensive research has revealed that soybean quality characteristics are influenced by both genetics and environmental factors [7–10]. Soybean varieties in China's three major ecological regions—the North, Huang-Huai-Hai, and the South—exhibit a north-to-south gradient with increasing protein content and a corresponding decrease in oil content. Soybeans with a high level of crude protein content are mainly concentrated in the Yangtze River basin and the southwestern mountainous area, while soybeans rich in crude oil content are primarily distributed in the northeastern and northwestern regions of China [11].

It has been suggested that the observed variations in fat accumulation are related to regional differences in environmental factors, such as temperature, precipitation, diurnal temperature variation, and sunlight exposure. As a result, the oil content in a single soybean variety may vary by over 1% due to differing meteorological conditions and cultivation practices across various locations [12]. Drawing on data from 2005 to 2018, Wang et al. [13] performed a quality analysis of Neidou 4, the predominant soybean variety cultivated in Inner Mongolia's premier production area and found that temperature and precipitation were critical meteorological factors influencing the protein content and that temperature alone was the principal factor affecting oil content. The Northeast, which has abundant sunlight, significant diurnal temperature variations, and moderate rainfall and growth-period temperatures, stands out as an optimal region for cultivating high-oil soybean varieties [14,15]. However, high-protein varieties thrive in the northern and central parts of China. The influence of latitude and terrain on soybean quality is the result and manifestation of the comprehensive effects of light, temperature, water, and nutrients [16].

The evaluation of soybean germplasm quality traits is often based on a single or a few experimental points [17,18], lacking comprehensive identification under a variety of ecological conditions; thus, exceptional resources of outstanding quality stability are seldom discovered. Nevertheless, identifying high-quality soybean germplasm that remains stable despite environmental variations is crucial for enhancing agricultural productivity, given that protein and oil contents are determined by genetic factors and modulated by the environment [19]. Accounting for 79% of China's soybean cultivation area in 2023, the Northeast and Huang-Huai-Hai regions are increasingly important for soybean growth (data sources: https://data.stats.gov.cn/?luicode=10000011) [20]. This study conducted multisite evaluations of germplasm from the Northeast and Huang-Huai-Hai regions, analyzing the mean values and stability of protein and oil content, with the aim of identifying outstanding germplasm with exceptional and stable quality traits to lay the material foundation for the cultivation of new high-oil, high-yield, and high-protein soybean varieties.

2. Materials and Methods

2.1. Experimental Material

This research utilized 150 soybean varieties from the Northeast and Huang-Huai-Hai regions as experimental materials (Table 1). These varieties were divided into three distinct geographic groups based on their growth locations. Groups A and B encompassed soybean varieties from the northern and central parts of the Northeast, respectively, and Group C comprised varieties from the Huang-Huai-Hai region. Each group notably consisted of an equal representation of 50 soybean varieties.

Table 1. Varieties used in this study and their breeding years.

Number	Material Name	Year of Approval	Number	Material Name	Year of Approval	Number	Material Name	Year of Approval
1	Fengshou 1	1958	1	Fengshou 12	1969	1	Shuilizhan	1956
2	Fengshou 10	1966	2	Suinong 4	1981	2	Yudou 1	1985
3	Heihe 3	1966	3	Dongnong 34	1982	3	Ludou 8	1988
4	Heihe 54	1967	4	Fengshou 19	1985	4	Zaoshou 17	1989
5	Beihudou	1972	5	Jilin 20	1985	5	Zhonghuang 3	1990
6	Fengshou 18	1981	6	Hefeng 27	1986	6	Yudou 12	1992
7	Heihe 4	1982	7	Heinong 30	1987	7	Ludou 10	1993
8	Beifeng 2	1983	8	Nenfeng 13	1987	8	Yudou 15	1993
9	Heihe 5	1986	9	Jiufeng 4	1988	9	Zhongpin 661	1994
10	Jiufeng 3	1986	10	Heinong 35	1990	10	Ludou 11	1995
11	Jiufeng 1	1987	11	Hongfeng 8	1993	11	Yudou 19	1995
12	Hefeng 30	1988	12	Heihe 11	1994	12	Yudou 20	1995
13	Heihe 7	1988	13	Suinong 10	1994	13	Nannong 217	1996
14	Kennong 2	1988	14	Bainong 6	1995	14	Tiefeng 28	1996

Table 1. *Cont.*

Number	Material Name	Year of Approval	Number	Material Name	Year of Approval	Number	Material Name	Year of Approval
15	Suinong 8	1989	15	Jilin 33	1995	15	Xudou 8	1996
16	Heinong 38	1992	16	Heihe 18	1998	16	Jindou 22	1998
17	Baofeng 7	1994	17	Hongfeng 11	1998	17	Handou 3	1999
18	Hefeng 35	1994	18	Suinong 15	1998	18	Huayou 542	1999
19	Neidou 4	1994	19	Dongnong 43	1999	19	Kexin 5	2000
20	Baofeng 8	1995	20	Jilin 47	1999	20	Jidou 12	2001
21	Beifeng 11	1995	21	Jiyuanyin 3	1999	21	Jindou 26	2001
22	Suinong 11	1995	22	Hefeng 39	2000	22	Tiefeng 31	2001
23	Suinong 14	1996	23	Jikedou 1	2001	23	Wuxing 1	2001
24	Heihe 18	1998	24	Jiyu 54	2001	24	Zheng 9007	2001
25	Heihe 19	1998	25	Kennong 17	2001	25	Zhonghuang 13	2001
26	Kennong 16	1998	26	Kennong 18	2001	26	Zhonghuang 20	2001
27	Kenjiandou 4	1999	27	Kennong 7	2001	27	Qichadou 2	2002
28	Dongnong 44	2000	28	Kenfeng 9	2002	28	Xudou 11	2002
29	Hefeng 40	2000	29	Kennong 19	2002	29	Zhongpin 662	2002
30	Heihe 23	2000	30	Dongnong 46	2003	30	Jinda 70	2003
31	Jiyu 58	2001	31	Dongsheng 1	2003	31	Liaodou 14	2003
32	Nenfeng 16	2001	32	Hefeng 44	2003	32	Zhonghuang 19	2003
33	Beifeng 16	2002	33	Heihe 28	2003	33	Handou 5	2004
34	Hefeng 42	2002	34	Heihe 30	2003	34	Jinda 74	2004
35	Hefeng 45	2002	35	Heinong 46	2003	35	Jindou 28	2004
36	Mengdou 11	2002	36	Hongfeng 12	2003	36	Jindou 29	2004
37	Suinong 18	2002	37	Jiyu 70	2003	37	Wuxing 2	2004
38	Dongda 1	2003	38	Kenfeng 10	2003	38	Dongdou 1	2005
39	Heihe 29	2003	39	Changnong 17	2003	39	Liaoshou 2	2005
40	Kenfeng 11	2003	40	Heinong 48	2004	40	84-51	NA
41	Kenjiandou 25	2003	41	Kenjiandou 33	2004	41	GR8836	NA
42	Kenjiandou 26	2003	42	Nenfeng 17	2004	42	Gaofeng 1	NA
43	Kenjiandou 27	2003	43	Suinong 21	2004	43	Heyin 1	NA
44	Mengdou 13	2003	44	Fengshou 14	NA	44	Heyin 2	NA
45	Heihe 34	2004	45	Fengshou 8	NA	45	Hedou 13	NA
46	Mengdou 14	2004	46	Jihuang 60	NA	46	Jinyi 30	NA
47	Fengshou 9	NA	47	Jilinxiaolidou 4	NA	47	Qingpipingdingxiang	NA
48	Jiufeng 6	NA	48	Kangxiandou 5	NA	48	Tiegan 1	NA
49	Jiufeng 7	NA	49	Nenfeng 10	NA	49	Wenfeng 1	NA
50	Nenliang 7	NA	50	Kato, Proto	NA	50	Yangyanjingdou	NA

NA indicates that the released year is unknown.

2.2. Analytical Methods

The varieties from the three regions were obtained from the Northeast and Huang-Huai-Hai regions in 2012. The trial sites for the varieties from the northern part of the Northeast (Group A) included Zhalantun (47°59′54″ N, 122°42′33″ E), Heihe (50°15′19″ N, 127°28′6″ E), Jiusan Farm (48°59′36″ N, 125°34′36″ E), and Yargenchu (47°44′52″ N, 122°36′44″ E). The central part of the Northeast (Group B) included trial sites such as Jiamusi (46°47′38″ N, 130°24′58″ E), Suihua (46°36′52″ N, 126°59′19″ E), Gongzhuling (43°30′46″ N, 124°48′35″ E), Tonghua (42°38′32″ N, 125°50′23″ E), and Yanbian (42°46′15″ N, 129°24′42″ E). The trial sites for the 50 varieties in the Huang-Huai-Hai region (Group C) were located in places namely Shijiazhuang (37°49′58″ N, 114°49′41″ E), Handan (36°33′28″ N, 114°31′46″ E), Zhoukou (33°38′37″ N, 114°41′1″ E), Funan in Fuyang (32°36′58″ N, 115°33′33″ E), Longkang in Bengbu (33°3′36″ N, 117°45′44″ E), and Mengcheng in Bozhou (33°28′55″ N, 116°14′26″ E) (Figure 1).

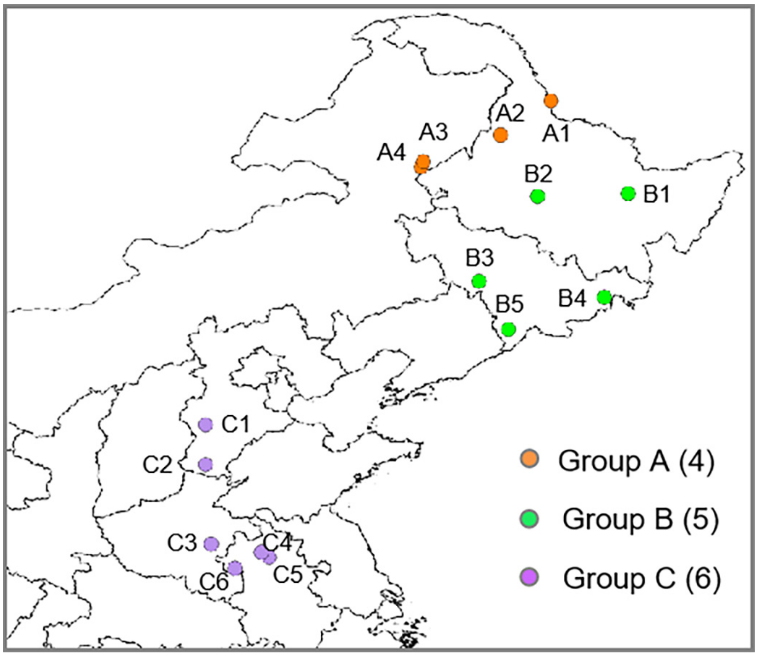


Figure 1. Distribution of experimental sites within the three regions. Three regions (Group A, Group B, and Group C) were set with 4, 5, and 6 experimental sites, respectively. The orange circles represent the distribution of experimental sites of Group A, with A1–A4 representing Zhalantun, Heihe, Jiusan Farm, and Yaergenchu, respectively. The green circles represent the distribution of experimental sites in Group B, with B1–B5 being Jiamusi, Suihua, Gongzhuling, Tonghua, and Yanbian, respectively. The purple circles represent the distribution of experimental sites in Group C, with C1–C6 being Shijiazhuang, Handan, Zhoukou, Fuyang, Bengbu, and Bozhou, respectively.

Each trial site followed a completely random experimental design, with a row length of 3 m. All trial sites maintained uniform management standards, applying 30 kg of compound fertilizer/acre before sowing and an additional 10 kg/acre before flowering, ensuring sufficient moisture with all materials harvested at full maturity. The content of protein and oil was determined using a near-infrared particle analyzer (Bruker, Germany). Soybean seed samples with clean surfaces, no cracks, no patches, and intact particles were selected. The spectral data of the samples were analyzed using OPUS 5.0 software, and the protein and oil content data were obtained by using a soybean protein and oil dry base model. Each material was measured three times and averaged to represent the protein and fat content of the sample [21]. Both protein content and oil content, as well as the sum of protein and oil contents, were expressed as percentages.

The GGE (genotype main effects and genotype × environment interaction) biplot is a method used to evaluate the interaction effects of germplasm (G) with the environment (E) [22,23]. In this study, the evaluation of the quality traits and stability of soybean germplasm at different trial sites in regions A, B, and C was performed through a GGE model using the R package (v4.3.1) GGEBiplotGUI. The specific parameters were as follows: Biplot tools = Rank genotypes with reference to the ideal genotype, Centered by = tester-centered G + GE, Scaled = no scaling, SVP = JK. Pearson correlation coefficient analysis was conducted to test the relationship between protein content and oil content in different ecological regions. T-tests were employed to verify statistical significance. Statistical analyses were performed using R (v4.3.1).

3. Results

3.1. Comparison of Quality Traits in Soybean Germplasms across Different Decades

To explore the quality characteristics of the varieties bred at different stages, comparisons of the protein content, oil content, and sum of protein and oil contents were made for varieties developed in different decades. Soybean germplasms from the three geographic areas were sorted into three chronological categories according to their year of official release: those released before 1990, those released between 1990 and 2000, and those released after 2000. In the three regions, the overall protein content tended to decline with the certification time of the variety (Figure 2A), with Group A showing a trend of first decreasing and then increasing and Group B showing a trend of decreasing, followed by a slow recovery. The protein content decline in Group C was the most significant. Conversely, the oil content generally showed an increasing trend over the certification years in all three regions (Figure 2B). The sum of protein and oil showed a continuous downward trend in Groups B and C, with a relatively slow decline in Group B. In Group A, it showed a trend of initial decline, followed by an increase. This means that the sum of protein and oil of the germplasm certified between 1990 and 2000 was less than that of the germplasm certified after 2000, which were both less than that of the germplasm certified before 1990 (Figure 2C). The above analysis indicates that, in recent years, the overall oil content of soybean germplasm in various regions has shown an upward trend, while the protein content has generally shown a downward trend.

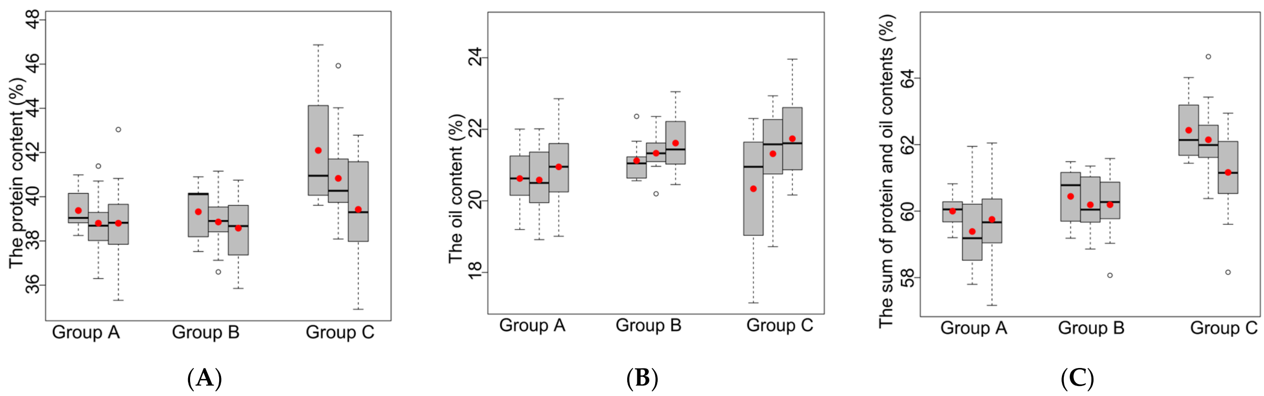


Figure 2. Comparison of quality traits of breeds developed in different eras in three regions: (**A**) protein content; (**B**) oil content; (**C**) sum of protein and oil contents. The three columns for each group represent varieties derived in the 1980s, 1990s, and 2000s. The red dots on the box plot represent the mean, while the black lines represent the median.

3.2. Correlation Analysis of Quality Traits among Different Regions

A correlation analysis was conducted on the protein content, oil content, and sum of protein and oil of soybean germplasms from different regions. The oil content was negatively correlated with both the protein content and the sum of protein and oil; the correlation coefficients were −0.76, −0.82, −0.93, −0.25, −0.48 and −0.77, with the negative correlation being strongest in Group C (−0.93, −0.77) and weakest in Group A (−0.76, −0.25) (Table 2). The protein content and the sum of protein and oil were positively correlated in all three regions, with the correlation strength decreasing from Group C (0.95) to Group B (0.9) and then to Group A (0.82) (Table 2). The analysis suggests that an increase in oil content often coincides with a decrease in protein content and in the sum of protein and oil contents. Conversely, there is a positive relationship between protein content and the sum of protein and oil contents that which strengthens as latitude decreases.

Table 2. Correlation analysis of quality traits in three regions.

	Correlation Coefficient	Significance
The protein and oil contents in Group A	−0.76	7.22×10^{-39}
The protein and oil contents in Group B	−0.82	8.64×10^{-61}
The protein and oil contents in Group C	−0.93	1.38×10^{-133}
The oil contents and sum of protein and oil in Group A	−0.25	0.000406
The oil contents and sum of protein and oil in Group B	−0.48	6.21×10^{-16}
The oil contents and sum of protein and oil in Group C	−0.77	2.54×10^{-61}
The protein content and sum of protein and oil in Group A	0.82	0
The protein content and sum of protein and oil in Group B	0.9	0
The protein content and sum of protein and oil in Group C	0.95	0

3.3. Analysis of Soybean Germplasm Quality Traits in Three Regions

Upon examining the protein and oil content and the combined protein–oil content in soybean germplasm samples from three geographical regions, discernable variations in the quality features among these regions were detected. The mean protein levels for the germplasm from Groups A, B, and C were 39.00, 38.98, and 40.11%, respectively (Figure 3A). Groups A and B exhibited comparable protein levels, whereas Group C exhibited a noteworthy increase in protein content when juxtaposed with Groups A and B (Figure 3A). Regarding oil content, germplasm from Groups A, B, and C had average percentages of 20.74, 21.34, and 21.45%, respectively (Figure 3B). There was an absence of a significant disparity between the oil content present in Groups B and C; however, both demonstrated significantly greater values than Group A (Figure 3B). The sum of protein and oil contents among the germplasm groups was in the following order from lowest to highest: Groups A, B, and C (Figure 3C). Collectively, the protein content, oil content, and sum of protein and oil contents in Group C were higher than those in Groups A and B, with the protein content and the sum of protein and oil contents of Group C being particularly notable.

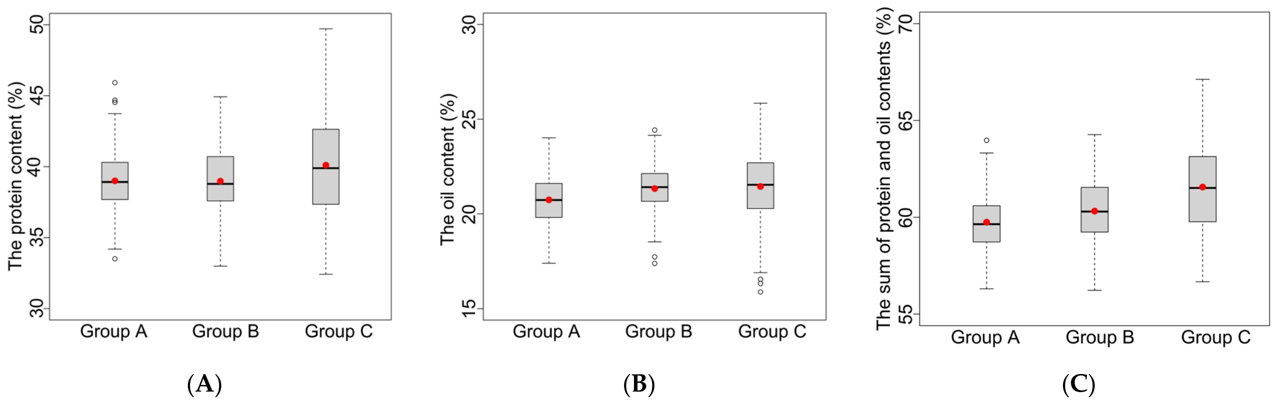


Figure 3. Comparison of quality traits in different regions: (**A**) protein content; (**B**) oil content; (**C**) sum of protein and oil contents. The red dots on the box plot represent the mean, while the black lines represent the median.

An analysis of the range of variation in quality traits of germplasm from different regions was also conducted. This evaluation included the measurement of the coefficient of variation (CV) for protein content within each germplasm group. Specifically, Groups A, B, and C showcased CVs of 0.035, 0.040, and 0.063, respectively, culminating in a mean CV of 0.046. The oil content featured CVs of 0.041, 0.037, and 0.065, with an overall average CV of 0.048. When considering the aggregate sum of protein and oil, the CVs were 0.017 for Group A, 0.015 for Group B, and 0.022 for Group C, with an average CV of 0.018 (Table 3). The CVs for protein content, oil content, and the sum of protein and oil were the highest in Group C. In addition, the range of variation in protein and oil content in the germplasm of

Group C was larger than that of Groups A and B (Table 3). These results suggest a greater variation in quality traits among different germplasms in Group C.

Table 3. Statistical analysis of qualitative traits in different regions.

Property	Group	Mean	Max	Min	Coefficient of Variation	Significance of Difference	Significance $p \leq 0.01$
The protein content	Group A	39	43.04	35.31	0.035	A:B—0.94	a
	Group B	38.98	42.95	35.85	0.04	B:C—7.98 × 10^{-3}	a
	Group C	40.11	46.87	34.91	0.063	C:A—7.17 × 10^{-3}	b
The oil content	Group A	20.74	22.85	18.92	0.041	A:B 0.000484	a
	Group B	21.34	23.05	19.62	0.037	B:C 0.62	b
	Group C	21.45	23.96	17.15	0.065	C:A 0.00276	b
The sum of protein and oil	Group A	59.75	62.05	57.16	0.017	A:B 0.00308	a
	Group B	60.32	62.57	58.07	0.015	B:C 0.000000309	b
	Group C	61.56	64.65	58.16	0.022	C:A 8.08 × 10^{-12}	c

Different lowercase letters (a, b, and c) indicate significant differences and identical letters suggest insignificant differences in one-way analysis of variance (ANOVA).

3.4. Stability Analysis of Quality Traits in Soybean Germplasms from Three Regions

In the pursuit of identifying germplasms that exemplify superior quality attributes alongside robust stability, a comparative analysis was conducted. This analysis assessed the average content alongside the variability of protein and oil content, as well as the cumulative protein and oil content, among various resources from multiple regions across distinct localities.

Within Group A, Mengdou 11 stood out, boasting the highest average protein content of 43%. The mains varieties with oil content greater than or equal to 22% were Hefeng 42, Kenjianbean 25, Suinong 11, and Fengshou 18. Hefeng 30 was distinguished by its remarkable stability regarding protein content, with a minimal CV of 1.12%. Hefeng 45 demonstrated an impressive blend of richness and relative stability in protein content, marked by a CV of 2.36% (Figure 4). In terms of oil content, Hefeng 42 was the frontrunner in the region, with an average of 22.9%, whereas Kenfeng 11 showcased remarkable consistency in oil content, evidenced by its low CV of 0.68%. Kenjiandou 25 also featured a noteworthy combination of high and relatively constant oil content (Figure 4). Mengdou 11 had the highest combined protein and oil content in the region, achieving a total of 62%. Considering stability, Suinong 18 emerged as the most reliable, with a CV of 0.46%. Beifeng 11 had a high and relatively stable sum of protein and oil contents (Figure 4, Table 4).

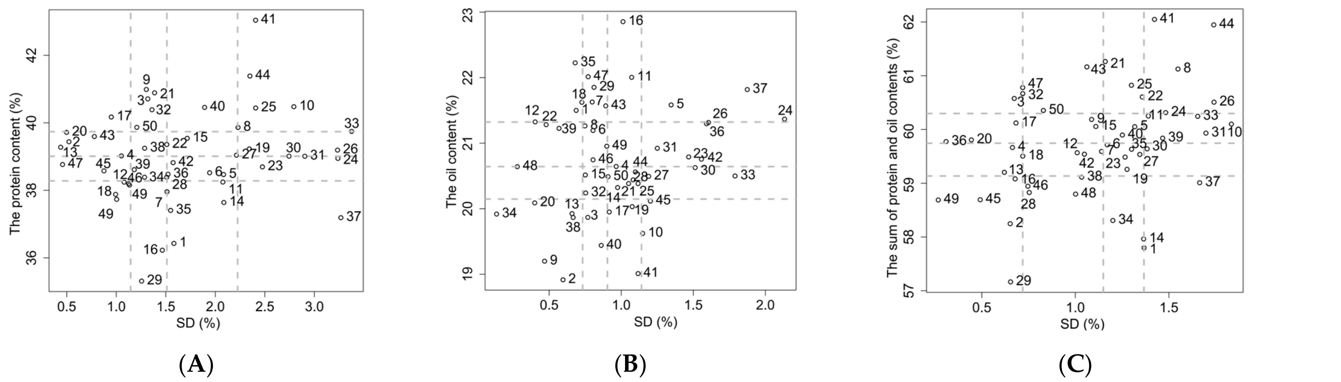
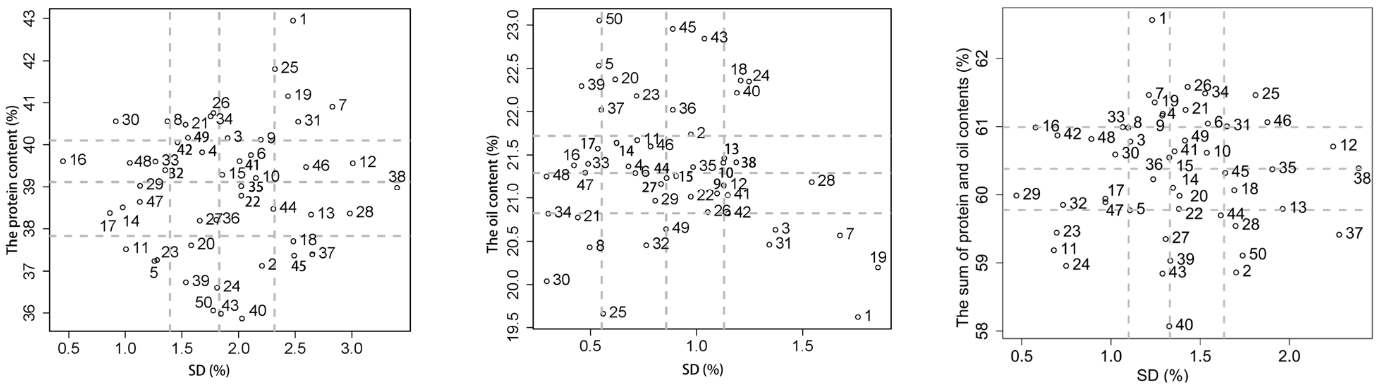


Figure 4. Analysis of quality traits and stability of varieties in Group A: (**A**) the protein content and coefficient of variation of the germplasm; (**B**) the oil content and coefficient of variation of the germplasm; (**C**) the sum of protein and oil contents and the coefficient of variation of the germplasm. Standard deviation (SD).

Table 4. List of germplasm with good quality traits and stability in Group A.

	Rank	The Protein Content			The Oil Content			The Sum of Protein and Oil Contents		
		Variety	**Mean**	**Coefficient of Variation (%)**	**Variety**	**Mean**	**Coefficient of Variation (%)**	**Variety**	**Mean**	**Coefficient of Variation (%)**
Mean	1	Mengdou 11	43	5.59	Hefeng 42	22.9	5.59	Mengdou 11	62	2.29
	2	Neidou 4	41.4	5.68	Kenjianbean 25	22.2	5.68	Neidou 4	61.9	2.81
	3	Fengshou 1	41	3.18	Suinong 11	22	3.18	Heihe 29	61.2	1.89
	4	Heihe 29	40.8	3.40	Fengshou 18	22	3.40	Mengdou 14	61.2	1.74
	5	Beifeng 11	40.7	3.24	Jiyu 58	21.9	3.24	Dongnong 44	61.1	2.53
	6	Fengshou 10	40.5	6.90	Kenjiandou 27	21.8	6.90	Heihe 54	60.8	2.14
	7	Kennong 2	40.5	4.67	Dongda 1	21.6	4.67	Suinong 11	60.8	1.18
	8	Heihe 54	40.4	5.95	Heihe 18	21.6	5.95	Jiufeng 6	60.6	1.19
	9	Jiufeng 6	40.4	3.37	Beifeng 2	21.6	3.37	Heihe 34	60.6	2.24
	10	Hefeng 45	40.2	2.36	Mengdou 14	21.6	2.36	Beifeng 11	60.6	1.11
Coefficient of Variation	1	Hefeng 30	39.3	1.12	Kenfeng 11	19.9	1.12	Suinong 18	58.7	0.46
	2	Suinong 11	38.8	1.18	Suinong 14	20.6	1.18	Kenjiandou 26	59.8	0.52
	3	Heihe 23	39.8	1.27	Fengshou 9	21.3	1.27	Heihe 23	59.8	0.81
	4	Baofeng 8	39.3	1.33	Heihe 23	20.1	1.33	Nenfeng 16	58.7	0.84
	5	Mengdou 14	39.6	1.97	Heihe 34	21.2	1.97	Hefeng 30	59.2	1.05
	6	Nenfeng 16	38.6	2.27	Fengshou 1	19.2	2.27	Beifeng 11	60.6	1.11
	7	Hefeng 45	40.2	2.36	Kennong 16	21.2	2.36	Beifeng 16	59.7	1.11
	8	Heihe 18	37.9	2.62	Kenjiandou 25	22.2	2.62	Baofeng 8	58.2	1.12
	9	Suinong 18	37.7	2.66	Baofeng 8	18.9	2.66	Hefeng 45	60.1	1.14
	10	Beifeng 16	39	2.70	Baofeng 7	21.5	2.70	Jiyu 58	57.2	1.14

In Group B, KatoProto had the highest protein content, with an average of 42.90%. Heihe 28 exhibited notable stability in this indicator, with a coefficient of variation (CV) of only 1.13%. Additionally, Jilinxiaolidou 4 had a protein content of 40.6% with a low degree of variation (Figure 5). Changnong 17 exhibited the highest oil content within its region, averaging 23.10%, and was characterized by a modest CV of 2.35%. Except for Suinong 21, Jiufeng 4, Jilinxiaolidou 4, Heihe 28, Heinong 48, Suinong 15, and Jiyuan Yin 3, the oil contents were equal to or greater than 22%. Changnong 17, Dongnong 46, and Kenfeng 17 had significant oil contents with low variation. Suinong 21, in particular, had the smallest CV for oil content, at 1.38%. KatoProto recorded the highest cumulative protein and oil content in the region, which reached 62.6%. In terms of consistency, Jilin 47 maintained a low CV of 0.78% (Table 5).



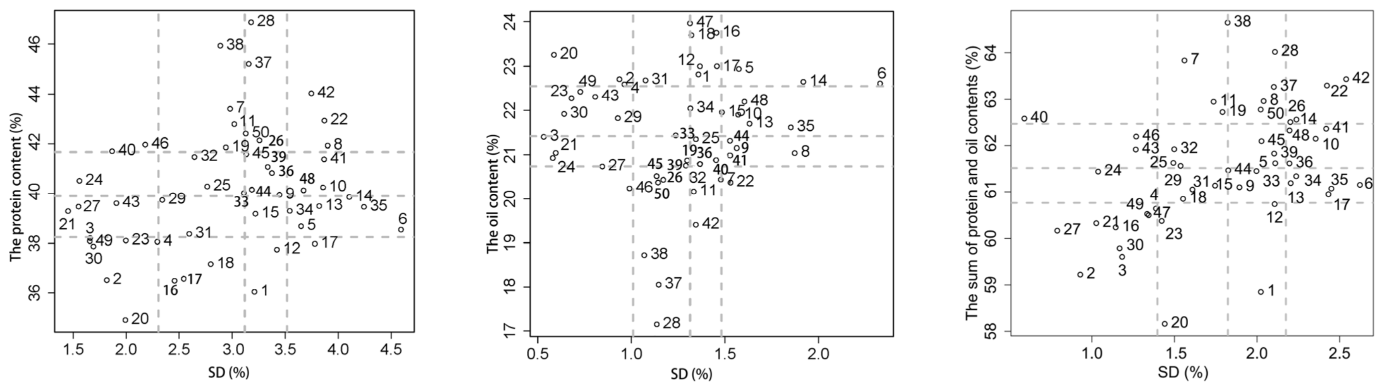
(**A**) (**B**) (**C**)

Figure 5. Analysis of quality traits and stability of varieties in Group B: (**A**) the protein content and coefficient of variation of the germplasm; (**B**) the oil content and coefficient of variation of the germplasm; (**C**) the sum of protein and oil contents and the coefficient of variation of the germplasm. Standard deviation (SD).

Table 5. List of varieties with good quality traits and stability in Group B.

		The Protein Content			The Oil Content			The Sum of Protein and Oil Contents		
	Rank	**Variety**	**Mean**	**Coefficient of Variation (%)**	**Variety**	**Mean**	**Coefficient of Variation (%)**	**Variety**	**Mean**	**Coefficient of Variation (%)**
Mean	1	Kato, Proto	42.9	5.78	Changnong 17	23.1	2.35	Kato, Proto	62.6	1.97
	2	Jihuang 60	41.8	5.55	Nenfeng 17	23	3.87	Jikedou 1	61.6	2.32
	3	Heinong 35	41.2	5.92	Nenfeng 10	22.8	4.54	Jiufeng 4	61.5	2.48
	4	Fengshou 12	40.9	6.91	Dongnong 46	22.5	2.39	Fengshou 12	61.5	1.97
	5	Jikedou 1	40.8	4.36	Heinong 46	22.4	2.76	Jihuang 60	61.5	2.94
	6	Jiufeng 4	40.7	4.31	Heinong 30	22.4	5.40	Heinong 35	61.4	2.03
	7	Fengshou 14	40.6	3.38	Hongfeng 8	22.4	5.58	Heinong 48	61.2	2.31
	8	Jilinxiaolidou 4	40.6	2.26	Kennong 17	22.3	2.05	Dongnong 43	61.2	2.11
	9	Jiyu 54	40.5	6.23	Kennong 18	22.2	5.36	Fengshou 19	61.2	2.11
	10	Heinong 48	40.5	3.78	Hongfeng 12	22.2	3.23	Suinong 10	61.1	3.07
Coefficient of Variation	1	Heihe 28	39.6	1.13	Suinong 21	21.2	1.38	Jilin 47	60	0.78
	2	Heihe 30	38.4	2.25	Jiufeng 4	20.8	1.45	Heihe 28	61	0.95
	3	Jilinxiaolidou 4	40.6	2.26	Jilinxiaolidou 4	20	1.47	Hefeng 27	59.2	1.15
	4	Heihe 11	38.5	2.54	Heihe 28	21.4	1.98	Kennong 7	60.9	1.15
	5	Suinong 21	39.6	2.63	Kennong 17	22.3	2.05	Hongfeng 12	59.4	1.17
	6	Hefeng 27	37.5	2.68	Heinong 48	20.8	2.12	Jiyu 70	59.9	1.22
	7	Jilin 47	39	2.89	Suinong 15	21.3	2.23	Hongfeng 8	59	1.27
	8	Suinong 15	38.6	2.93	Jiyuan Yin 3	21.4	2.33	Suinong 21	60.8	1.46
	9	Jiyuan Yin 3	39.6	3.19	Changnong 17	23.1	2.35	Heihe 30	59.9	1.62
	10	Dongnong 46	37.2	3.37	Dongnong 46	22.5	2.39	Suinong 15	59.9	1.62

Group C's Shuilizhan, Yudou 12, and Yangyanjingdou had more than 45% protein content, with Shuili Station having the highest protein content of 46.9%. The protein content of Liaoshou 2 remained stable, with a coefficient of variation (CV) of 3.69%. Zhonghuang 19 had a high protein content of 42%, on average, and a low CV of 5.19% (Figure 6). Zhonghuang 20 had the highest oil content in the region, with an average of 24%, while Dongdou 1 was the most stable, with a CV of just 2.48%. Liaodou 14 and GR8836 exhibited high and comparatively steady oil contents (Figure 6). Except for Dongdou 1, Ludou 8, Liaoshou 2, Tiefeng 31, and Qingpipingdingxiang, the oil contents were more than 22%. Yudou 12 had the highest sum of protein and oil in the region, reaching 64.60%, and Yudou 19 had the most stable sum of protein and oil, with a CV of 0.94% (Figure 6, Table 6).



(**A**) (**B**) (**C**)

Figure 6. Analysis of quality traits and stability of varieties in Group C: (**A**) the protein content and coefficient of variation of the germplasm; (**B**) the oil content and coefficient of variation of the germplasm; (**C**) the sum of protein and oil contents and coefficient of the variation of the germplasm. standard deviation (SD).

Table 6. The list of varieties with good quality traits and stability in Group C.

	Rank	The Protein Content			The Oil Content			The Sum of Protein and Oil Contents		
		Variety	Mean	Coefficient of Variation (%)	Variety	Mean	Coefficient of Variation (%)	Variety	Mean	Coefficient of Variation (%)
Mean	1	Shuilizhan	46.9	6.78	Zhonghuang 20	24	5.48	Yudou 12	64.6	2.82
	2	Yudou 12	45.9	6.29	Jindou 28	23.7	6.12	Shuilizhan	64	3.29
	3	Yangyan-jingdou	45.2	6.98	Jinyi 30	23.7	5.57	Heyin 1	63.8	2.44
	4	Yudou 20	44	8.51	Liaodou 14	23.3	2.52	Yudou 20	63.4	4.00
	5	Heyin 1	43.4	6.86	Jinda 70	23	5.94	Ludou 10	63.3	3.83
	6	Ludou 10	42.9	9.01	Jindou 29	23	6.33	Yangyan-jingdou	63.3	3.32
	7	Jidou 12	42.8	7.06	Handou 3	22.9	6.86	Heyin 2	63	3.24
	8	Zhongpin 662	42.4	7.37	84-51	22.8	5.95	Jidou 12	62.9	2.76
	9	Qichadou 2	42.1	7.73	GR8836	22.7	4.12	Zhongpin 662	62.8	3.22
	10	Zhonghuang 19	42	5.19	Tiegan 1	22.7	4.74	Kexin 5	62.7	2.86
Coefficient of Variation	1	Liaoshou 2	39.3	3.69	Dongdou 1	21.4	2.48	Yudou 19	62.6	0.94
	2	Ludou 8	40.5	3.85	Liaodou 14	23.3	2.52	Qingpiping-dingxiang	60.2	1.31
	3	Qingpiping-dingxiang	39.4	3.92	Ludou 8	20.9	2.77	GR8836	59.2	1.57
	4	Dongdou 1	38.2	4.34	Liaoshou 2	21	2.83	Ludou 8	61.4	1.69
	5	Zhongpin 661	38.1	4.35	Tiefeng 31	21.9	2.92	Liaoshou 2	60.3	1.70
	6	Yudou 19	41.7	4.47	Ludou 11	22.3	3.05	Jindou 28	60.2	1.90
	7	Tiefeng 31	37.9	4.48	Zhongpin 661	22.4	3.24	Tiefeng 31	59.8	1.95
	8	Zaoshou 17	39.6	4.81	Zaoshou 17	22.3	3.62	Dongdou 1	59.6	1.99
	9	GR8836	36.5	4.97	Qingpiping-dingxiang	20.7	4.07	Zhonghuang 19	62.2	2.04
	10	Zhonghuang 19	42	5.19	GR8836	22.7	4.12	Zaoshou 17	61.9	2.04

3.5. Adaptation Analysis of Germplasm Quality Traits Based on the GGE Model

Based on the GGE model, an adaptability analysis of germplasm quality traits was conducted in three regions. In Group A, Mengdou 11, Neidou 4, Fengshou 1, Heihe 29, and Jiufeng 6 exhibited good protein content, with higher and more stable protein levels. Hefeng 42, Kenjiandou 25, Jiyu 58, Fengshou 18, and Suinong 11 showed good oil content. Mengdou 11, Neidou 4, Mengdou 14, Heihe 29, and Suinong 11 demonstrated a higher and more stable sum of protein and oil contents (Figure 7A–C, Table 7). In Group B, Jihuang 60, Kato Proto, Heinong 35, Jikedou 1, and Jiufeng 4 showed higher and more stable protein content. Changnong 17, Nenfeng 10, Nenfeng 17, Dongnong 46, and Heinong 46 exhibited good oil content. Kato Proto, Jikedou 1, Jihuang 60, Jiufeng 4, and Heinong 35 showed a higher and more stable sum of protein and oil contents (Figure 7D–F, Table 7). In Group C, Shuilizhan, Yudou 12, Yangyanjingdou, Yudou 20, and Heyin 1 had higher and more stable protein content. Zhonghuang 20, Jindou 28, Jinyi 30, Liaodou 14, and Jinda 70 showed high and stable oil content. Yudou 12, Shuilizhan, Heyin 1, Yudou 20, and Ludou 10 demonstrated a higher and more stable sum of protein and oil contents (Figure 7G–I, Table 7). These research findings indicate significant variability in the adaptability of different germplasms to various environmental conditions in terms of quality traits. There are some germplasm varieties with favorable overall performance, predominantly composed of cultivated varieties but also including a few local varieties, such as Shui Li Zhan in Group C.

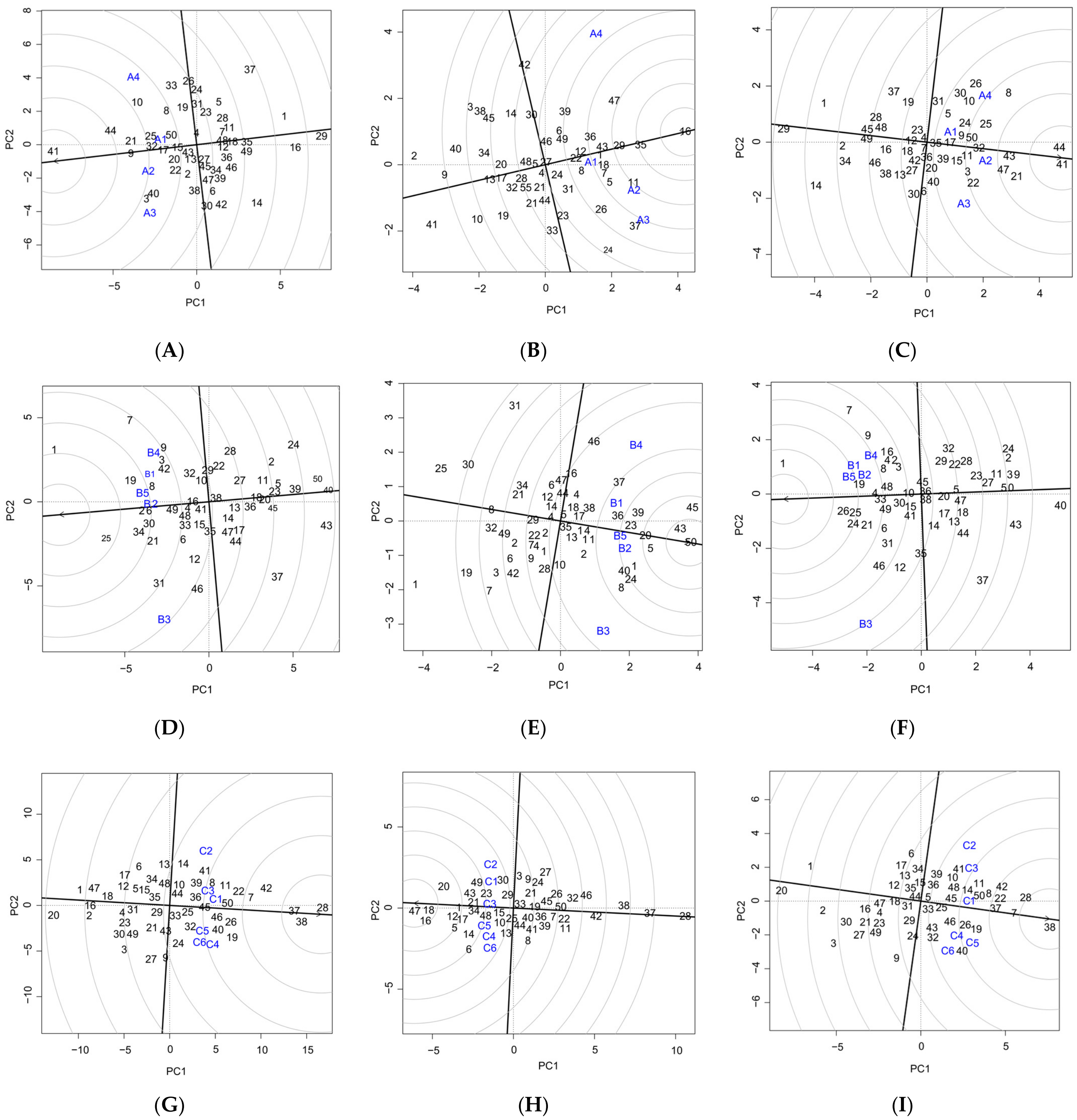


Figure 7. Stability of quality traits based on the GGE model: (**A**–**C**) the distribution of protein content, oil content, and the sum of protein and oil contents in Group A; (**D**–**F**) the distribution of protein content, oil content, and the sum of protein and oil contents in Group B; (**G**–**I**) the distribution of protein content, oil content, and the sum of protein and oil contents in Group C.

Table 7. The varieties with higher and more stable total protein and oil content.

Group	Rank	Variety	The Protein-Content (%)	Variety	The Oil Content (%)	Variety	The Sum of Protein and Oil Contents (%)
A	1	Mengdou 11	43	Hefeng 42	22.9	Mengdou 11	62
	2	Neidou 4	41.4	Kenjiandou 25	22.2	Neidou 4	61.9
	3	Fengshou 1	41	Jiyu 58	21.9	Mengdou 14	61.2
	4	Heihe 29	40.4	Fengshou 18	22	Heihe 29	61.2
	5	Jiufeng 6	40.4	Suinong 11	22	Suinong 11	60.8

Table 7. *Cont.*

Group	Rank	Variety	The Protein-Content (%)	Variety	The Oil Content (%)	Variety	The Sum of Protein and Oil Contents (%)
B	1	Jihuang 60	41.8	Changnong 17	23.1	Kato, Proto	62.6
	2	Kato, Proto	42.9	Nenfeng 10	22.8	Jikedou 1	61.6
	3	Heinong 35	41.2	Nenfeng 17	23	Jihuang 60	61.5
	4	Jikedou 1	40.8	Dongnong 46	22.5	Jiufeng 4	61.5
	5	Jiufeng 4	40.7	Heinong 46	22.4	Heinong 35	61.4
C	1	Shuilizhan	46.9	Zhonghuang 20	24	Yudou 12	64.6
	2	Yudou 12	45.9	Jindou 28	23.7	Shuilizhan	64
	3	Yangyanjingdou	45.2	Jinyi 30	23.7	Heyin 1	63.8
	4	Yudou 20	44	Liaodou 14	23.3	Yudou 20	63.4
	5	Heyin 1	43.4	Jinda 70	23	Ludou 10	63.3

4. Discussion

Soybean is one of the most widely cultivated crops in the world, and its protein and oil account for 69% and 30% of human and livestock consumption, respectively [24,25]. As a major source of plant fat and protein, modern cultivated soybean seeds contain about 17% oil and 35% protein (including essential and non-essential amino acids) [26]. In China, the Northeast and Huang-Huai-Hai regions account for approximately 64% and 15% of the total soybean planting area, respectively (data sources: https://data.stats.gov.cn/?luicode=10000011) [20], making them the main soybean-producing regions. Protein content and oil content are the most important quality indicators for soybeans, but they are easily influenced by the environment. This study compared the variability in protein and oil content among 150 varieties across multiple locations in the Northeast and Huang-Huai-Hai regions. It also evaluated the quality traits and stability of these varieties using the mean, CV, and GGE biplot models, among other methods.

4.1. Excellent Quality Traits of Varieties

Soybean quality traits are significantly influenced by the combined effects of genotype and environment [27–30], and the interaction between genotype and environment notably affects soybean protein and amino acid concentrations. However, the variations in soybean protein and amino acid content are dominated by genotype and environment rather than by the interaction between them [31,32]. For example, each soybean genotype was planted in four locations in Manitoba during 2018 and 2019, genotypes and environments exhibited the largest variation for protein and amino acid contents in soybeans [29]. This study analyzed 150 varieties from the perspectives of the mean value and stability of multiple location quality measurement values, selecting germplasm with higher mean values and better stability of quality traits within different planting areas, some of which are of high quality and relatively stable. For example, HeFeng 45 from Group A in the northern portion of the Northeast, Jilinxiaolidou 4 from Group B in the central portion of the Northeast, and Zhonghuang 19 from the Huang-Huai-Hai region performed better in terms of protein content with an average value that was greater than 40% and these areas were also better in terms of stability. Meanwhile, Kenjiandou 25 from Group A, Changnong 17, Dongnong 46, and Kennong 17 from Group B in the Northeast region, and Liaodou 14 and GR8836 from the Huang-Huai-Hai region were greater than 22% that were more stable in the environment. The above materials can serve as parental lines for quality improvement breeding programs, providing clues for the development of new varieties with good quality and stability through hybrid convergence breeding.

4.2. Changes in Soybean Variety Quality Traits in the Huang-Huai-Hai and Northeast Regions during Different Periods

The economic and nutritional value of soybeans is determined by their seed protein and oil content [33]. To understand the impact of the breeding process on quality traits, this study compared the quality trait changes of varieties bred during different periods. Varieties bred in the 1980s and earlier exhibited a lower oil content and a higher protein content compared to those bred after the 1990s. Over time, the protein content generally showed a decreasing trend, while the oil content increased, indicating that soybean breeding in recent years has primarily focused on increasing the oil content [34,35]. However, it is important to note that with genetic improvement, both the protein content and the combined protein and oil content decreased [36]. Since domestic soybeans are mainly used for consumption, subsequent soybean genetic improvements should focus on increasing the protein content and gradually increasing yield levels.

Protein content and oil content are the main quality traits of soybean seeds, determined by quantitative loci and their interaction with the environment [37]. Prenger, based on 2017 yield trial data, found significant negative relationships between protein and yield and between protein and oil [38]. The analysis of soybean protein and oil content was conducted on 292 soybean materials, revealing that these two traits exhibited a normal distribution within natural populations and were widely mutated within the population and showed a negative correlation [39]. Comparing the protein content among varieties from different regions showed that the protein content of varieties in the Huang-Huai-Hai region has always been higher than that of varieties in the Northeast region. Among varieties bred before the 1990s, the oil content of varieties in the Huang-Huai-Hai region was significantly lower than that of varieties in the Northeast region. For varieties bred after the 1990s, the oil content of varieties in the Huang-Huai-Hai region increased significantly, and their overall oil content was higher than that of varieties in the Northeast region. Relative to the Northeast region, the protein and oil content in the Huang-Huai-Hai region was maintained at a higher level. Considering both protein content and oil contents, the sum of protein and oil showed a downward trend due to the decrease in the protein contents of varieties in different regions, but the sum of protein and oil of varieties in the Huang-Huai-Hai region had always been higher than that in the Northeast region. Therefore, in terms of quality traits, the Huang-Huai-Hai region maintained higher levels of protein and oil content, making it suitable for the production of high-quality soybeans. Additionally, the range of variation in protein and oil content among varieties in the Huang-Huai-Hai region was wide, and there was a strong negative correlation between protein and oil content, which is conducive to breeding varieties with specific uses for protein or oil.

In summary, this study evaluated the quality traits of 150 soybean varieties from the Huang-Huai-Hai and Northeast regions across multiple locations, revealed patterns of quality variation among regional varieties, identified excellent varieties of resources with good quality traits and stability, and provided a theoretical basis and material support for promoting soybean quality improvement.

5. Conclusions

Across the Northeast and Huang-Huai-Hai regions, soybean varieties showed an overall increasing trend in oil content through successive breeding generations, while the protein content generally exhibited a decreasing trend. There was a negative correlation between oil content and both protein content and the sum of protein and oil contents, whereas the protein content was positively correlated with the sum of protein and oil contents. Furthermore, these correlations strengthened with decreasing latitude. The stability of quality traits among various resources under various environmental conditions showed significant variation. Hefeng 45, Jilinxiaolidou 4, and Zhonghuang 19 had a relatively high protein content and exhibited good stability across different environments. Kenjiandou 25, Changnong 17, Dongnong 46, Kennong 17, Liaodou 14, and GR8836 all had a relatively high oil content, with stable performance in varying environments. Through multi-point evaluations of soybean germplasm quality traits in the Northeast and Huang-Huai-Hai regions, it was evident that not only was there a large variance in quality among varieties, but the degree of environmental impact also varied greatly. The selection of varieties with superior quality and stability is of significance for the genetic improvement of soybean varieties.

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Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author/s.

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