Developing Improved Soybean Lines for Seed Composition, Quality, and Heat Tolerance in Mississippi (Project No: 33-2021)

PI: Dr. Nacer Bellaloui; Email: Nacer.Bellalui@ars.usda.gov

Background and Objectives

High heat in the Early Soybean Production System (ESPS) is a major environmental stress factor resulting in yield loss and poor seed quality, lowering the level of seed composition constituents in heat sensitive soybeans, lowering market grade, and reducing the quality of soymeal and oil. According to the Risk Management Agency, seed damage in the Southeast caused by heat was 40.4 % of the national total acreage with heat damage, and the monetary payouts were 36.1 % of the national payout total for heat damage. Concerning U.S. seed composition, historic data from 1986 to 2015 showed a decreasing trend of protein content in soybean. Therefore, among the objectives of the USB 2011-2016 Strategic Plan is to increase the value of US soymeal and oil in the value chain by changing seed composition. To our knowledge, there are no commercial soybean cultivars that are heat-tolerant with high levels of seed composition (seed protein, oil, and minerals) and quality components (reduced seed damage including reduced green seed, seed wrinkling, hard seed, and diseased seed). Therefore, developing heat tolerant germplasm with high seed composition and quality is essential.

This research will provide seed compositional and quality phenotypes for the future identification of genes associated with seed protein, oil, fatty acids, sugars, and minerals and will identify breeding lines with both heat-tolerance and high seed compositional qualities for release. These heat-tolerant breeding lines will be used by public and private breeders to develop improved cultivars which, when adopted by Mississippi producers, will be a valuable seed quality component, enabling producers to more effectively compete nationally and internationally in soybean markets.

Objective One

To phenotype seed composition constituents (protein, oil, fatty acids, sugars, and minerals), leaf minerals, as well as seed quality traits, including Federal Grain Inspection Service (FGIS) seed damage ratings (green seed, seed wrinkling and stink bug damage), the presence of seed pathogens (especially Phomopsis) and seed physical characteristics such as seed size and 100 seed weight in two RIL populations. Identifying heat tolerant breeding lines with high seed compositional qualities will be an essential component for soybean producers to compete nationally and internationally in the global market.

Report of Progress/Activity

The research was conducted at the USDA ARS Jamie Whitten Delta States Research Center at Stoneville, MS. The field trial was conducted using two recombinant inbred line populations [(One population, 201 lines, derived from the cross DS25-1 (heat tolerant) x DT97-4290, planted in the field in 2018 and 2019; and the second population, 301 lines, planted in 2020, derived from the cross between DS34-1 (heat tolerant) x LD00-3309 (high-yielding cultivar)]. These RILs, segregating for tolerance to heat-induced seed damage, will allow us to phenotype seed composition traits (protein, oil, fatty acids, sugars, amino acids, and minerals) that may be related to heat tolerance. Plots were hand-harvested shortly after R8 for seed composition analysis, germination, viability, and seed damage assessment. Seed analyses were performed using standard laboratory protocols, including near infra-red (NIR) for seed protein, oil, fatty acids, and sugars; inductively coupled plasma (ICP) spectrometry (Thermo Jarrell-Ash Model 61E ICP and Thermo Jarrell-Ash Autosampler 300) for minerals analysis; and C/N/S (carbon, nitrogen, and sulfur) Elemental Analyzer for C, N, and S. Grain damage estimates will follow official protocols from the Federal Grain Inspection Service (FGIS). Results of seed composition constituents from the two RIL populations showed significant variability and distribution among the RILs and between the RILs and the parents. For example, Figure 1-Figure 10 for RIL population 1 [(across between DS25-1 (heat tolerant) x DT97-4290)] in 2018 and 2019; (Figure 11-Figure 17) in 2020 for RIL population 2 (across between DS34-1 x LD00-3309); Figure 18-Figure 21 for leaf minerals of population 1 (across between DS25-1 (heat tolerant) x DT97-4290) in 2019. No significant seed damage, as measured by FGIS, was noticed among the RILs or parents, as FGIS was recorded to be lower than 2%; FGIS includes grain damage due to multiple factors, including mold, heat, green seed, stink bug, and purple stain. Grain elevators assess discounts on the value of grain produced by soybean producers based on FGIS standards. This can result in a loss of revenue to producers when they sell their grain. A common level of grain damage that could result in discounting at grain elevators is the 2% level, meaning that damage >2% would result in discounting of payments to producers.

Impacts and Benefits to Mississippi Soybean Producers

Acreage of soybean planted in Mississippi (estimated soybean planted is 2.22 million acres: USDA, National Agricultural Statistics Service, Mississippi Acreage Report, 2021) with about 117 million bushels produced in 2021, with a value of $ 1.5 billion that contributed to the Mississippi economy. High heat in the Midsouth is a major environmental stress factor, leading to poor seed quality and influencing seed composition constituents, including protein, oil, fatty acids, sugars, and mineral contents. These constituents determine seed quality and are essential for human consumption and livestock nutrition. Protein content determines soymeal quality and economic value. High seed oil is desirable for human consumption. High oleic and low linolenic acids contribute to oil stability. Raffinose and stachyose sugars are undesirable components because they have detrimental effects on the nutritive value of the meal and are indigestible by human and animals, often causing flatulence or diarrhea in non-ruminants. Sucrose sugar is desirable because it improves taste and flavor in tofu, soymilk, and natto and is digestible. Higher mineral contents such as iron, zinc, magnesium, and potassium are desirable for human nutrition and animal rations. Reports from USB indicated that the trend of protein content in U.S. soybeans has been declining during the period of 1986 to 2015.

Therefore, in order to maintain high seed compositional qualities, the continued evaluation of seed composition and mineral nutrition qualities is critical. Identifying heat tolerance varieties with high levels of seed composition, especially protein and minerals, and seed quality, will be essential for the Midsouth. Also, high levels of seed compositional qualities, especially protein and minerals will impact soybean producers to compete nationally and internationally in the global market.

Results obtained from this research will be published in peer-reviewed journal articles. Results will also be presented at scientific meetings and field days. The seed trait measurements obtained through the research outlined herein, can be used in conjunction with a molecular map to identify the genomic location of genes controlling/influencing the traits. Knowing these genomic locations would allow the development of molecular markers for specific traits, which could increase the efficiency of selection and thereby reduce development time for new germplasm and cultivar releases.

End Products–Completed or Forthcoming

Results will be published in peer-reviewed journals, presented at regional and national scientific meetings, field days, and workshops. Additionally, we anticipate identifying RILs with improved heat-tolerance as well as better seed composition and quality for future germplasm releases. These lines will be incorporated into the breeding program. Results from this research were already presented at the 82nd Annual Meeting of the Southern Section of the American Society of Plant Biologists (SS-ASPB), April 16 -18, 2021, on " Developing improved soybean lines for seed composition, quality, and heat tolerance in Mississippi". Other presentations will be given at different scientific and stakeholder meetings, which will follow afterwards. At least two manuscripts will be published in peer-reviewed journals.

Graphics/Tables

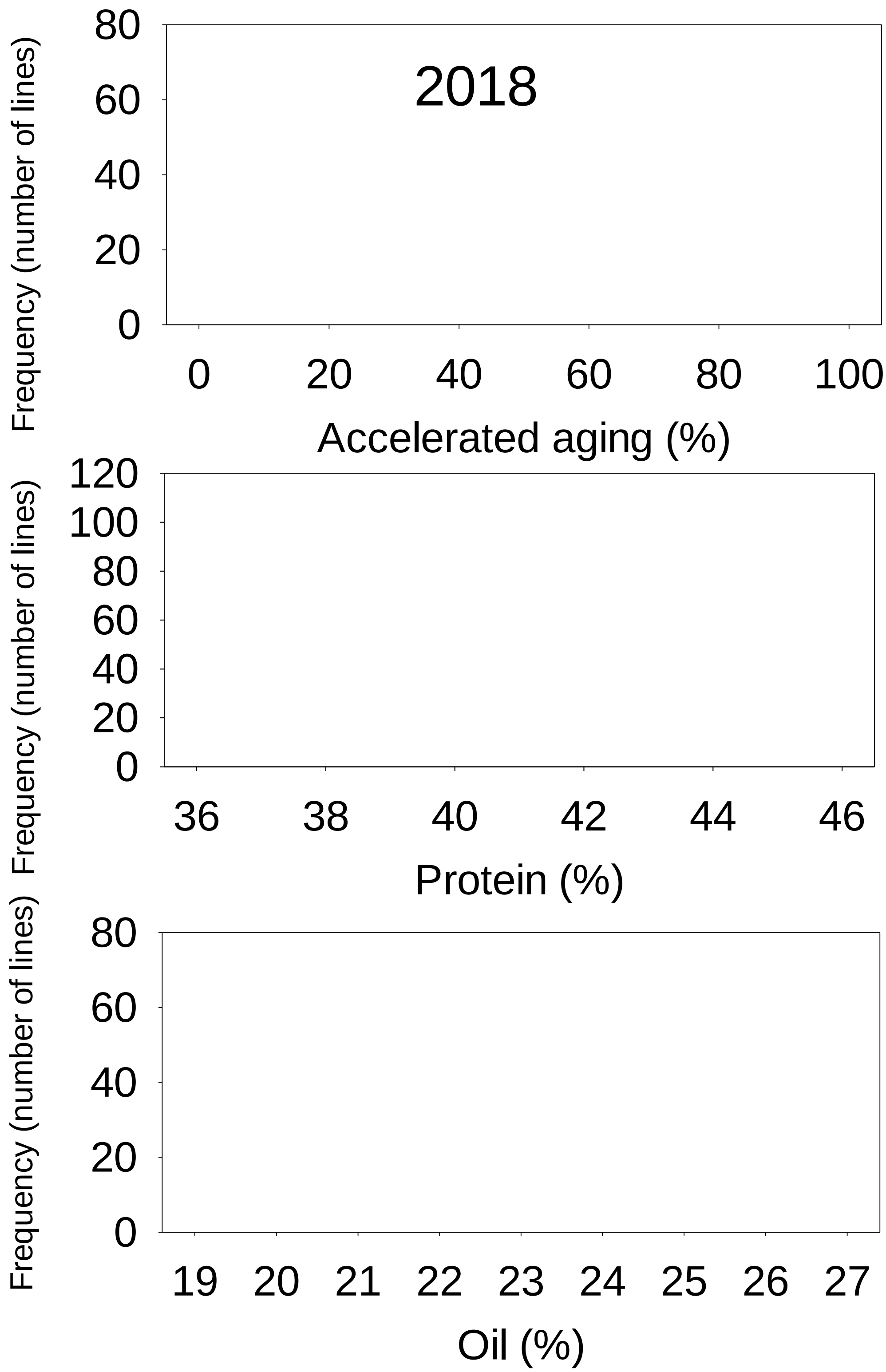


Figure 1: Significant variability and distribution of seed quality components across RILs. The RIL

population was a cross between DS25-1 (heat tolerant) x DT97-4290. The experiment was planted in 2018 in Stoneville, MS, USA.

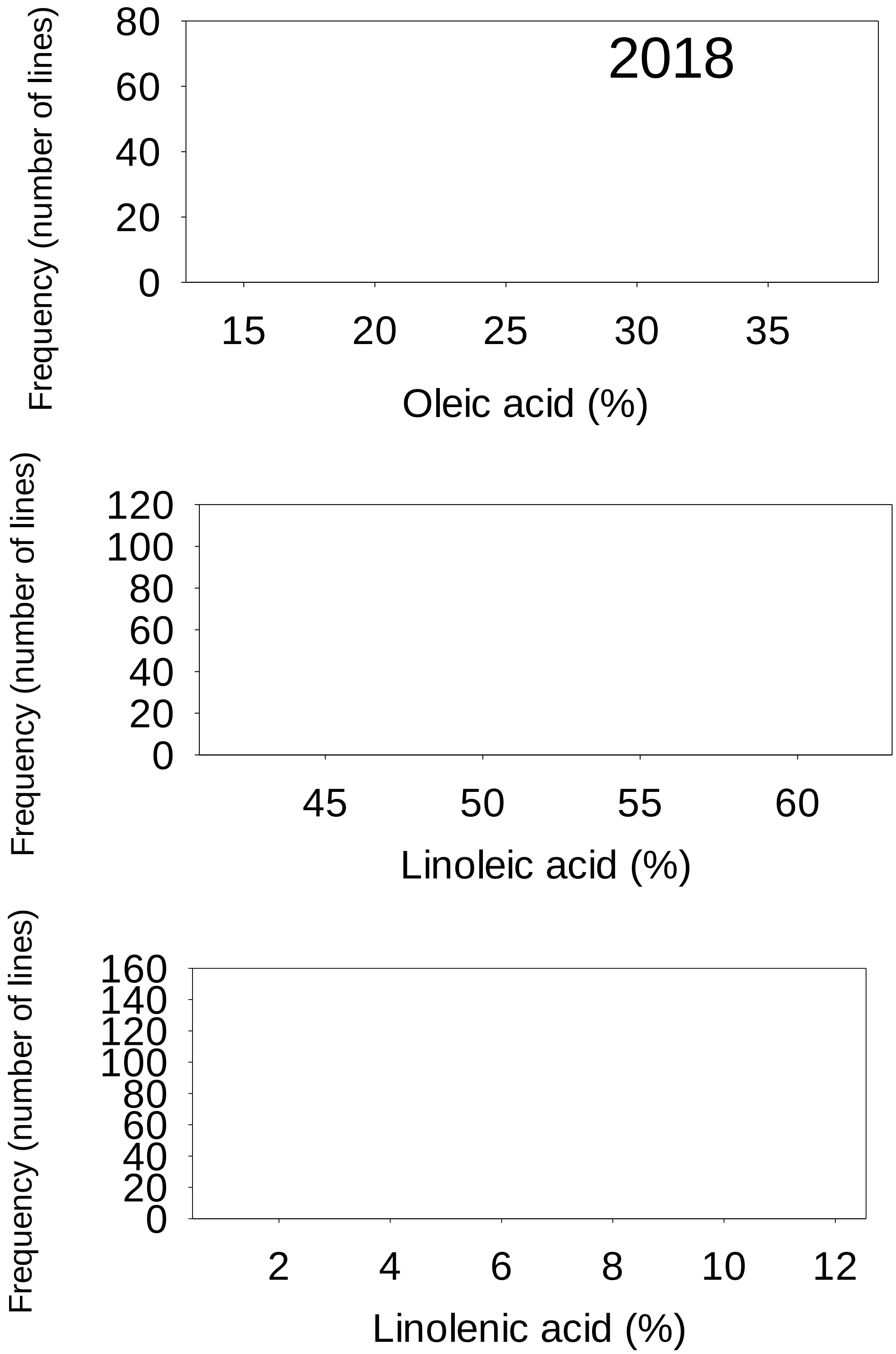


Figure 2: Significant variability and distribution of seed quality components across RILs. The RIL population was a cross between DS25-1 (heat tolerant) x DT97-4290 (moderately resistant to charcoal rot). The experiment was planted in 2018 in Stoneville, MS, USA.

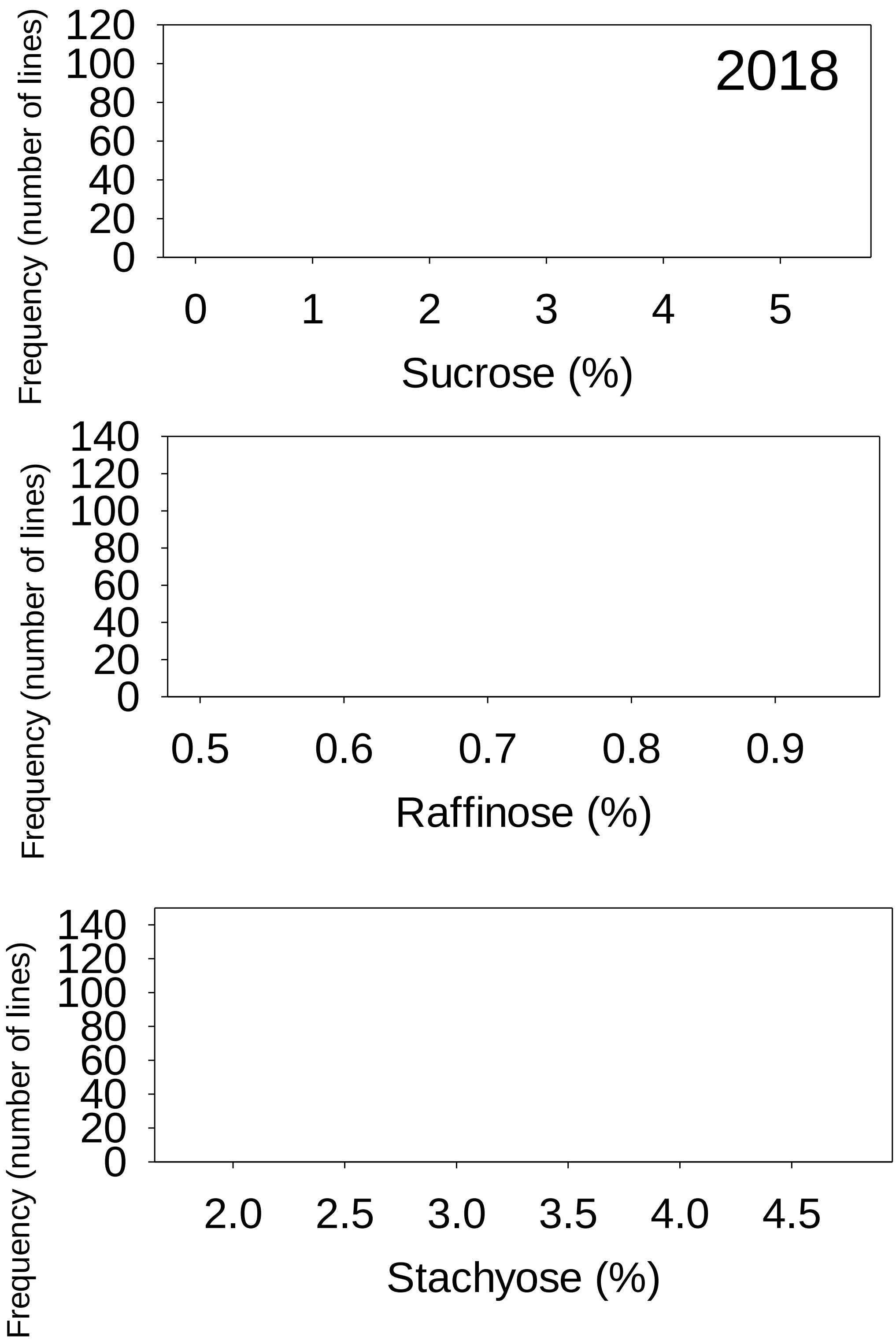


Figure 3: Significant variability and distribution of seed quality components across RILs. The RIL population was a cross between DS25-1 (heat tolerant) x DT97-4290 (moderately resistant to charcoal rot). The experiment was planted in 2018 in Stoneville, MS, USA.

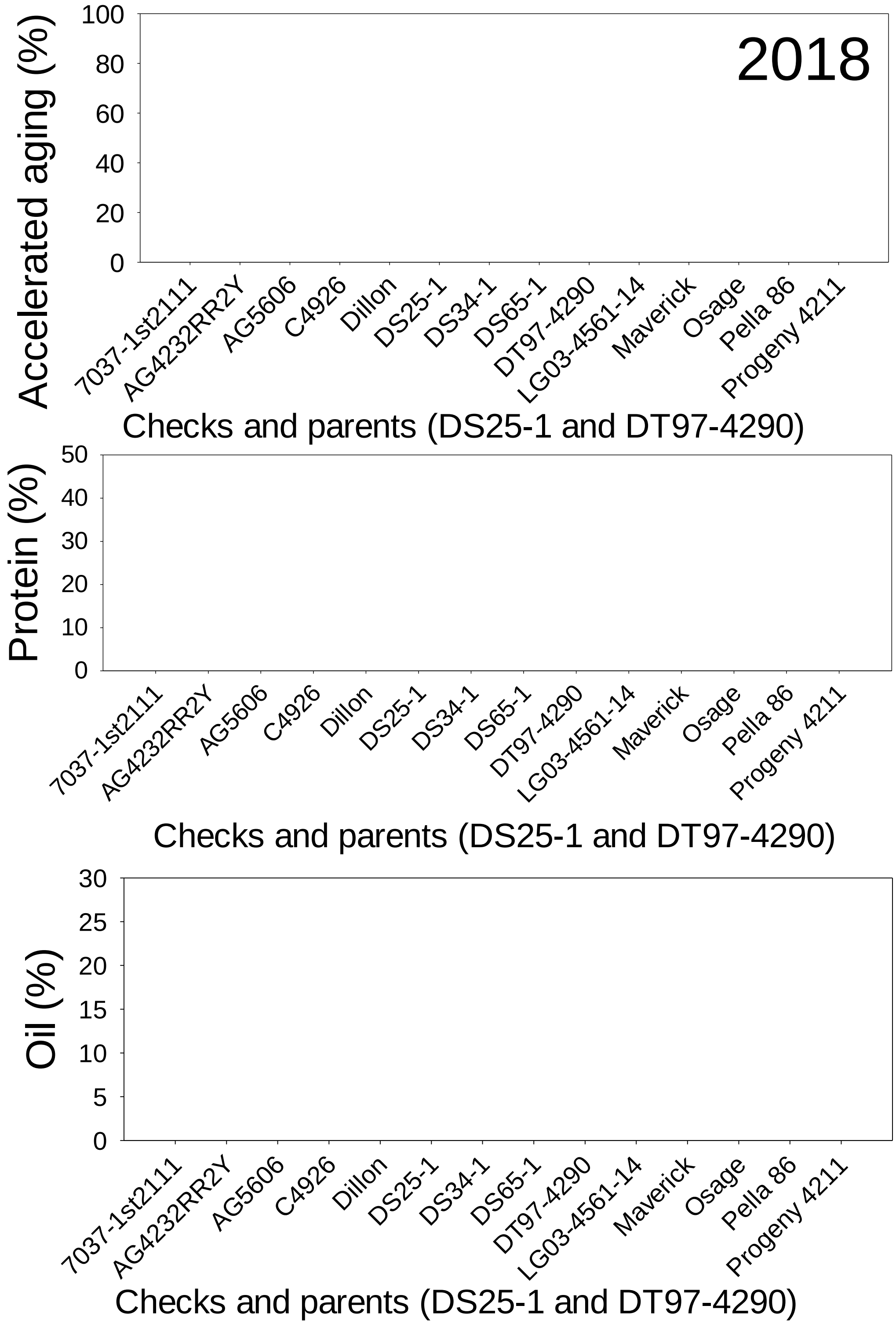


Figure 4: Significant variability and distribution of seed quality components in checks, and parents. The experiment was planted in 2018 in Stoneville, MS, USA.

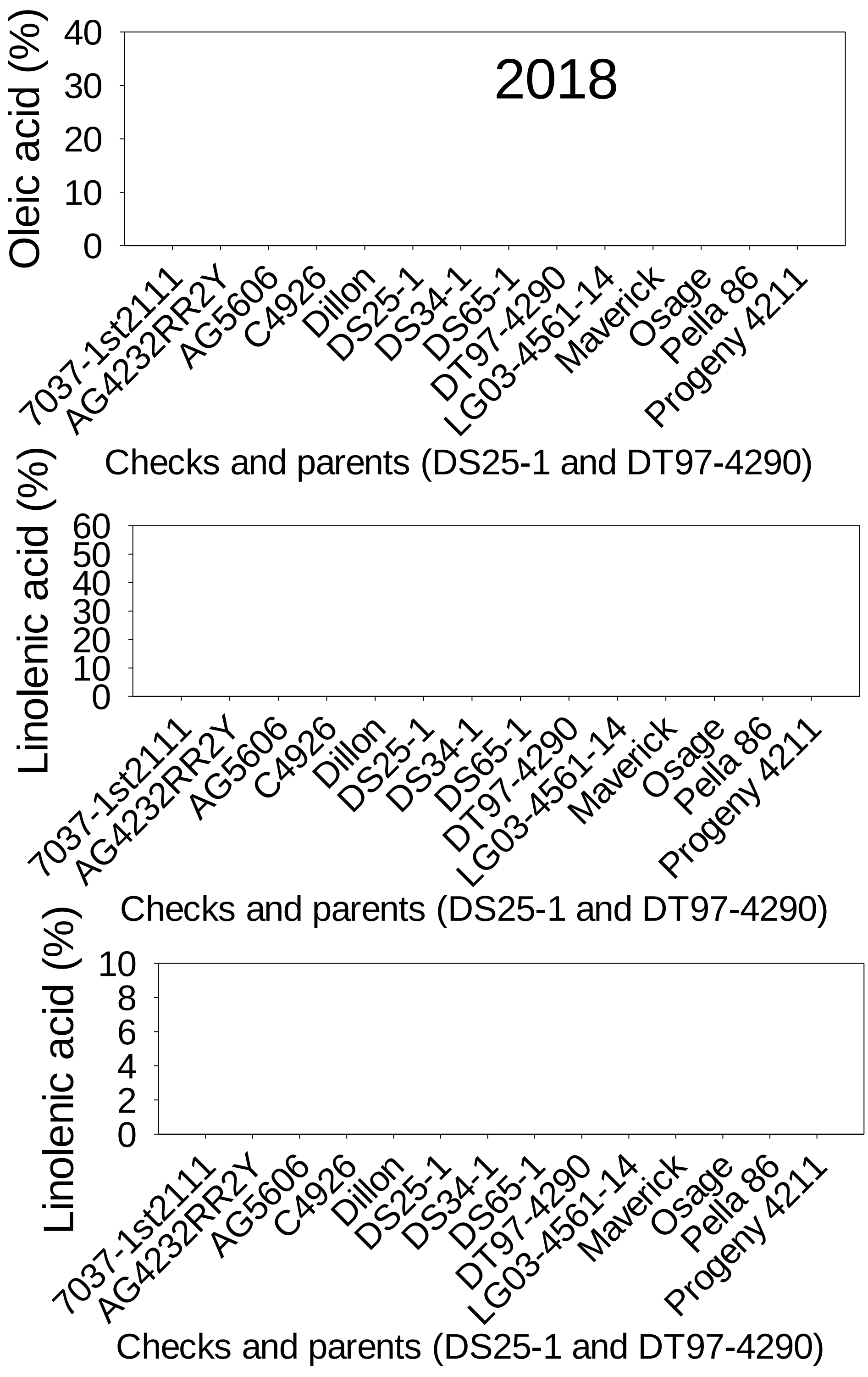


Figure 5: Significant variability and distribution of seed quality components in checks, and parents. The experiment was planted in 2018 in Stoneville, MS, USA.

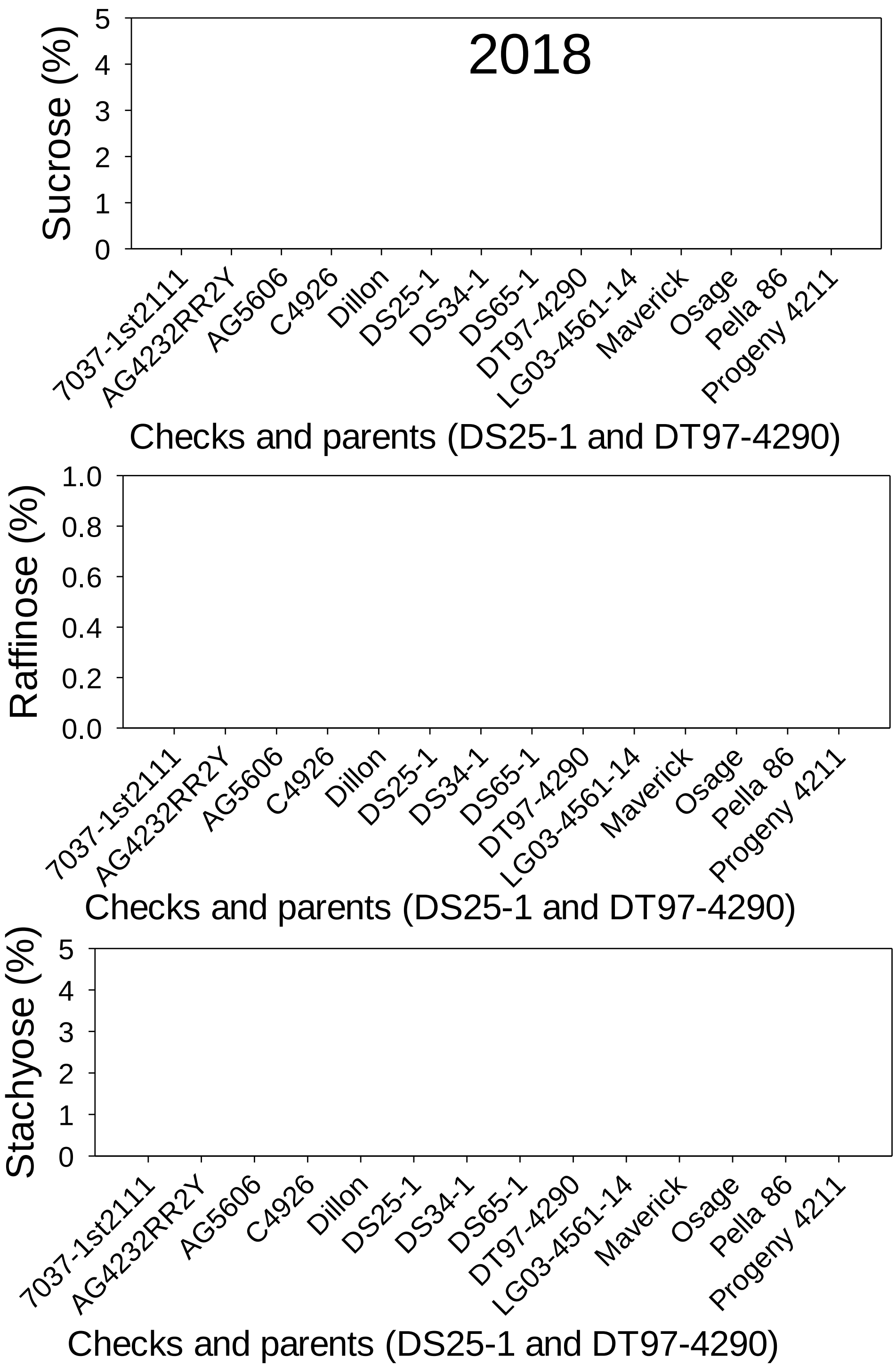
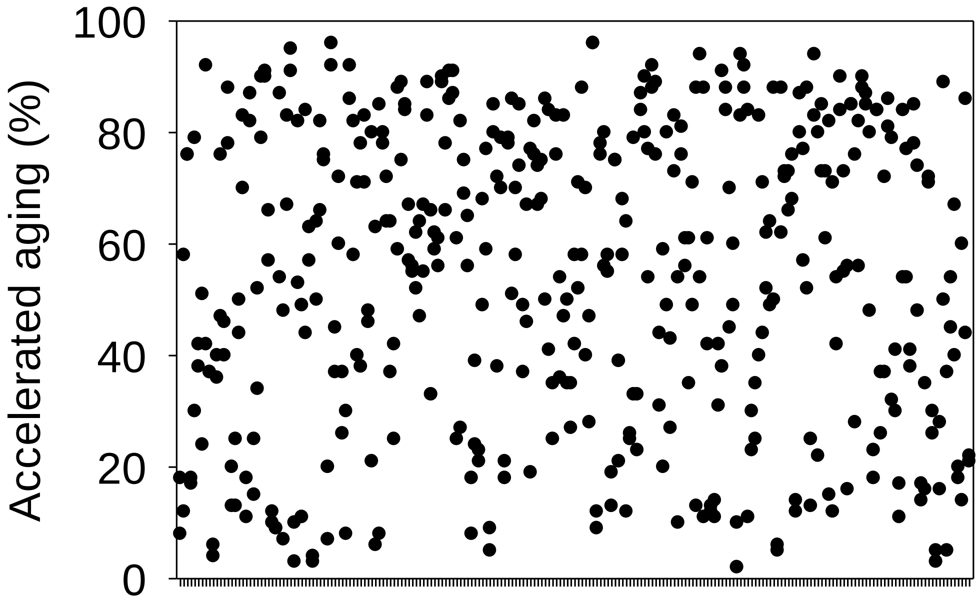
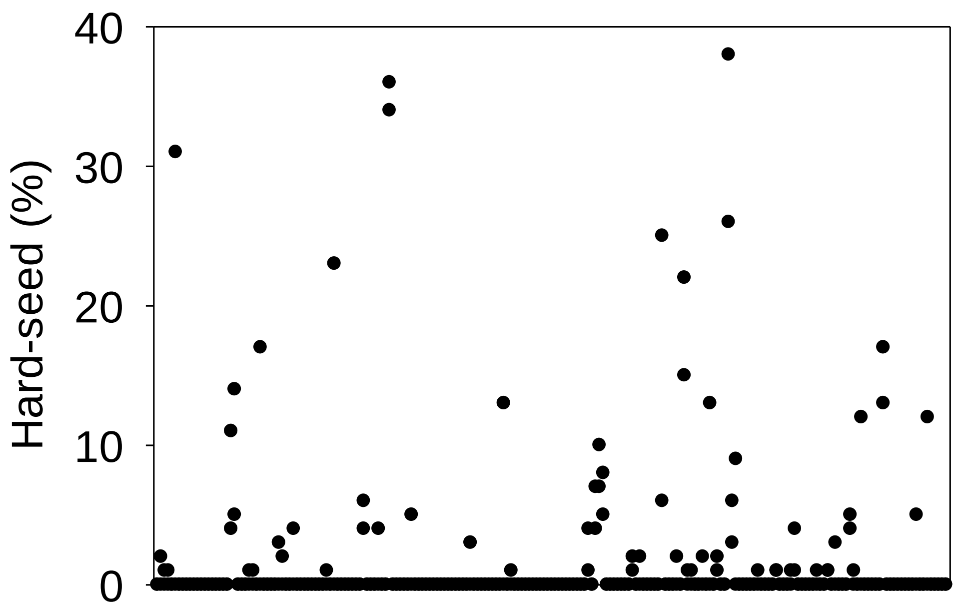


Figure 6: Significant variability and distribution of seed quality components in checks, and parents. The experiment was planted in 2018 in Stoneville, MS, USA.



Distribution of Accelerated aging across all RILs, checks, and parents



Distribution of hard-seed across all RILs, checks, and parents

Figure 7: Significant variability and distribution of seed quality components across RILs, checks, and parents. The RIL population was a cross between DS25-1 (heat tolerant) x DT97-4290 (moderately resistant to charcoal rot). The experiment was planted in 2019 in Stoneville, MS, USA.

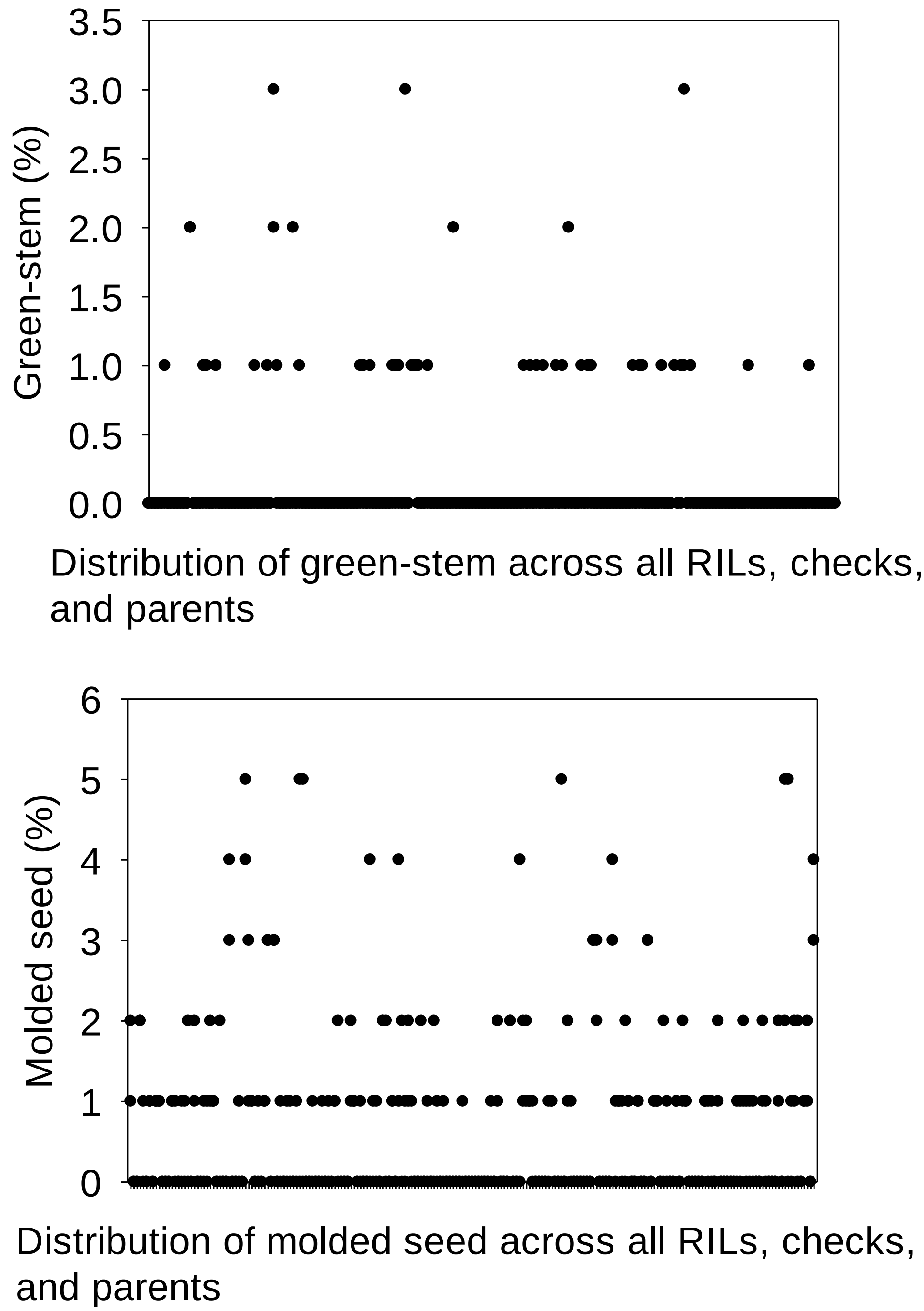
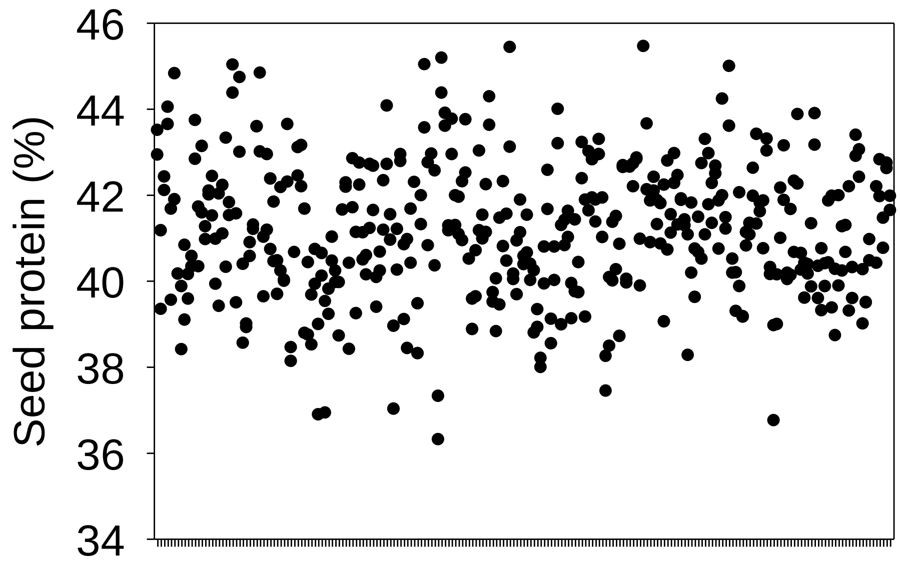
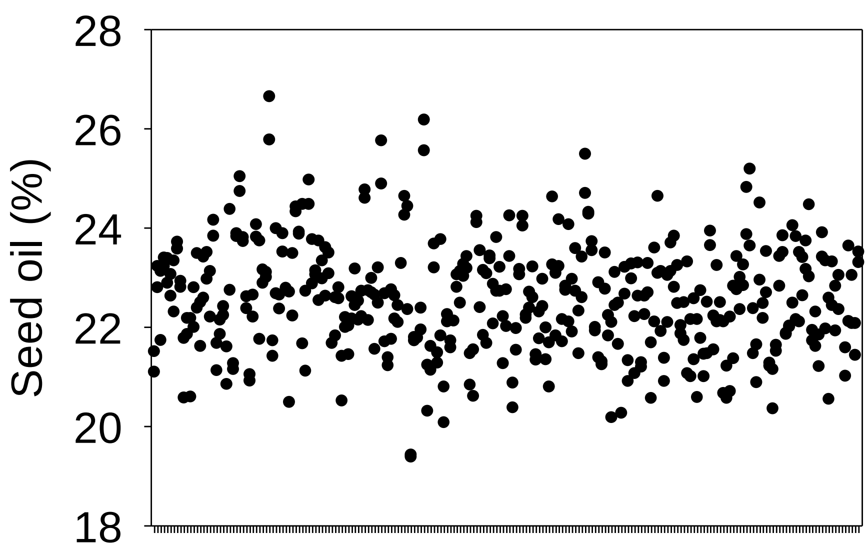


Figure 8: Significant variability and distribution of seed quality components across RILs, checks, and parents. The RIL population was a cross between DS25-1 (heat tolerant) x DT97-4290 (moderately resistant to charcoal rot). The experiment was planted in 2019 in Stoneville, MS, USA.

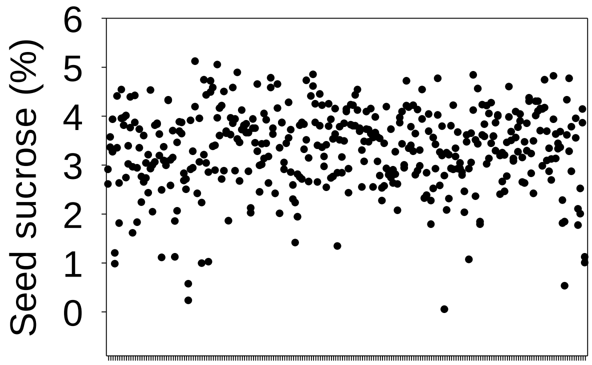


Distribution of seed protein across all RILs, checks, and parents

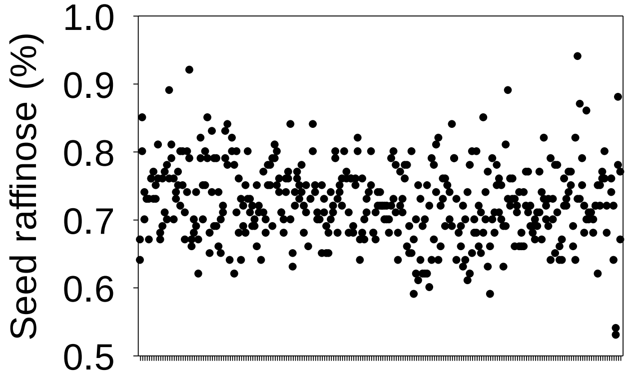


Distribution of seed oil across all RILs, checks, and parents

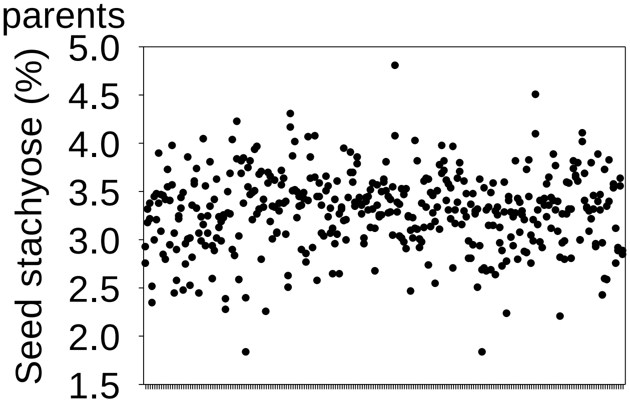
Figure 9: Significant variability and distribution of seed quality components across RILs, checks, and parents. The RIL population was a cross between DS25-1 (heat tolerant) x DT97-4290 (moderately resistant to charcoal rot). The experiment was planted in 2019 in Stoneville, MS, USA.



Distribution of seed sucrose across all RILs, checks, and parents



Distribution of seed raffinose across all RILs, checks, and parents



Distribution of seed stachyose across all RILs, checks, and parents

Figure 10: Significant variability and distribution of seed quality components across RILs, checks, and parents. The RIL population was a cross between DS25-1 (heat tolerant) x DT97-4290 (moderately resistant to charcoal rot). The experiment was planted in 2019 in Stoneville, MS, USA.

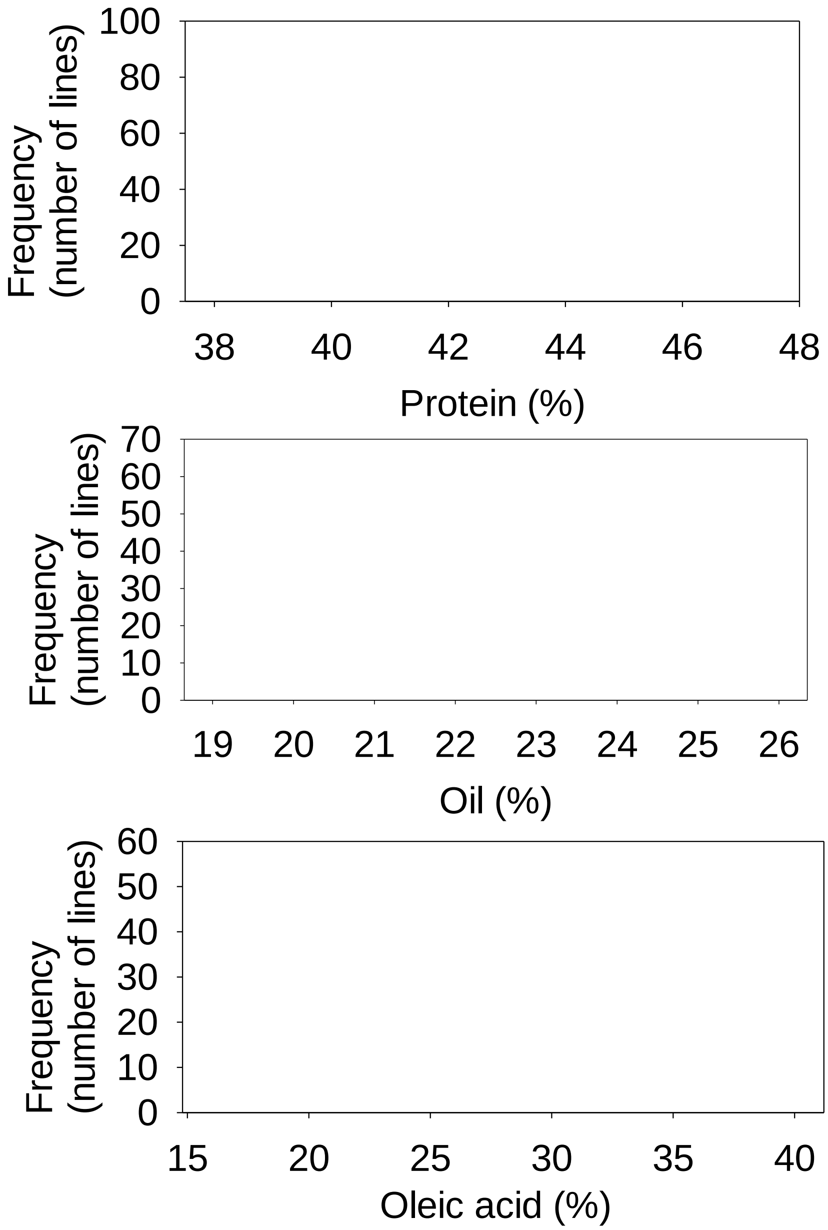


Figure 11: Significant variability and distribution of seed quality components across RILs. The RIL population was a cross between DS34-1 x LD00-3309. The experiment was planted in 2020 in Stoneville, MS, USA.

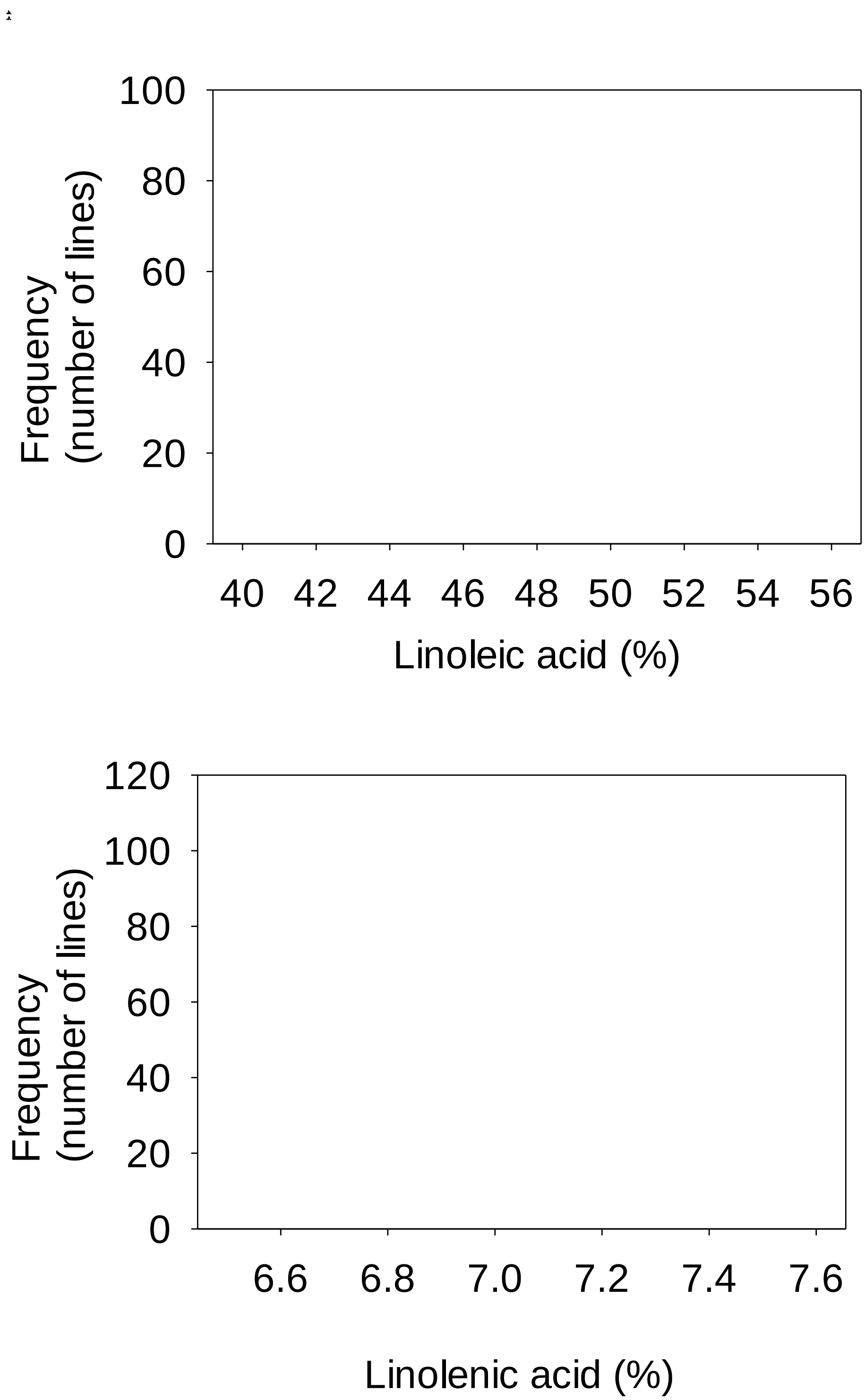


Figure 12: Significant variability and distribution of seed quality components across RILs. The RIL population was a cross between DS34-1 x LD00-3309. The experiment was planted in 2020 in Stoneville, MS, USA.

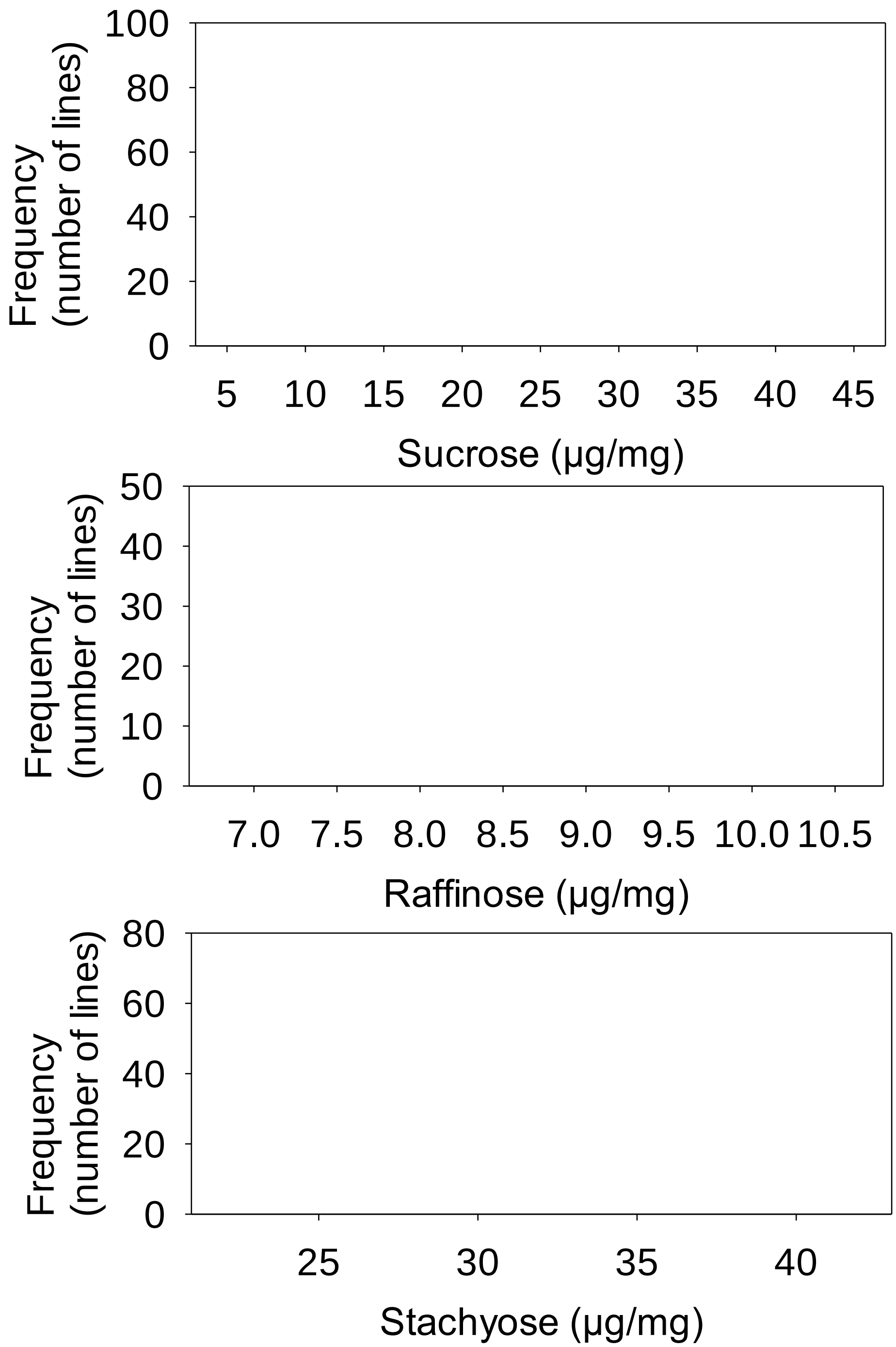


Figure 13: Significant variability and distribution of seed quality components across RILs. The RIL population was a cross between DS34-1 x LD00-3309. The experiment was planted in 2020 in Stoneville, MS, USA.

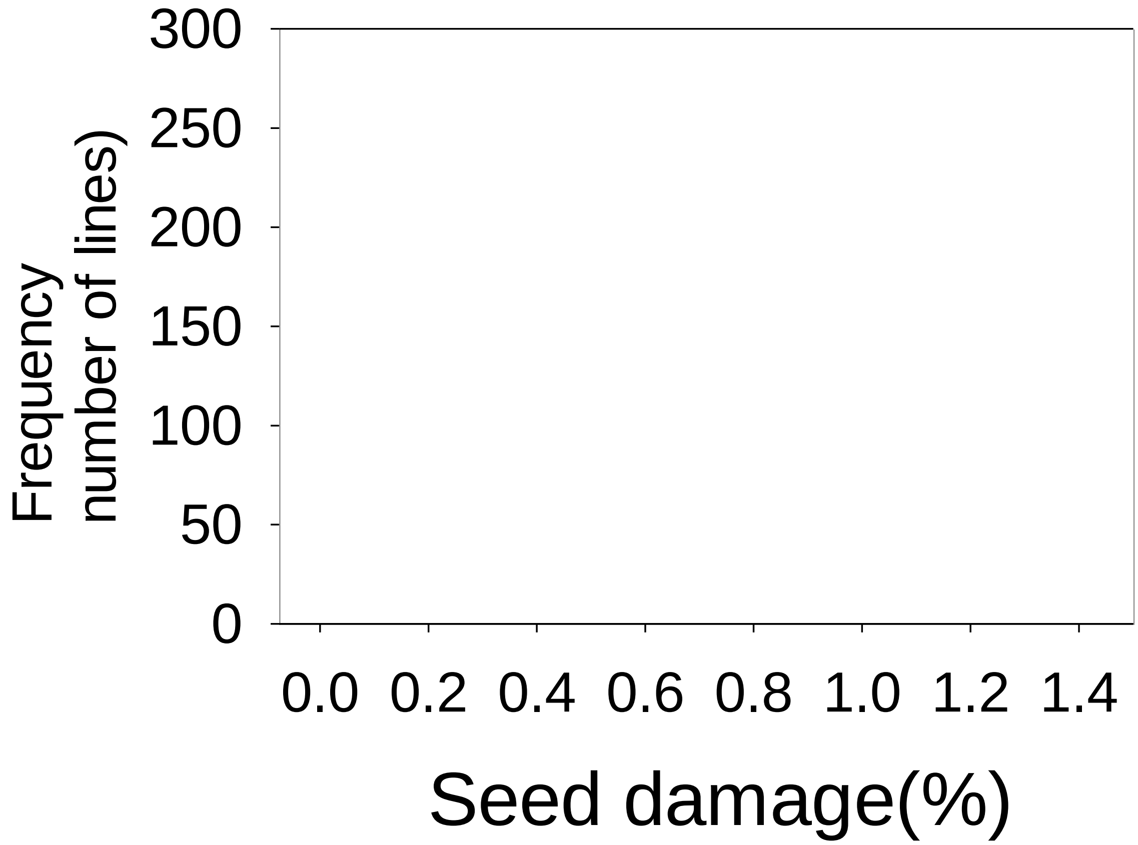


Figure 14: Significant variability and distribution of seed quality components across RILs. The RIL population was a cross between DS34-1 x LD00-3309. The experiment was planted in 2020 in Stoneville, MS, USA.

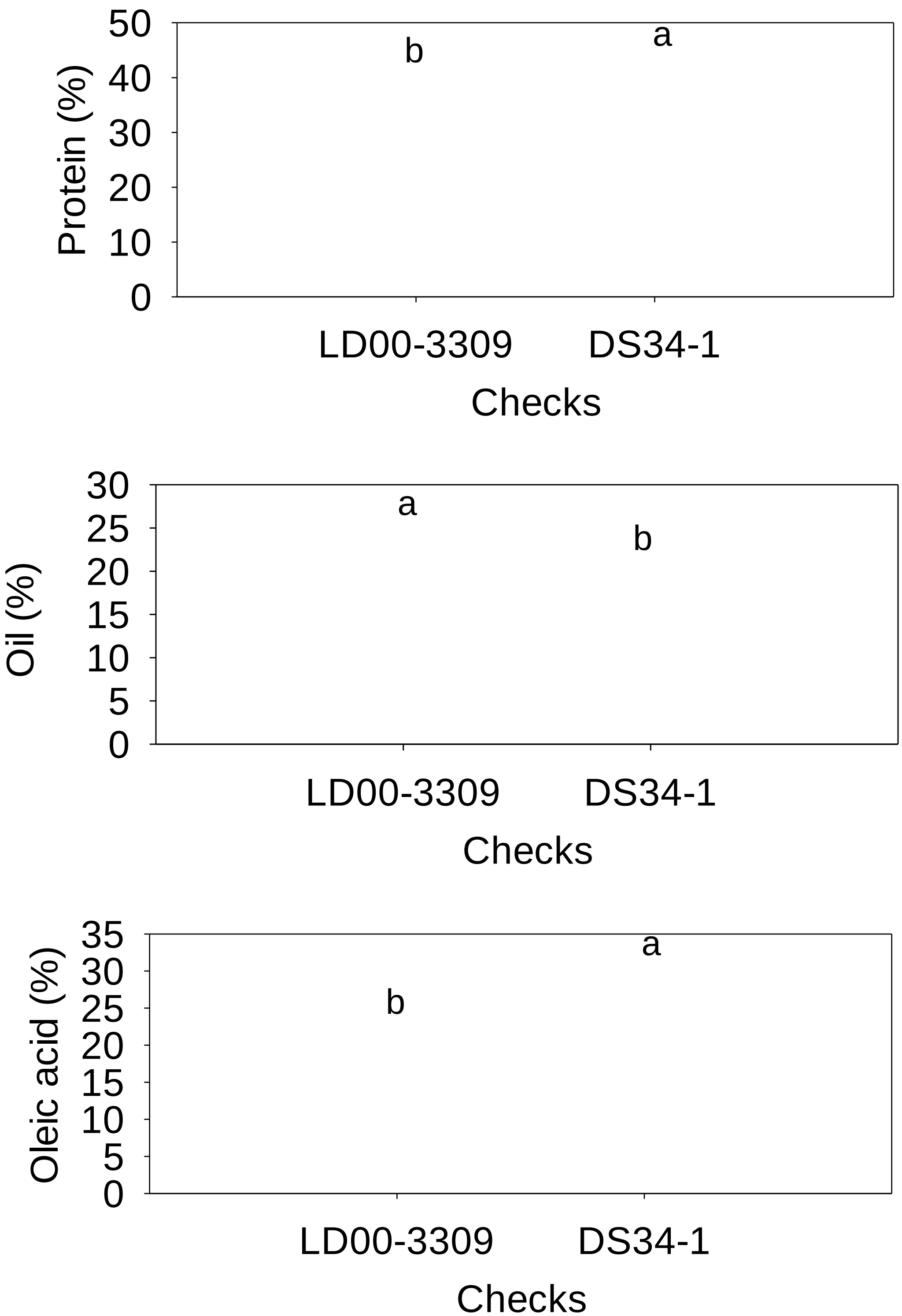


Figure 15: Significant variability and distribution of seed quality components in checks/parents. The experiment was planted in 2020 in Stoneville, MS, USA.

:

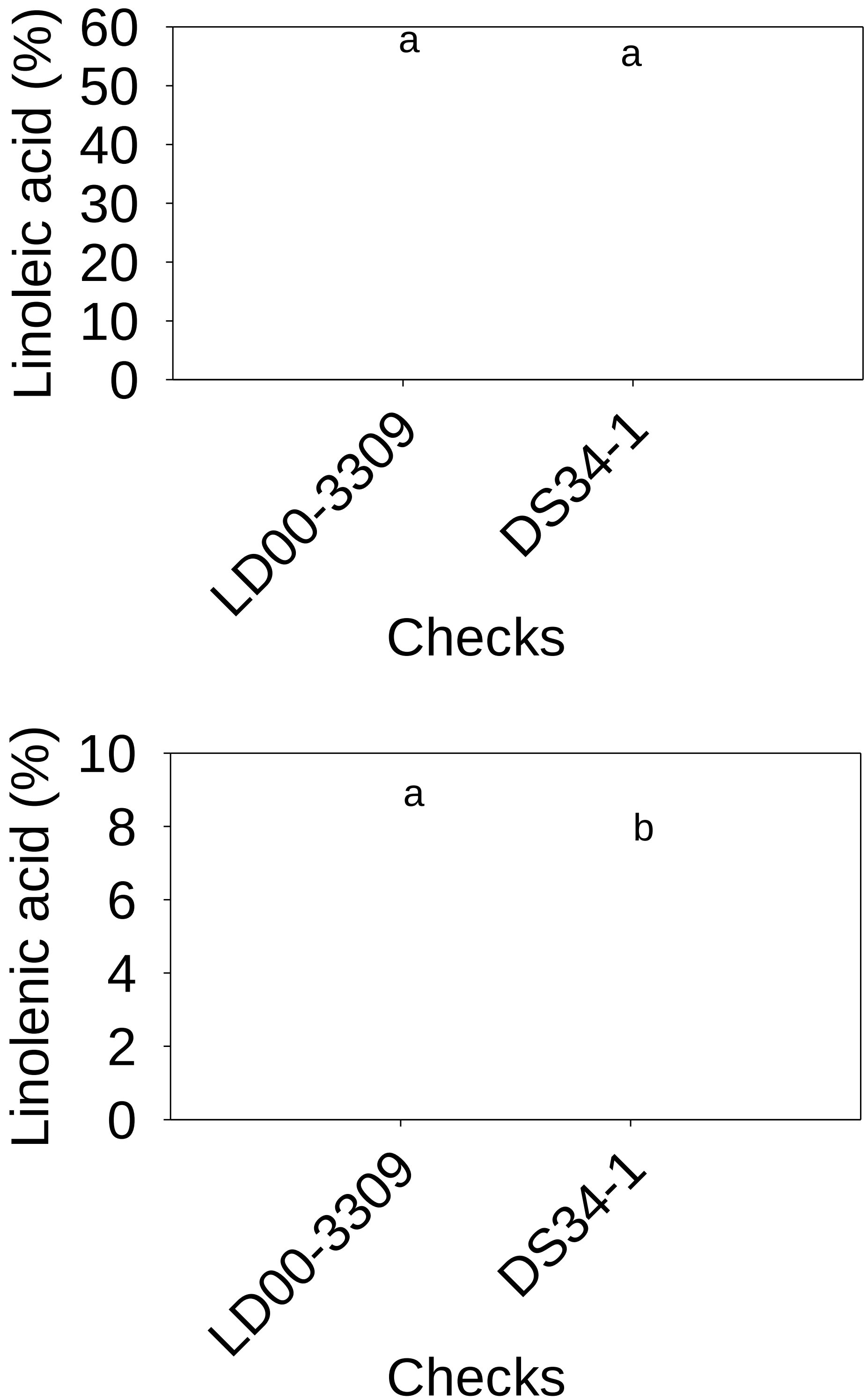


Figure 16: Significant variability and distribution of seed quality components in checks/parents. The experiment was planted in 2020 in Stoneville, MS, USA.

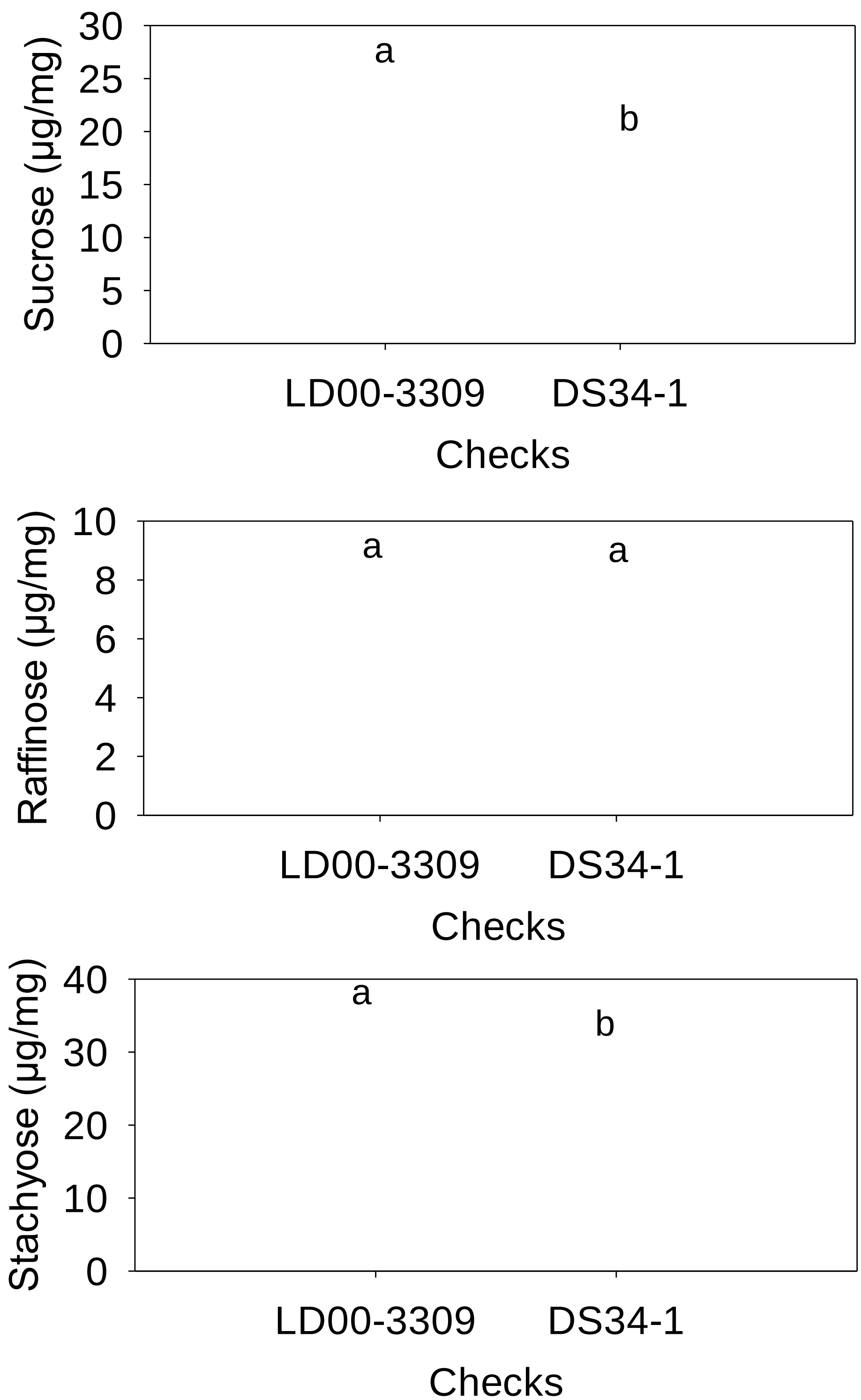


Figure 17: Significant variability and distribution of seed quality components in checks/parents. The experiment was planted in 2020 in Stoneville, MS, USA.

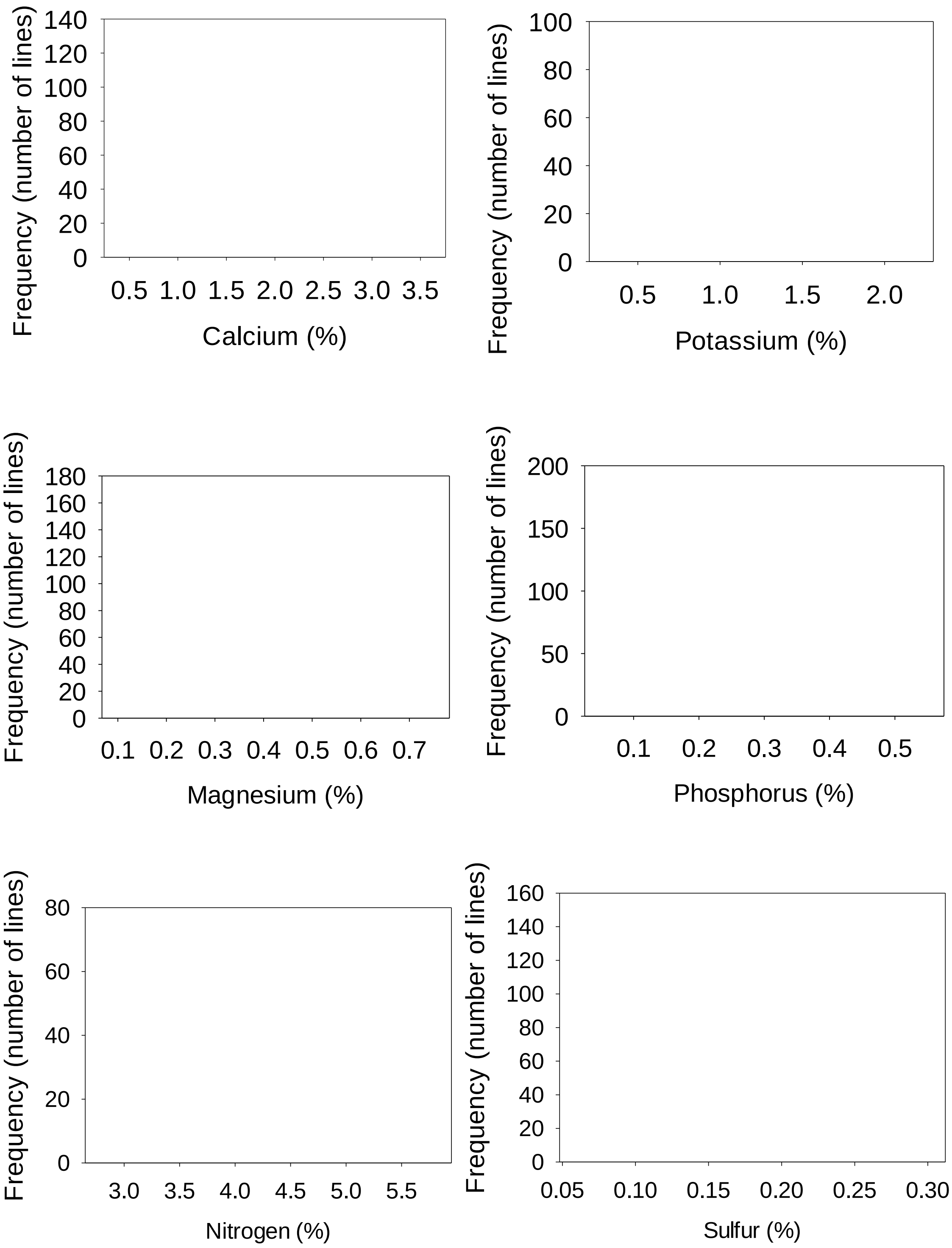


Figure 18: Significant variability and distribution of leaf nutrients (macro-nutrients) across RILs, checks, and parents. The RIL population was a cross between DS25-1 x DT97-4290. The experiment was planted in 2019 in Stoneville, MS, USA.

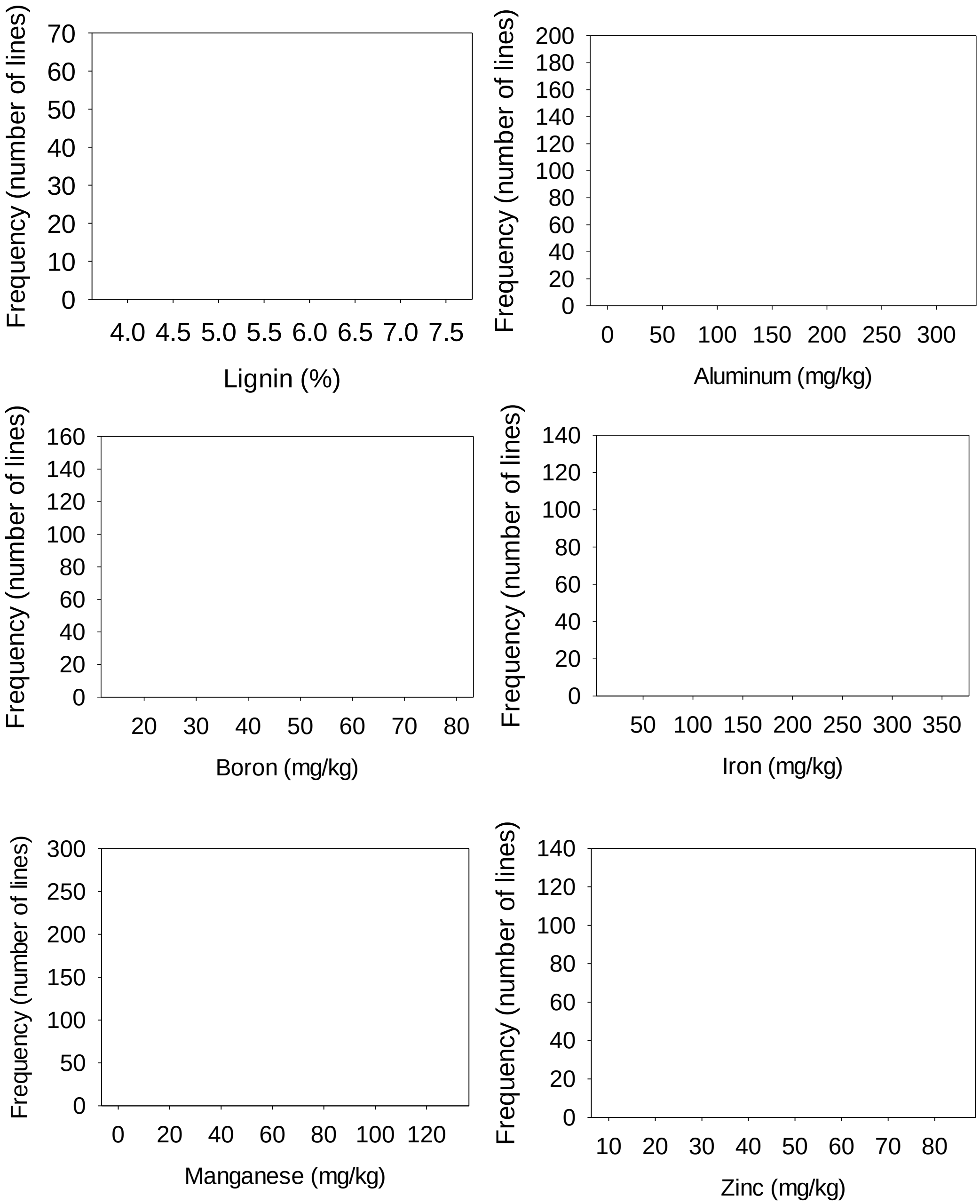


Figure 19: Significant variability and distribution of leaf lignin and nutrients (micro-nutrients) across RILs, checks, and parents. The RIL population was a cross between DS25-1 x DT97-4290. The experiment was planted in 2019 in Stoneville, MS, USA.

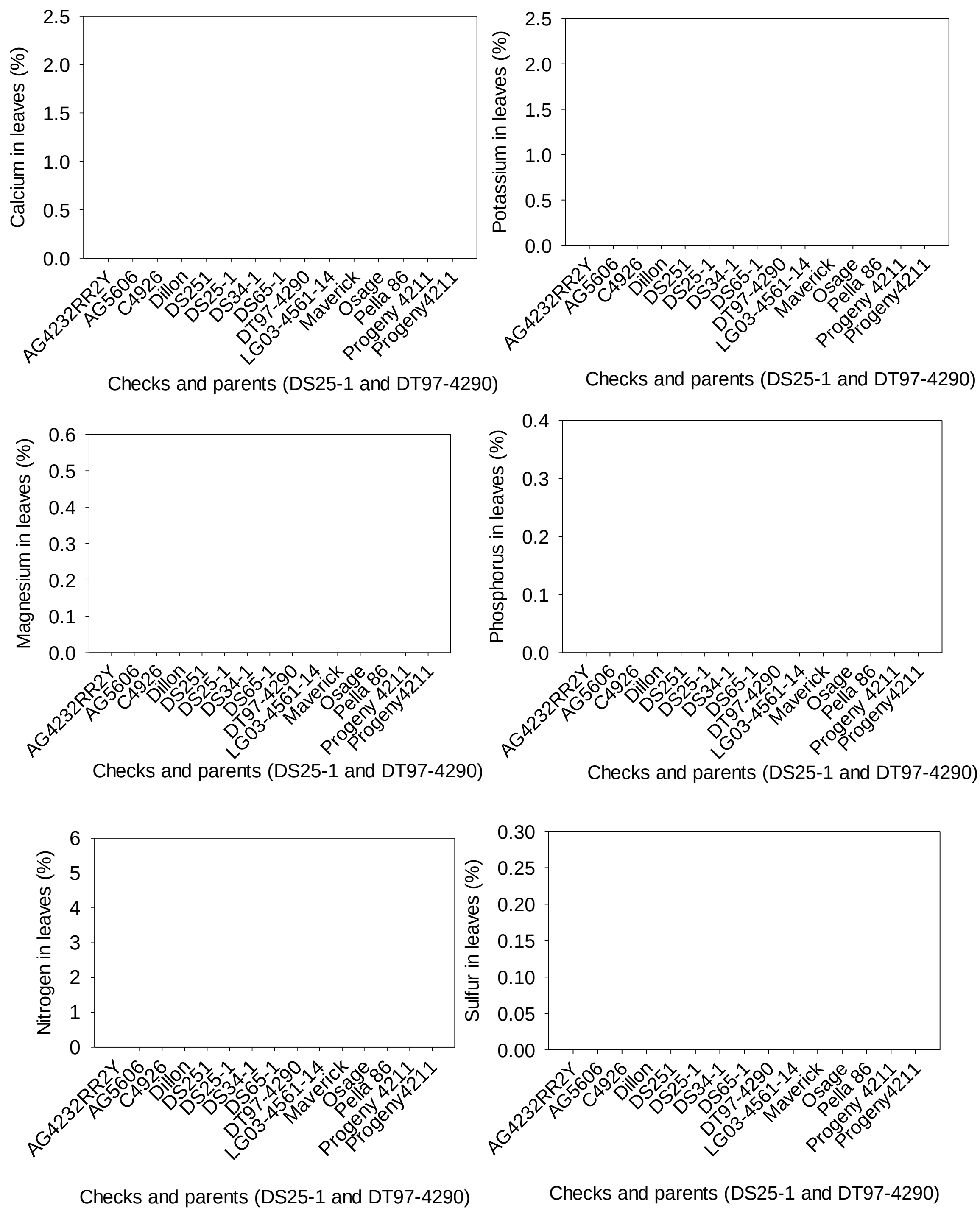


Figure 20: Significant variability and distribution of leaf nutrients (macro-nutrients) in checks, and parents. The experiment was planted in 2019 in Stoneville, MS, USA.

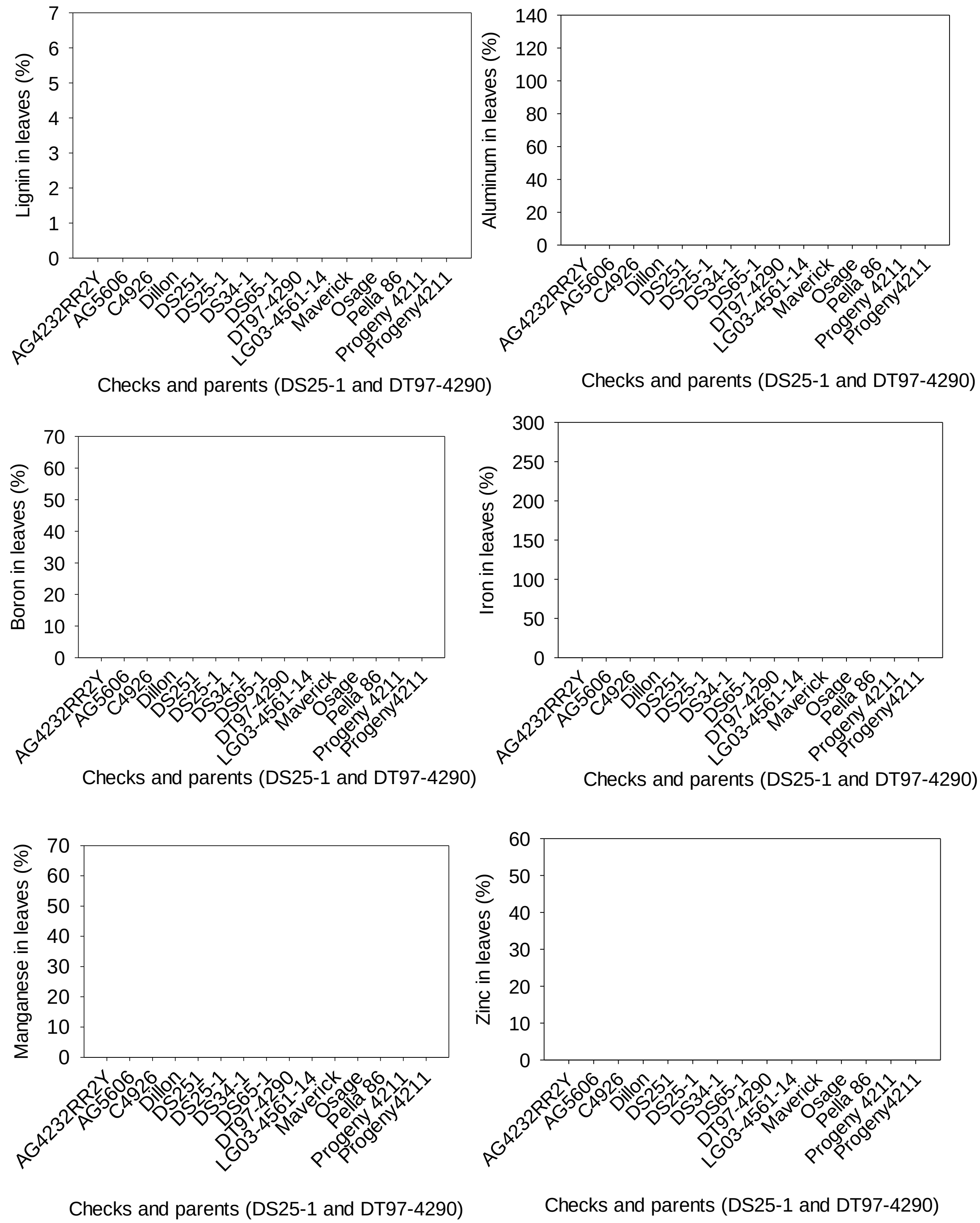


Figure 21: Significant variability and distribution of leaf nutrients (micro-nutrients) in checks, and parents. The experiment was planted in 2019 in Stoneville, MS, USA.