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Nutrient Management for Balancing Yield and Quality of Malting Barley in Southern Brazil

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ABSTRACT

Barley is mainly cultivated for malt production, essential to the brewing industry. Grain quality is determined by factors such as climate, genetics, and management, and must meet certain standards, such as germination (>95%) and protein content (<12%). This study evaluated different levels of NPK fertilization in barley, considering quality standards related to germination and protein content, seeking to increase crop grain yield without compromising its quality. The experiment was conducted in Lages-SC during the 2022 and 2023 growing seasons involving average grain yield of Brazilian barley of 100-175% (% to 4 t/ha). The variables analyzed included grain yield, sieve index, thousand-grain weight, hectoliter weight, seed germination content and grain protein content. Results indicated the strong influence of climate weather of each growing season on traits like yield, hectoliter weight, thousand grain weight, germination rate and grain protein content. The intermediate fertilization levels, corresponding to grain yield of 125 and 150%, favored higher germination rate, while low or high levels reduced seed quality. Fertilization targeting grain yield of 175% increased protein content but remained within the ideal range (10-11%). Balanced NPK management is fundamental to reconciling yield and quality, ensuring grains are suitable for the brewing industry.

Keywords: *Hordeum vulgare*, physiological quality, agronomic performance.

INTRODUCTION

Barley (*Hordeum vulgare*), belonging to the Poaceae family, is cultivated, on a commercial scale, almost exclusively to produce malt, an essential raw material for the brewing industry. Due to its economic relevance, investment in research aimed at increasing grain yield and the viability of cultivation is fully justified (Eagles et al., 1995; Barzotto et al., 2018).

In the 1970s and 1980s, there was significant growth in world barley production, a period that also marked the expansion of cultivation in Brazil, driven by demand from the brewing industry (De Mori and Minella, 2012; Embrapa, 2023). Since then, the cultivated area in the country has remained relatively stable, while yields have shown a significant increase, reaching approximately 4.0 t/ha in 2022, with an approximate production of 490,000 tons (Barzotto et al., 2018; CONAB, 2023; Embrapa, 2023). According to De Almeida et al. (2026), fertilization levels should be adjusted to each season's environmental conditions, aiming to optimize grain yield and the sustainability of the barley chain to achieve the standard grain quality required for malting by the brewing industry.

In Romania, historical studies by Vasilescu et al. (2022) about barley genetic progress, yield stability, and the impact of breeding on grain quality traits under varying pedoclimatic conditions. These findings underscore the value of long-term varietal studies for improving both agronomic performance and end-use quality in barley.

Nitrogen fertilization in barley is widely researched and documented in the literature (Qi et al., 2006; Barzotto et al., 2018; Boero et al., 2023). However, balanced fertilization with nitrogen, phosphorus, and potassium still requires further research. For example,

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fertilization with phosphorus and potassium has been shown to have a positive effect on the yield and quality of barley grains. Moderate phosphorus fertilization combined with high potassium levels resulted in the highest grain yields and the highest protein concentrations in the grains. The protein concentration in the grains increased from 12.5% to 13.5% (Kostadinova, 2014).

Climate, genetics, and management are the main factors that determine grain quality, ensuring that they meet the standards established by official regulations. Among these standards, defined by Ordinance 691/1996 of the Ministry of Agriculture, Livestock and Supply (MAPA, Brasil 1996), the protein content, which must be less than 12%, and germination, which must exceed 95%, stand out (Minella, 2015; Minella et al., 2019). In this context, nutritional management, especially through NPK fertilization, plays a relevant role in the formation and composition of grains, and can directly influence these quality attributes.

Increasing barley grain yield without compromising quality standards is one of the main challenges for the crop, demanding the improvement of management practices. In this context, NPK fertilization stands out as a fundamental strategy to increase yield and, can also influence grain quality. Thus, the present study aimed to evaluate the effects of different levels of NPK fertilization on grain yield and others traits related to grain quality, such as germination and protein content in barley grains, aiming to reconcile yield and grain quality for the brewing industry.

MATERIAL AND METHODS

The experiments were carried out in the municipality of Lages, Santa Catarina, Brazil, during the 2022 and 2023 growing seasons, using the Imperatriz barley cultivar in a no-till system.

The soil in the experimental area was classified as a Humic Aluminic Cambisol (Embrapa, 2017). In the 0-20 cm layer, the chemical attributes of the soil in the 2022 and 2023 growing seasons were, respectively: P = 4.0 and 18.3 mg/dm^3; K = 168 and 175.6 mg/dm^3; Ca = 2.33 and 6.4 $cmolc/dm^3$; Mg = 2.7 and 2.6 $cmolc/dm^3$; H+Al = 12.30 and 7.6 $cmolc/dm^3$; O.M. (organic matter) = 2.1% and 3.4%; and clay = 44% and 42%.

The region's climate, according to the Köppen classification, is type Cfb, with an average annual rainfall of 1441 mm and an average temperature of 16.6°C (Wrege et al., 2012; Epagri, 2006), characterized by cold winters, occurrence of frosts and well-distributed rainfall throughout the year (Epagri, 2006). The rainfall and temperature values for the two growing seasons (2022 and 2023) are shown in Figure 1.

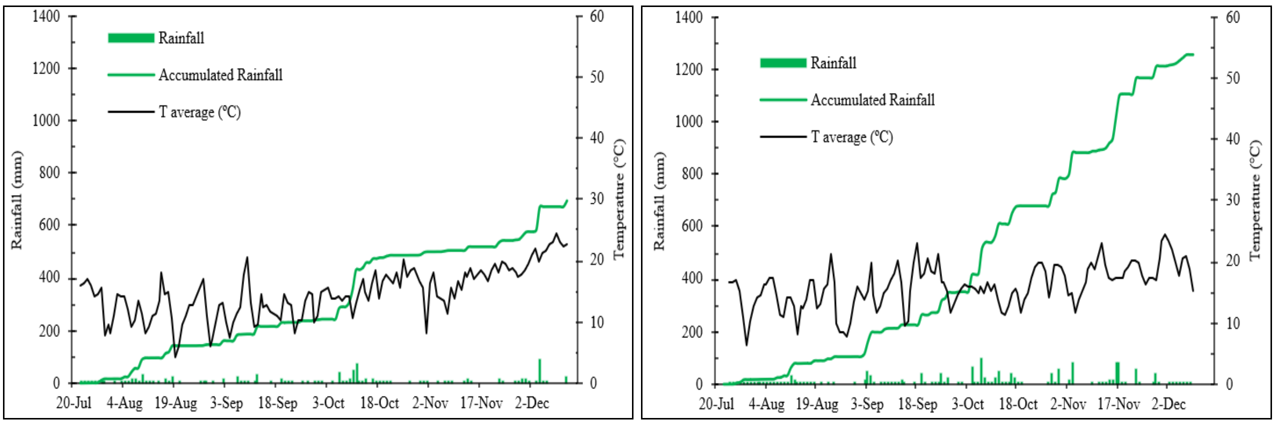

Figure 1. Rainfall (daily and accumulated) and temperatures (daily) during the experiments

Sowing was carried out on July 12, 2022 and July 24, 2023. Each plot was 5.5 square meters sowing with experimental seed plotter of 5 lines, 5.5 m length spaced between rows 0.2 m. The experimental design was completely randomized, with four treatments and four replications, totaling 16 experimental plots. The treatments consisted of four levels of NPK fertilization, based on the expected grain yield of 4 t/ha around the average grain yield of Brazilian barley, considered 100%, 125%, 150% and 175% of a reference yield of 4 t/ha, as according preconized by the Liming and Fertilization Manual for the states of Rio Grande do Sul and Santa Catarina (CQFS - RS/SC, 2016).

At harvest, the grain yield was estimated (t/ha) based on the production of the total useful area of the plot, correcting the value at the standard water content of 13%, sieve index, taking into account grains with a transverse diameter greater than 2.5, 2.2 and 2.0 mm (G>2.5, G>2.2 and G>2.0 mm), respectively; hectoliter weight (test weight), with a standard cylinder of 0.25 liter (DalleMolle, model 45), and the weight of one thousand grains measured with the aid of an electronic grain counter (Sanick, model ESC 2011), and subsequent weighing on a semi-analytical balance, with a precision of 0.01 g (Shimadzu, Brazil, model BL3200H).

After harvesting, the physiological quality of the seeds was evaluated by means of a germination test, conducted with four replicates of 50 seeds per plot, distributed among three sheets of germitest® paper, moistened with deionized water in a proportion of 2.5 times the weight of the dry paper. The rolls were kept in a Mangelsdorf-type chamber, and the results were expressed as a percentage of normal seedlings (according to Brazilian Seeds Rules, Brasil 2009).

For the determination of protein content, grain samples were previously dried at 65-70°C for 24 hours and ground until a finely homogeneous material was achieved. Nitrogen content was determined by the Kjeldahl method, according to Tedesco et al. (1995), with total protein content obtained by a conversion factor of 6.25 times the percentage of N in the sample.

The data were subjected to analysis of variance using the F test ($p<0.05$). When significant, the effects of qualitative treatments were compared using Tukey's test at a 5% probability level, while quantitative treatments were analyzed by regression. The analyses were performed using the SISVAR software.

RESULTS AND DISCUSSION

Grain yield in the first season ranged from 4.24 to 5.26 t/ha, whereas in the second season values were considerably lower, ranging from 2.02 to 2.73 t/ha, with no significant effect fertilization levels on yield within the tested range variety (Figure 2).

The reduced productivity in the second season (55-68% of the Brazilian reference yield, where 100% = 4 t/ha) indicates a strong environmental limitation, likely associated with excessive rainfall, particularly after October (Figure 1B).

The fact that there was no difference between fertilizer levels from 100% to 175% shows that the plant was already reaching its maximum potential in regular or that adverse environment, or that the nutrient uptake and utilization were severely constrained by adverse environmental factors. Adverse weather conditions due to excessive rainfall meant that even improvements in soil fertilization did not result in increased grain yield. This is explained by the higher incidence of fungal diseases in barley plants, coupled with cloudy days resulting in less solar radiation available for photosynthesis (Erreguerena et al., 2025).

Barley is a temperate crop and high levels of nitrogen, phosphorus and potassium under water excess conditions at the final growth stage may exacerbate grain abortion and reduce yield. Studies confirm that excess water during grain filling causes production drops of approximately 50% (De Castro et al., 2022), consistent with what has been reported.

The low response to fertilization under excess water, the plant cannot absorb the nutrients applied to the soil (Chen et al., 2024). The lack of a significant response indicates that fertilizer was not the limiting factor when we see both results of first and second season.

The influence of its two seasons highlighted that success of barley depends on tillering (emission of tillers) (Yigit and Chmielewski, 2024). The "second season" in Brazil faces shorter periods with higher temperatures, reducing tillering and grain weight (TGW), leading to significant yield drops.

The genotype per environment interaction highlights that nutritional management must be adjusted, but the environment at reproductive stages, excess rain during grain set and filling, proved to decisive (Eagles et al., 1995).

Thousand-grain weight (Figure 3) ranged from 44.8 to 45.9 g in the 2022 season and from 35.9 to 36.6 g in the 2023 season. Indicating that the less favorable environmental conditions for grain yield in the second season were also reflected in grains with less weight.

The hectoliter weight ranged from 63.3 kg/100 liters to 66.3 kg/100 liters, respectively, in the 2022 and 2023 season (Figure 4). It test weight remained stable and was not affected by crop seasons or by the levels of fertilizers applied to barley.

The sieve index, which considers the percentage of retention of large (G>2.5 mm), medium (G>2.2 mm), and small (G1>2.0 mm) grains in barley, illustrated in Figure 5, indicates that this barley cultivar is very stable and produces over 91% large grains with a diameter greater than 2.5 mm. Around 6% are medium grains and only 1% are small grains. These values for large grains are far above the requirements of the Brazilian brewing industry, which considers 75% large grains acceptable (Brazil, 1996). This is true even under such contrasting production conditions, considering the levels of fertilizers applied and the climatic differences between crop seasons.

The NPK fertilization levels significantly influenced barley seed germination in both growing seasons ($P<0.05$). In the 2022 growing season, treatments corresponding to fertilization to achieve grain yield of 125% and 150% showed higher germination percentages (96% and 90%, respectively), while levels of 100% and 175% resulted in lower values (germination of 70% and 75%) (Figure 6). These results indicate that both nutrient deficiency and excess can compromise the physiological quality of the seeds.

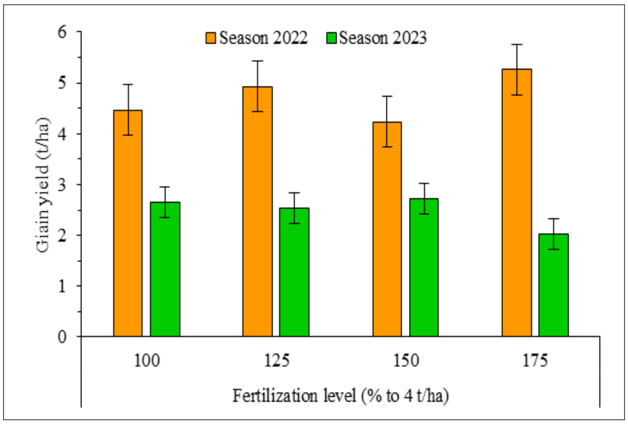

Figure 2. Grain yield of barley
as a function of NPK fertilization levels
in the 2022 and 2023 growing seasons

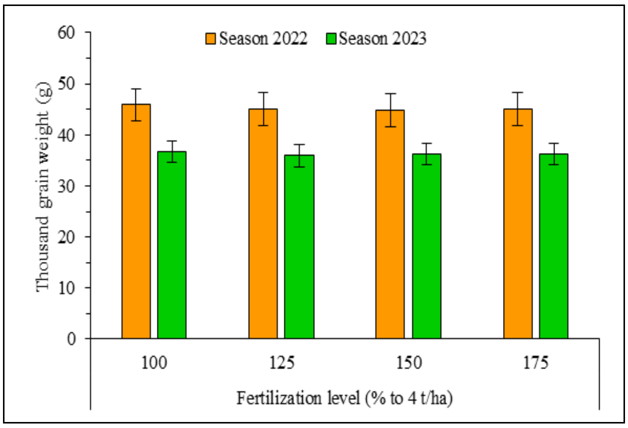

Figure 3. Thousand grain weight of barley
as a function of NPK fertilization levels
in the 2022 and 2023 growing seasons

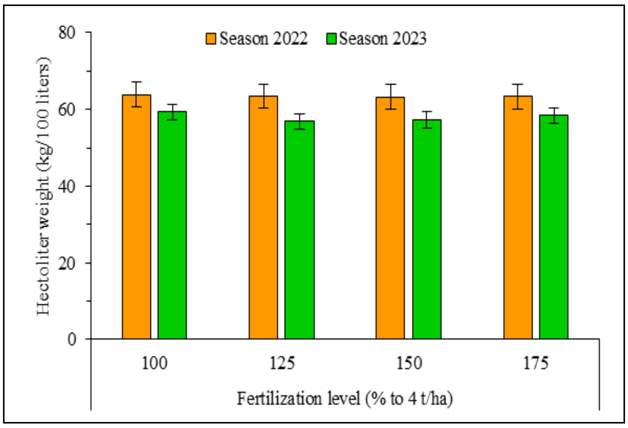

Figure 4. Grain hectoliter weight of barley as a function of NPK fertilization levels in the 2022 and 2023 growing seasons

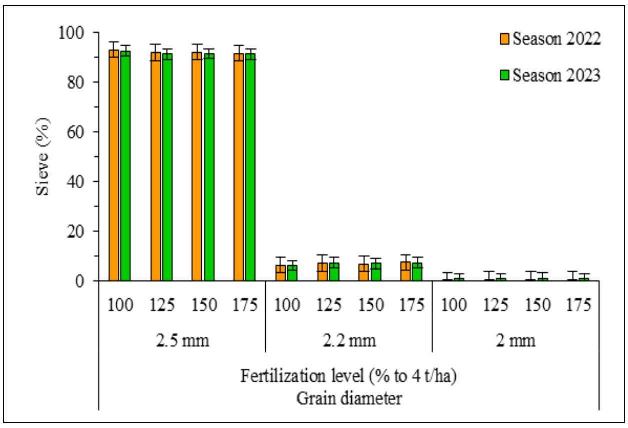

Figure 5. Grain sieve index of barley as a function of NPK fertilization levels in the 2022 and 2023 growing seasons

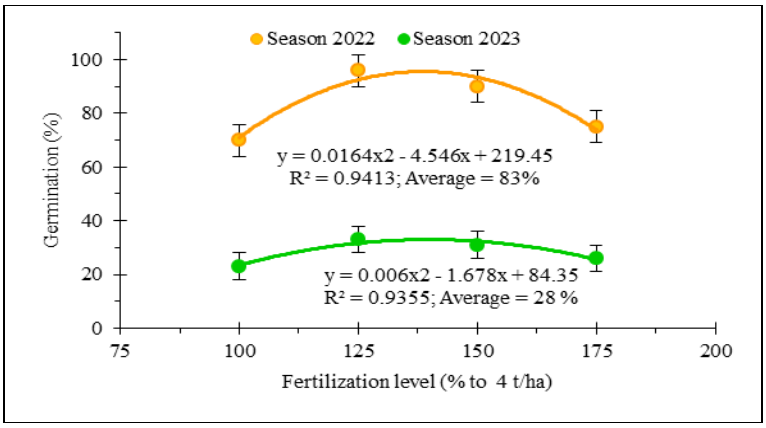

Figure 6. Seeds germination rate of barley as a function of NPK fertilization levels in the 2022 and 2023 growing seasons

In the 2023 growing season, a marked reduction in germination was observed in all treatments, with values ranging from 23% to 33% (Figure 6). This significant drop can be attributed to adverse climatic conditions during the crop cycle, associated with the occurrence of the El Niño phenomenon, which promotes changes in the rainfall regime (Katz, 2002). In the experimental area, high volumes of precipitation were recorded, exceeding 1,200 mm, which compromised plant development and seed formation.

The occurrence of excess rainfall during critical development phases, especially during the reproductive period, can negatively affect the physiological quality of seeds, reducing germination (Minella et al., 2019). In addition, high humidity conditions can favor deterioration processes and compromise the integrity of embryonic tissues. Similar results were reported by Noori (2018), who observed an increase in wheat seed germination with adequate N, P, and K supply, highlighting the importance of nutritional management in physiological quality. Complementarily, Marinho et al. (2022) emphasize that adequate nutrition of mother plants directly influences the formation of the embryo and reserve tissues, reflecting on seed viability.

Nutrients play an important role in seed composition, such as in the formation of the embryo and reserve organs, influencing, for example, the germination rate (Marinho et al., 2022). Fertilization can affect seed quality and provide better plant nutrition conditions, since, when carried out properly, according to the requirements of a given situation, it can guarantee not only higher yield but also higher quality (Bertoncello, 2010).

Protein content was also affected by fertilization in both seasons (Figure 7). Treatments with lower fertilization levels (100%, 125% and 150% to 4 t/ha) showed lower protein content, while the highest fertilization level (175%) increased protein accumulation. This behavior can be explained by the greater availability of nitrogen, which, when it exceeds the demand for carbohydrate synthesis, is directed towards protein formation.

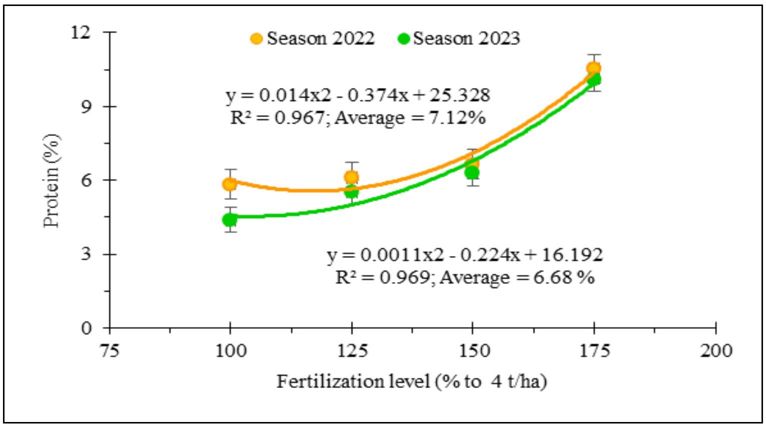

Figure 7. Grain total protein of Imperatriz barley variety as a function of NPK fertilization levels in the 2022 and 2023 growing seasons

According to Kelling and Fixen (1992) and Yin et al. (2025) there is competition between starch and protein synthesis pathways during grain filling, with the balance between these compounds being influenced by nitrogen availability. Studies such as those by Yin et al. (2002); Qi et al. (2006) and Boero et al. (2023) also report an increase in protein content in barley grains with increased nitrogen fertilization, corroborating the results obtained in this work.

Total protein is considered one of the most important nutritional components for barley grains, and protein synthesis and accumulation in the grain strongly depend on the availability of fertilizers, especially nitrogen (Weston et al., 1993; Howard et al., 1996; Qi et al., 2006). The high protein content in barley is considered negative because it slows down the malting process and negatively impacts the quality of the malt, that is, the beer, where grains with this characteristic will generally be harder, since the protein binds the starch granules to the cell wall of the endosperm, making them more compact, and causing poorer distribution of water and enzymes throughout the endosperm, delaying its modification and degradation and, consequently, delaying the malting process (Fang et al., 2019). In wheat the increasing of N and P fertilization rates significantly influenced the mineral composition of wheat grain, particularly, increased grain nitrogen content (Xu et al., 2012; Tanase et al., 2026).

Although an increase in protein content can be observed with higher doses of fertilizers, high values can compromise the quality of the malt, since they are associated with a reduction in starch content and alteration of technological properties (Floriani, 2002). On the other hand, very low protein levels are also undesirable, as they can limit the availability of amino acids for fermentation (Fox, 2009; Jaeger et al., 2021).

In the present study, despite the increase observed in the higher fertilization treatment, the protein levels remained within the range considered ideal for the brewing industry (10-11%; Brasil 1996), indicating that the nutritional management adopted allowed for a balance between productivity and grain quality.

CONCLUSIONS

This study demonstrated that NPK fertilization influenced the physiological quality of seeds and the protein content of barley grains (Imperatriz variety). Intermediate fertilization levels (125 and 150% to 4 t/ha) resulted in higher germination rates, while low and high levels reduced germination rate. The NPK fertilization under barley growing in high soil fertility had low or no influenced the grain yield and quality (sieve index, hectoliter weight and thousand grain weight). But had strong influence of climate weather of each growing season on traits like yield, hectoliter weight, thousand grain weight, germination rate and grain protein content.

Increased fertilization, particularly at the highest level (175% relative to 4 t/ha), led to higher grain protein content; however, protein values remained within the acceptable range for the brewing industry (10-11%). This indicates that although nitrogen availability promotes protein accumulation, the levels applied did not compromise malting quality standards. Overall, no direct relationship was observed between increased fertilization and the simultaneous optimization of germination and protein content. However, balanced fertilization management proved essential to maintain the balance between physiological quality and industrial quality of barley grains.

These findings highlight the importance of balanced fertilization with nitrogen, phosphorus, and potassium management to optimizing barley performance under no-till crop rotation systems. Such management contributes not only to maintaining soil fertility in the long term but also to stabilizing grain quality and supporting the production requirements of the brewing industry.

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REFERENCES

Barzotto, G.R., Lima, S.F., Santos, O.F., Piati, G.L., Wassolowski, C.R., 2018. *Nitrogen fertilization and inoculation with Azospirillum brasilense in barley*. Nativa (Sinop), 6(1): 1-8. (In Portuguese)

Bertoncello, M.R., 2010. *Evaluation of the physiological quality of wheat seeds produced in soil with different phosphorus levels*. Master's thesis, Federal University of Pelotas.

Boero, J.J., Gutiérrez Boem, F.H., Prystupa, P., Veliz, C.G., Criado, M.V., Gómez, F.M., Caputo, C., 2023. *Nitrogen application at anthesis increases barley grain protein by enhancing phloem amino acid mobilisation*. Crop and Pasture Science, 74(4): 312-323.

Brasil, 1996. *Portaria 691/1996. Norma de identidade e qualidade da cevada cervejeira*. Brasília: Ministério da Agricultura, Pecuária e Abastecimento (MAPA). https://sistemasweb.agricultura.gov.br/sislegis/action/detalhaAto.do?method=visualizarAtoPortalMapa&chave=2140540241.

Chen, J., Zhao, C., Harrison, M.T., Zhou, M., 2024. *Nitrogen fertilization alleviates barley (Hordeum vulgare L.) waterlogging*. Agronomy, 14(8): e1712.

CONAB - National Supply Company, 2023. *Grain Crop Bulletin*. Brasília: Conab. https://www.conab.gov.br/info-agro/safras/graos/boletim-da-safra-de-graos

De Almeida, P.M., Luz, S., Mützenberg, L.A., Silva, R.O., Souza, C.A., 2026. *Barley production performance under NPK fertilization, growth regulators and artificial lodging*. Romanian Agricultural Research, 43(1): 581-590. https://doi.org/10.59665/rar4351

De Castro, J., Hill, R.D., Stasolla, C., Badea, A., 2022. *Waterlogging stress physiology in barley*. Agronomy, 12: e780.

De Mori, C., and Minella, E., 2012. *Economic and situational aspects of barley cultivation*. Embrapa Wheat Documents, 20 pp.

Eagles, H.A., Bedggood, A.G., Panozzo, J.F., Martin, P.J., 1995. *Cultivar and environmental effects on malting quality in barley*. Australian Journal of Agricultural Research, 46(5): 831-844.

Embrapa - Brazilian Agricultural Research Company, 2017. *Brazilian soil classification system*. 3nd ed. Rev. Ampl. - Brasília, DF: Embrapa.

Embrapa, 2023. *Linha do tempo da pesquisa com cevada cervejeira no Brasil.* Embrapa Soja. https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1153780/1/Documentos-204-online.pdf

Epagri - Agricultural Research and Rural Extension Company of Santa Catarina, 2006. *Climate of Santa Catarina*. Florianópolis: Epagri. https://www.epagri.sc.gov.br/clima-de-santa-catarina

Erreguerena, I.A., Quiroz, F.J., Cambareri, M., Pereyra, S., Havis, N.D., Carmona, M.A. 2025. *Assessing the impact of ramularia leaf spot on barley: prospects for fungicide protection strategies and weather-based prediction models in Argentina*. Plant Pathology, 74(3): 858-872.

Fang, Y.X., Zhang, X.Q., Xue, D., 2019. *Genetic analysis and molecular breeding applications of* *malting quality QTLs in barley*. Frontiers in Genetics, 10(1): e352.

Floriani, A.P., 2002. *Brewing barley: biochemical characteristics.* Federal University of Rio Grande do Sul. http://www.ufrgs.br/Alimentus/feira/mpcerea/cevada%20cervejeira/t%20bioqui.html.

Fox, G., 2009. *Chemical composition in barley grains and malt quality*. Genetics and improvement of barley malt quality, Berlim, Heidelberg, Springer Berlin Heidelberg: 63-98.

Howard, K.A., Gayler, K.R., Eagles, H.A., Halloran, G.M., 1996. *The relationship between D hordein and malting quality in barley*. Journal of Cereal Science, 24(1): 47-54.

Jaeger, A., Zannini, E., Sahin, A.W., Arendt, E.K., 2021. *Barley protein properties, extraction and applications, with a focus on brewers' spent grain protein*. Foods, 10(6): e1389.

Katz, R.W., 2002. *El Niño and Southern Oscillation: a review of the impact on global climate*. Journal of Climate, 15(3): 1-12.

Kelling, K., and Fixen, P., 1992. *Soil and nutrient requeriments for oat production*. In: Marshall, H., Sorrelis, M. (eds.), Oat science and technology. Madison: ASA/CSSA: 165-190.

Kostadinova, S., 2014. *Grain yield and protein of barley in dependence of phosphorus and potassium nutrition*. Scientific Papers, Series A, Agronomy, 57(1): 232-235.

Marinho, J.L., Silva, S.R., Fonseca, I.C.B., Zucareli, C., 2022. *Seed physiological quality of wheat cultivars in response to phosphate fertilization*. Journal of Seed Science, 44(1): e202244005.

Minella, E., 2015. *Cultivo de cevada*. Passo Fundo: Embrapa Trigo. Sistema de Produção, 39 pp. https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1155367/1/Cultivo-de-Cevada.pdf

Minella, E., Marsaro Júnior, A.L., Pasinato, A., Lau, D., Santana, F.M., Cunha, G.R., Maciel, J.L.N., Denardin, J.E., Vargas, L., Antoniazzi, N., Pereira, P.R.V.S., Wiethölter, S., Monteiro, V.A., 2019. *Technical guidelines for the production of malting Barley in the 2019 and 2020 seasons*. Passo Fundo: Embrapa Wheat, 116 pp.

Noori, M.S., 2018. *Physiological and biochemical changes during seed germination of wheat (Triticum aestivum L.) as influenced by mother plant NPK nutrition.* International Journal of Agronomy and Agricultural Research, 12(3): 19-24.

Qi, J.-C., Zhang, G.-P., Zhou, M.-X., 2006. *Protein and hordein content in barley seeds as affected by nitrogen level and their relationship to β-amylase activity*. Journal of Cereal Science, 43(1): 102-107.

Tanase, V., Vrinceanu, N.O., Preda, M., Costea, M., Ursan, P., 2026. *Effect of increasing nitrogen and phosphorus fertilization rates on the micro- and macronutrient contents in wheat grain grown on acidic soil*. Romanian Agricultural Research, 43(1): 273-282. https://doi.org/10.59665/rar4325

Tedesco, J.M., Gianello, C., Bissani, C.A., Bohnem, H., Volkweiss, S.J., 1995. *Análise de solo, plantas e outros materiais.* 2 ed. Porto Alegre, RS: Universidade Federal do Rio Grande do Sul. (Boletim Técnico de Solos, 5).

Vasilescu, L., Petcu, E., Sîrbu, A., Lazăr, C., Epure, L.I., Petcu, E., Cană, L., Toader, M., 2022. *Barley yield response to agroclimatic indices variability*. Scientific Papers, Series A, Agronomy, LXV(1): 567-576.

Weston, D.T., Horsley, R.D., Schwarz, P.B., Goos, R.J., 1993. *Nitrogen and planting date effects on low-protein spring barley*. Agronomy Journal, 85(6): 1170-1174.

Wrege, M.S., Steinmetz, S., Reisser Junior, C., Almeida, I.R., 2012. *Climate Atlas of the Southern Region of Brazil: States of Paraná, Santa Catarina and Rio Grande do Sul*. 2nd ed. Brasília: EMBRAPA, 333 pp.

Xu, F.J., Zhao, G.C., Tian, Q.Z., Chang, X.H., Yang, Y.S., Wang, D.M., Liu, X., 2012. *Effects of nitrogen fertilization on grain yield and processing quality of different wheat genotypes*. Journal of Plant Nutrition and Fertilizers, 18(2): 300-306.

Yigit, A., and Chmielewski, F.-M., 2024. *A deeper insight into the yield formation of winter and spring barley in relation to weather and climate variability*. Agronomy, 14(7): e1503.

Yin, C., Zhang, G.-P., Wang, J.-M., Chen, J.-X., 2002. *Variation of beta-amylase activity in barley as affected by cultivar and environment and its relation to protein content and grain weight.* Journal of Cereal Science, 36(1): 307-312.

Yin, P.J., Wang, X.L., Wu, Y.W., Liu, F., Tao, Y., Liu, Q.L., Yuan, J.C., 2025. *Effects of nitrogen fertilizer on protein accumulation in basal-middle and apical kernels of different low nitrogen tolerant maize hybrids*. Frontiers in Plant Science, 16(1): e1526026.