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Relationship between the rheological parameters, Alveograph elasticity index, and Farinograph stability in the assessment of wheat quality

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Abstract

Alveography and farinography are the most widely used rheological tests for evaluating wheat quality. The use of the elasticity index instead of stability has been suggested since not all laboratories have a farinograph. Besides, such analysis is time-consuming. The objectives of this study were to investigate the relationship between the elasticity index and stability and to verify the possibility of using the elasticity index as a predictive variable for stability. For statistical analyses, 8,037 wheat samples were selected, which participated in eight groups. Groups 1 and 2 consisted, respectively, of all samples and of samples separated by minimum values of test weight and falling number. The remaining groups were formed by samples classified by stability values defined in the Technical Regulation for Wheat. Spearman's correlation test was used to verify the relationships between the elasticity index and stability, and a spline regression was applied for modeling these variables. Groups 1 and 2 showed the highest correlation coefficient (p = .71), indicating the presence of a monotonic relationship. A mathematical model was obtained that explains only 35% of the total variability of stability.

Keywords: *Triticum aestivum*; wheat flour; rheology; Brazilian wheat legislation.

Practical Application: The alveograph elasticity index is related and can be used as an indicator of farinograph stability.

1 INTRODUCTION

Wheat, particularly wheat flour, holds a central role in human nutrition, serving as the essential base for a wide variety of food products, such as breads, cakes, pasta, and biscuits. Its importance, beyond its versatility, stems from its presence in virtually all cultures globally.

The end-use quality of wheat and flour is a crucial factor in ensuring the production of bakery and food products with desirable characteristics, including flavor, texture, and shelf life. This quality can be assessed through various laboratory tests, among which are those mandated by Normative Instruction No. 38 (IN 38), issued by the Ministry of Agriculture, Livestock, and Food Supply (Brasil, 2010), which establishes the Technical Regulation for Wheat in Brazil.

In this regulation, wheat classes are established based on the values of gluten strength (W, from alveography), expressed in 10^{-4} J, or stability (STA, from farinography), expressed in minutes, and the grain falling number (FNG), expressed in seconds. Only the Improver Class must consider values for both parameters, W and STA. The classes are named: Improver Wheat (FNG ≥ 250, W ≥ 300, and STA ≥ 14), Bread Wheat (FNG ≥ 220, 220 ≤ W < 300, or 10 ≤ STA < 14), Domestic Wheat (FNG ≥ 220, 160 ≤ W < 220, or 6 ≤ STA < 10), Basic Wheat (FNG ≥ 200, 100 ≤ W < 160, or 3 ≤ STA < 6), and Wheat for Other Uses (any values for W, STA, and FNG, when the wheat does not fit into the other classes).

Alveograph gluten strength and farinograph stability were included in IN 38 because these analyses represent the most widely used tests related to rheological quality in Brazil, especially by milling industries and end-product manufacturers (baking, pasta, biscuit, among others). IN 38 defines "Gluten strength" (W), as the mechanical work necessary to expand the dough until its rupture; and "Stability" (STA), as the time, in minutes, that a dough maintains its viscoelastic characteristics stably when subjected to the kneading process, according to an officially recognized method. The falling number is an indirect measure of the alpha-amylase enzyme activity associated with the pre-harvest germination of wheat (Guarienti & Miranda, 2004).

In addition to the quality parameters covered in the Technical Regulation for Wheat, others are demanded by end-product industries:

- in alveography: the tenacity (P) and the P/L ratio (the ratio between tenacity "P" and extensibility "L") parameters;
- in farinography: the water absorption and the dough development time parameters;
- in flour color determination: the lightness (L*) and the tendency toward red color (a*) and yellow color (b*) parameters;
- total protein content (Reunião da Comissão Brasileira de Pesquisa de Trigo e Triticale, 2024).

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Besides the aforementioned alveograph parameters, the elasticity index (Ie) could be included as one of the wheat quality assessment criteria in the baking and biscuit industries, as it is closely related to the phenomenon of elasticity, which is the dough's capacity to recover its initial shape after deformation. The Ie is obtained either by direct reading through the alveograph's software or can be calculated by the P200 value, which is the tenacity (P) corresponding to an extensibility (L) length of 4 cm, divided by the maximum tenacity (Pmax), and then multiplied by 100 (Dubois et al., 2008).

Comparisons between Ie and bread properties are limited in the literature. Duyvejonck et al. (2012) found a significant positive correlation ($p < .05$) between Ie and bread volume. There is an ideal Ie value for each manufacturing process of a wheat flour-based product (Bosc-Bierne, 2025). The Ie value related to the baking quality of the flour typically ranges from 10 to 85%. The closer the value is to 100%, the greater the elastic resistance of the dough. Very high or very low Ie values are undesirable for industrial and domestic baking (Kitissou, 1995).

However, the use of Ie is limited when working with highly tenacious doughs, as they tend to be difficult to stretch and may shrink. Furthermore, in an alveograph analysis, when doughs are highly elastic, the pressure may not reach 40 mm, thus making it impossible to calculate the Ie, which is then recorded as zero (Jødal & Larsen, 2021).

Some publications have related the elasticity index and stability, focusing mainly on biochemical aspects. The link between the elasticity index and stability can be established by the protein components of wheat gluten. In its hydrated form, gliadins are responsible for the dough's viscosity and extensibility, while glutenins are responsible for its resistance and elasticity (Belitz & Grosch, 1997). However, the explanation of how this relationship occurs is often only tangentially addressed, as seen in the works of Don et al. (2005) and Rezette et al. (2025), which demonstrates that this topic still requires further experimental approaches for a better understanding of the factors involved.

In a preliminary study involving 22 wheat cultivars harvested in three distinct regions in the state of Paraná, Brazil (Homogeneous Regions for Wheat Cultivar Adaptation—HRWCA 1, 2, and 3), Miranda et al. (2015) found a significant linear correlation ($p < .05$) between stability and the elasticity index, but this correlation varied among cultivars. The correlation coefficients were 0.72 (HRWCA 1), 0.86 (HRWCA 2), and 0.77 (HRWCA 3). The number of samples included in that study (which ranged from 2 to 44, depending on the cultivar and HRWCA) is not representative of the variability of Ie and the stability of all Brazilian wheat. Furthermore, the segregation of samples based on the values established in the Technical Regulation for Wheat (IN 38) could be another factor that would allow for the obtainment of distinct results.

This study investigated the relationship between the elasticity index (Ie), obtained through alveography, and farinograph stability (STA), and evaluated the potential use of Ie as a predictive variable for stability.

1.1 Relevance of the work

Considering the scarce studies on the relationship between the elasticity index (Ie) from alveography and stability from farinography, further research is needed to expand the knowledge on this subject. Farinography analysis is often time-consuming, complex to interpret, expensive, and requires qualified personnel, making it inaccessible in many laboratories. Alternatives to replace this test could represent a solution to the problem, even when considering stability alone. Thus, this study aimed to investigate the relationship between Ie and stability and to verify the possibility of using Ie as a predictor variable for stability.

2 MATERIALS AND METHODS

2.1 Sample selection

The samples used in this study were selected from the database of the Grain Post-Harvest Laboratory at Embrapa Trigo, using the following requirements:

- the samples were obtained following the same criteria and originated from competition trials of wheat lines and cultivars from diverse Brazilian wheat-growing regions;
- the samples were evaluated according to official methods of the American Association of Cereal Chemists (2010) using the following equipment and analyses/parameters: test weight—Method 55-10.01 (with results expressed in kg/hL); falling number—Method 56-81.03 (Perten® equipment, model FN1900, Huddinge, Sweden); alveography—Method 54-30.02, considering only the parameters gluten strength, W and Ie (Alveograph-Consistograph Chopin® equipment, model NG, Villeneuve La Garenne, France); and farinography—Method 54-21.01, considering only the parameter stability (Farinograph Resistograph Brabender® equipment, model 821000, Duisburg, Germany).

Samples where the Ie was equal to zero were excluded, which represents wheat with high tenacity. This condition may be a genetic characteristic of wheat, as well as being caused by drying the samples at high temperatures or by insect and/or mold damage to the grains. Since it was not possible to identify the reason for Ie being equal to zero, the decision was made to exclude these samples.

Based on these criteria, 8,037 wheat samples produced between 2007 and 2024 were selected, which comprised the following groupings:

- Group 1: all samples;
- Group 2: samples selected with a test weight equal to or greater than 72 kg/hL (Type 3 wheat, according to Annex IV of IN 38) and a falling number equal to or greater than 250 s (minimum FN value frequently used by milling industries in Brazil);
- Groups 3 (Improver), 5 (Bread), 6 (Domestic), 7 (Basic), and 8 (Other uses): samples classified according to the stability values and falling number defined in Annex III of IN 38 to form each group;

- Group 4: samples classified as Improver Wheat according to the values of gluten strength, stability, and falling number established in Annex III of IN 38.

2.2 Statistical analysis

The Shapiro–Wilk test was performed to check the normality of the elasticity index and stability variables. This analysis was executed using the Sisvar statistical software (Ferreira, 2011). For Groups 1 and 2, since they had a sample size greater than 5,000 (the limiting value for using the Shapiro–Wilk test), the histogram and box plot graphical tools were used to evaluate the data distribution.

Once the non-normality of the distribution of at least one of the variables was confirmed, the nonparametric Spearman correlation test was performed. The purpose of this test was to establish the relationship (strength and direction) between elasticity index and stability. This test was conducted using StatSoft software (2011). The classification of the correlation coefficients (p) was based on Baba et al. (2014).

To model the relationship between the elasticity index and stability variables, aiming to predict continuous stability values, the Multivariate Adaptive Regression Splines (MARS) statistical technique from the Data Mining system was applied, using the StatSoft software (2011).

3 RESULTS AND DISCUSSION

3.1 Normality of the sample distribution

The eight groups of samples did not present a normal distribution in at least one of the analyzed variables (elasticity index and stability).

In Groups 1 and 2 (data sets with sample numbers greater than 5,000), the elasticity index showed a histogram distribution that was very close to normal (Figures 1a and 2a). This situation is evidenced in Figures 1b and 2b, where the box plots show the medians (55.1 and 55.2, respectively) as slightly higher than the means (54.2 and 54.4). Most of the outlier data were in the first quartile, representing the Ie values with the lowest occurrence in the evaluated data set.

In these same groups (1 and 2), stability showed an asymmetric histogram with a concentration of data to the left of the curve, clearly indicating the non-normality of the sample distribution (Figures 1c and 2c). A similar situation was evidenced in the box plots (Figures 1d and 2d), with the medians (7.5 and 7.9, respectively) being lower than the means (9.8 and 10.3). All the outlier data were in the third quartile and correspond to stability values above 25 min, which characterize a small number of samples in the evaluated data set.

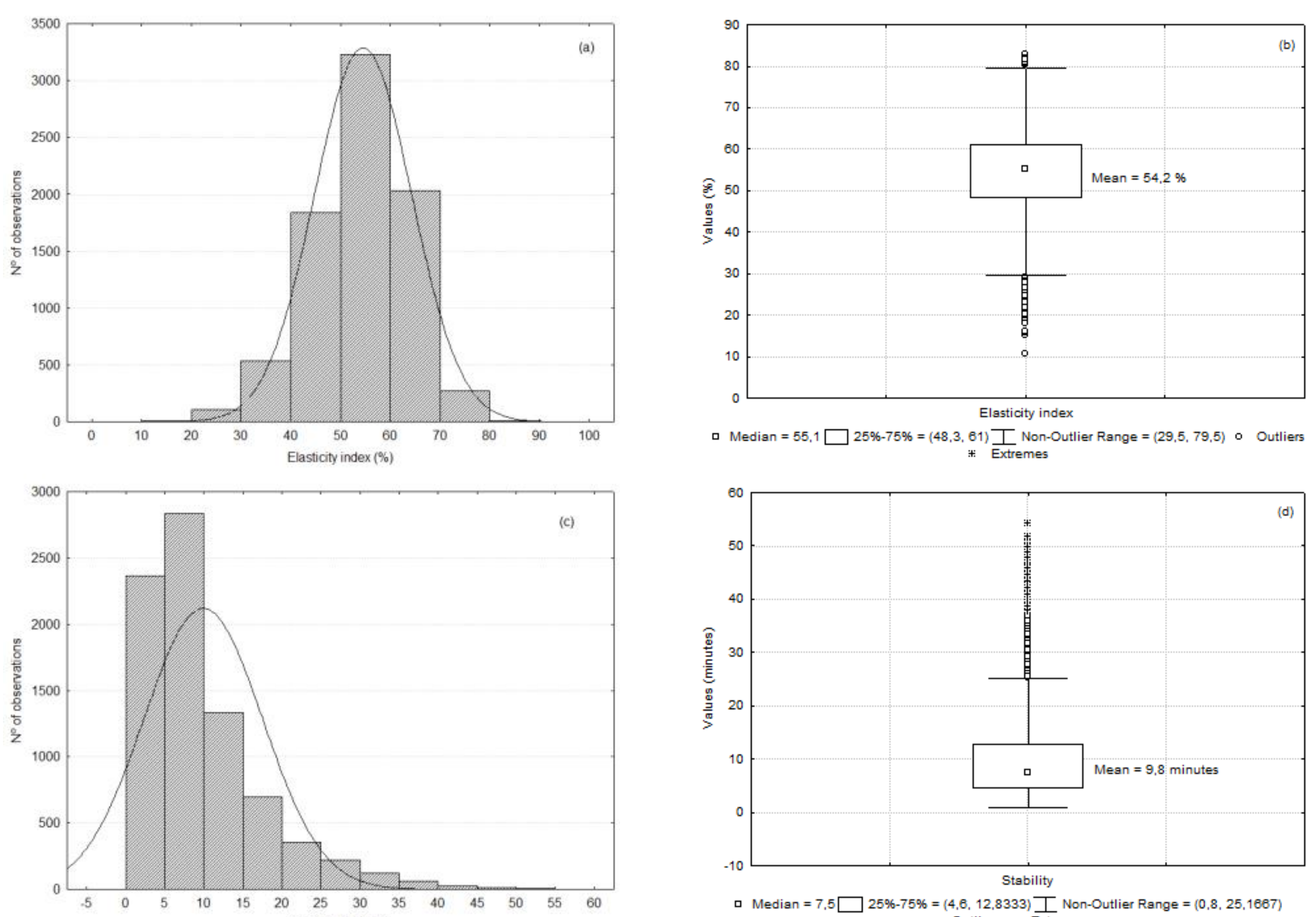


Figure 1. Graphical representation of the data distribution for Group 1 (8,037 samples), where: (a) histogram of the elasticity index parameter; (b) box plot of the elasticity index parameter; (c) histogram of stability parameter; and (d) box plot of stability parameter.

3.2 Spearman correlation analysis

It is possible to observe in Table 1 that, except for the Wheat Improver Class samples in Group 4 (those classified by the gluten strength, stability, and falling number values referenced in IN 38), the other data sets showed a significant Spearman correlation ($p < .05$). The coefficients ranged from 0.05 in the Based on Wheat Improver Class (Group 3) to 0.71 in Group 1 (the set of all samples) and Group 2 (samples selected with a test weight ≥ 72 kg/hL and falling number ≥ 250 s).

According to the classification proposed by Baba et al. (2014), the magnitude of the correlation coefficients varied as follows:

- Very weak (Wheat commercial classes: Improver, Bread, Domestic, and Other Uses);
- Weak (Wheat Basic commercial class);
- Strong (Group 1—set of all samples and Group 2—selected samples with test weight ≥ 72 kg/hL and falling number ≥ 250 s.

This indicates that when framing the observations (samples) into groups that represented the different commercial classes, the values of the variables computed in the calculation reduced the strength of the correlations, likely because the limits are narrower.

The significant correlation between the elasticity index and stability parameters indicated a monotonic increasing relationship. That is, as the value of Ie increases, stability also increases or may remain constant, indicating a nonlinear relationship.

The nonlinear relationship between elasticity index and stability observed in the present study contrasts with the findings of Miranda et al. (2015), where significant positive linear correlations were obtained. Their research was based on 22 wheat cultivars harvested across three HRWCAs from Paraná state, with a sample size ranging from 2 to 44. The Ie limits ranged from 31 to 74%, and the stability limits from 2 to 20 min.

A study published by Barak et al. (2013) correlated the gluten protein subfractions—gliadins (GLI) and glutenins (GLU), as well as the GLI/GLU ratio—with stability, measured using the Chopin Mixolab® equipment. The correlation coefficients obtained were 0.139, 0.903, and -0.940, respectively. In all cases, statistical significance, despite a high correlation between GLU content and the GLI/GLU ratio, was not observed. This fact may be due to the small number of samples

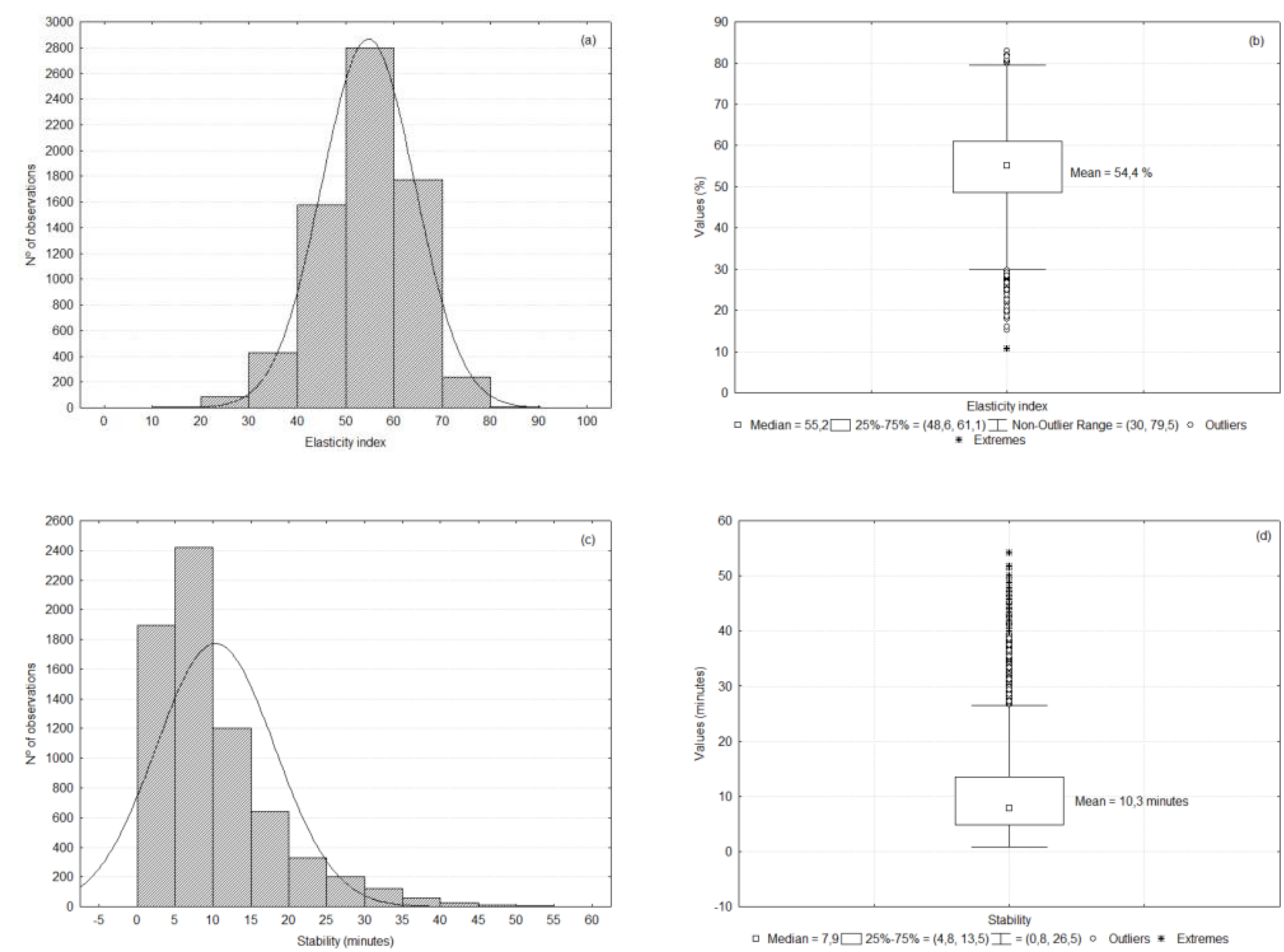


Figure 2. Graphical representation of the data distribution for Group 2 (6,914 samples), where: (a) histogram of the elasticity index parameter; (b) box plot of the elasticity index parameter; (c) histogram of stability parameter; and (d) box plot of stability parameter.

Table 1. Spearman correlation coefficient (p) between the elasticity index (Ie) and stability for groups of samples and commercial wheat classes, according to the stability and falling number values established in Annex III of Normative Instruction No. 38 (IN 38), dated 11/30/2010, from Mapa (Brasil, 2010).

Sample group	Nº of samples	Correlation coefficient (ρ)	Classification of correlation strength p[1]
1—All samples	8.037	0.71*	Strong
2—Samples selected[2]	6.914	0.71*	Strong
By commercial class			
3—Improver	1.631	0.05*	Very weak
4—Improver IN 38[3]	844	0.06	-
5—Bread	999	0.15*	Very weak
6—Domestic	1.845	0.29*	Very weak
7—Basic	1.772	0.38*	Weak
8—Other uses	667	0.26*	Very weak

[1]Source: Baba et al. (2014); [2]sample selection criteria: Test weight ≥ 72 kg/hL and falling number ≥ 250 s; [3]samples classified according to gluten strength, stability, and falling number values, according to Annex III of IN 38; *significant ($p < .05$).

analyzed (four), which increases the uncertainty (standard error) of the correlation coefficient estimate. This situation reinforced the understanding of the need to increase the number of samples to accurately estimate the correlation between the target variables.

Conversely, a significant negative linear correlation ($r = -0.350$, $p < .01$) was found by Tamba-Berehoiu et al. (2018), analyzing 81 flour samples marketed in Romania between 2015 and 2017, with Ie limits of 0.0–68.3% and stability limits of 1.3–19.6 min. These authors pursued a physical approach to try to explain the non-relationship between alveograph and farinograph measurements, suggesting that the way mechanical energy is transmitted to the dough differs between the two methods: In farinography, energy is transmitted through two kneading arms, and changes in the dough are measured in real-time, and in alveography, mechanical energy is initially transferred through a single kneading arm, and after a dough relaxation period, air pressure is applied, causing biaxial stretching.

The present study did not allow for the identification of the cause(s) of the nonlinear behavior of the relationship between the analyzed variables, and it was observed that there was a gap in the understanding of the positive and negative linear relationships seen in the different cited works.

3.3 Regression splines

In Figure 3, it is possible to visualize the nonparametric spline regression curve, which presented a low r^2 across all evaluated groups, ranging from 0.01 in Group 3—Wheat Improver Class (Figure 3c), to 0.35 in Group 1—set of all samples, and Group 2—selected samples (Figures 3a and 3b, respectively).

Apart from Groups 1 and 2, the regression model showed low performance in the remaining groups, with the elasticity index variable not satisfactorily explaining the variation found in stability. This suggests that the variability of this characteristic is influenced by other factors not addressed in this study.

Although Groups 1 and 2 presented a low r^2 (0.35), given the complexity of the relationship between the variables, this value was considered sufficient to partially explain how much of the stability can be attributed to Ie (35%), according to the proposed mathematical curve model.

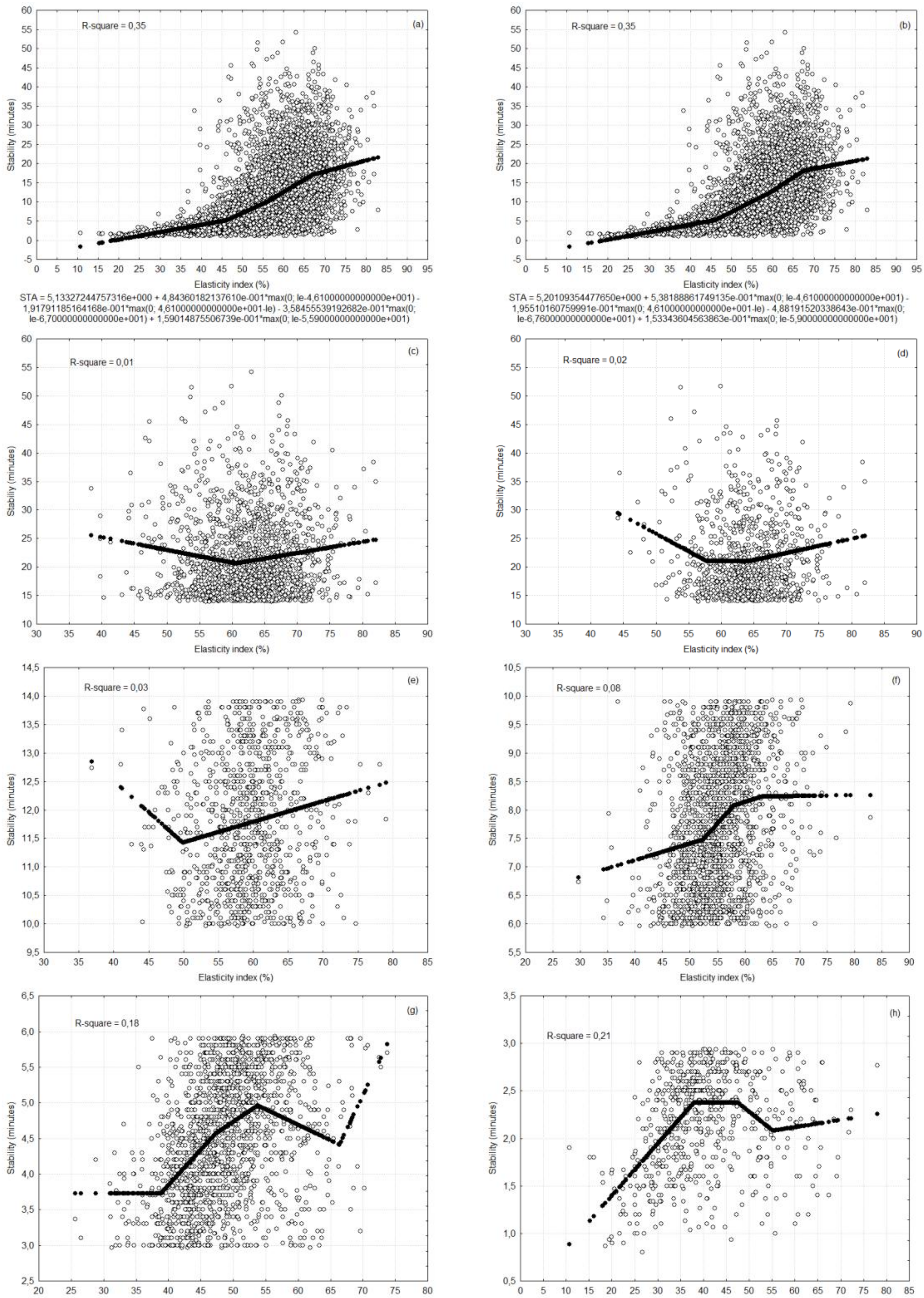
In Group 1 (Figure 3a) and Group 2 (Figure 3b), it was verified that the graphical representation of the sample distribution and the nonlinear spline regression curve are similar, as well as the regression models showed only a small difference in the values of the function coefficients. A similar situation was presented in Table 1 regarding the correlation coefficients ρ, where the removal of the 1,123 samples that had a test weight lower than 72 kg/hL and a falling number lower than 250 s (criteria established for Group 2) did not impact the value of the correlation coefficient p compared to the one obtained by the set composed of all samples (Group 1; 8,037 samples).

Regarding Groups 1 and 2, it was observed that the sample dispersion was very large. This situation may have been caused by the variability of the samples produced across different cultivars, locations, years, and sowing dates.

In the groups where the correlation coefficients p (Table 1) were classified as having very weak to weak magnitude or were nonexistent (nonsignificant), the r^2 of the models was also very low (Figures 3c to 3f). In these cases, the analyzed sets of samples (groups) showed a poorly consistent relationship between the two variables, and the models were unable to significantly capture the variance in stability.

4 CONCLUSIONS

The measure of association between the elasticity index (Ie) and stability (STA) was significant and showed a high Spearman correlation coefficient (p) in Group 1 (all samples; 8,037 samples) and Group 2 (selected samples with test weight ≥ 72 kg/hL and falling number ≥ 250 s; 6,914 samples). Segmentation by commercial classes, with their narrow stability ranges, weakened the Ie–STA relationship, resulting in ρ values that ranged from very low to low magnitude or nonexistent. The results of the spline regression allowed the presentation of two predictive models for predicting stability as a function of Ie, corresponding to sample Groups 1 and 2. However, these models only explain 35% of the total variance in stability present in the data.



*Considering only stability and falling number values.

Figure 3. Graphical representation of the sample distribution and the nonlinear spline regression curve, where: (a) Group 1—all samples; (b) Group 2—selected samples (with test weight ≥ 72 kg/hL and falling number ≥ 250 s); (c) Group 3—Improver Wheat*; (d) Group 4—Improver Wheat IN 38 (according to gluten strength, stability, and falling number values [Annex III of IN 38 (Brasil, 2010)]); (e) Group 5—Bread Wheat*; (f) Group 6—Domestic Wheat*; (g) Group 7—Basic Wheat*; and (h) Group 8—Wheat for Other Uses*).

REFERENCES

American Association of Cereal Chemists (2010). *Approved Methods of Analysis* (11th Ed). Cereals & Grains Association.

Baba, R. K., Vaz, M. S. M. G., & Costa. J. (2014). Correção de dados agrometeorológicos utilizando métodos estatísticos. *Revista Brasileira de Meteorologia*, *29*(4), 515–526. https://doi.org/10.1590/0102-778620130611

Barak, S., Mudgil, D., & Khatkar, B. S. (2013). Relationship of gliadin and glutenin proteins with dough rheology, flour pasting and bread making performance of wheat varieties. *LWT - Food Science and Technology*, *51*(1), 211–217. https://doi.org/10.1016/j.lwt.2012.09.011

Belitz, H.-D., & Grosch, W. (1997). Cereales y produtos derivados. In H.-D. Belitz & W. Grosch (Eds.), *Química de los alimentos* (pp. 537–584). Acribia.

Bosc-Bierne, L. (2025). The science *behind dough elasticity*. KPM Analytics. Retrieved from: https://www.kpmanalytics.com/blog/the-science-behind-dough-elasticity

Brasil (2010). Instrução normativa n. 38, de 30 de novembro de 2010. Estabelece o Regulamento Técnico do Trigo, definindo o seu padrão oficial de classificação, com os requisitos de identidade e qualidade, a amostragem, o modo de apresentação e a marcação ou rotulagem, nos aspectos referentes à classificação do produto. *Diário Oficial da União*.

Don, C., Lichtendonk, W. J., Plijter, J. J., Vliet, T. V., & Hamer, R. J. (2005). The effect of mixing on glutenin particle properties: aggregation factors that affect gluten function in dough. *Journal of Cereal Science*, *41*(1), 69–83. https://doi.org/10.1016/j.jcs.2004.09.009

Dubois, M., Dubar, A., & Launay, B. (2008). Interpretation of alveogram. In M. Dubois, A. Dubar & B. Launay (Eds.), *The alveoconsistograph handbook* (pp. 33–37). AACC International.

Duyvejonck, A. E., Lagrain, B., Dornez, E., Delcour, J. A., & Courtin, C. M. (2012). Suitability of solvent retention capacity tests to assess the cookie and bread making quality of European wheat flours. *LWT Food Science Technology*, *47*(1), 56–63. https://doi.org/10.1016/j.lwt.2012.01.002

Ferreira, D. F. (2011). Sisvar: a computer statistical analysis system. *Ciência e Agrotecnologia*, *35*(6), 1039–1042. https://doi.org/10.1590/S1413-70542011000600001

Guarienti, E. M., & Miranda, M. Z. (2004). Determinação da germinação pré-colheita em trigo. In G. R. Cunha & J. L. F. Pires (Eds.), *Germinação pré-colheita em trigo* (pp. 291–308). Embrapa Trigo.

Jødal, A. S. S., & Larsen, K. L. (2021). Investigation of the relationships between the alveograph parameters. *Scientific Reports*, *11*, Article 5349. https://doi.org/10.1038/s41598-021-84959-3

Kitissou, P. (1995). Un nouveau paramètre alvéographique: L´indice d´élasticité (Ie). *Industries des Céreales*, (92), 9–14.

Miranda, M. Z., Guarienti, E. M., Bassoi, M. C., Scheeren, P. L., Só e Silva, M., Caierão, E., & Castro, R. L. (2015). Correlação de força de glúten e índice de elasticidade com estabilidade, para genótipos de trigo da Embrapa no Paraná. In *Proceedings of 8th Reunião da Comissão Brasileira de Pesquisa de Trigo e Triticale* (CBPTT) and *9th Seminário Técnico do Trigo*, Canela, Brasil; *9th Reunião da Comissão Brasileira de Pesquisa de Trigo e Triticale* (CBPTT) and *10th Seminário Técnico do Trigo*, Passo Fundo, Brasil. 1 CD-ROM.

Reunião da Comissão Brasileira de Pesquisa de Trigo e Triticale (2024). Classificação comercial de trigo. In *16th Reunião da Comissão Brasileira de Pesquisa de Trigo e Triticale*, Guarapuava, Brasil.

Rezette, L., Saulnier, L., Morel, M.-H., Méléard, B., Gall, S. L., & Kansou, K. (2025). Impact of wheat flour composition on dough properties: focus on the minor components. *Journal of Cereal Science*, *124*, Article 104233.

StatSoft (2011). *Statistica: data analysis software system*. Version 7. StatSoft, Inc..

Tamba-Berehoiu, R.-M., Popa, C. N., Vișan, L. V., Simion, V., Dobrinoiu, R. V., & Dănăilă-Guidea, S. M. (2018). Farinograph vs alveograph in predictive modelling of wheat flours quality. In *Agriculture for Life, for Agriculture Conference Proceedings*, *1*(1), 586–593. https://doi.org/10.2478/alife-2018-0092