# Gel Strength of the Native Egg White

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**Abstract**

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The study examined gel strength of the native egg white as a function of pH and the dry matter content. The egg white samples were isolated from fresh eggs and the eggs in different stages of storage. The gel strength was measured with Texture Analyser of TA-XT2i type. The study has shown that the gel strength increases with rising pH and the content of dry matter. The influence of the egg age is more complicated. The gel strength increases over the first 14 days after egg laying and slowly decreases afterwards. Mathematical dependence of the gel strength was predicted on the basis of the measured data by the method of non-linear regression: gel strength (p/cm$^2$) = exp[0.00674*time (days) + 0.289*dry matter (%) + 0.1165*pH + 1.433].

**Keywords**: native egg white; gel strength; pH; dry matter; time of storage

We came across the issue of the coagulated gel strength with respect to thermal treatment and sterilisation of dried egg white (Cotterill *et al*. 1974; Mulder *et al*. 1978). This strength is a measure of the extent of the thermal treatment, the egg white ability to bind water, and is monitored as a quality parameter by the manufacturers of dried egg white (Kato *et al*. 1990).

The method of the gel strength measurement is described in the materials of the company Taiyo Kagaku Co. (1988). The Food Research Institute Prague, the Czech Republic, further improved this method (Kýhos *et al*. 1997), which was supported by the development of a new device (GS-meter) enabling the measurement of this parameter in the manufacturers' laboratories.

In the course of its industrial treatment, the egg white occasionally significantly changes its properties, especially viscosity. Homogenisation and filtration under pressure compress the egg white into firm, highly viscous cords, which are untreatable and frequently put the production equipment out of order. Variations of these properties manifest them selves particularly in the ability of foam generation, its stability and firmness, and influence the strength of the gel prepared of such egg whites. This is the reason why we decided to monitor systematically the influence of the native egg white properties on the gel strength and studied the gel strength in the dependence on pH value, the dry matter content, the age of eggs, and the hen genus.

## MATERIAL AND METHODS

### Equipment and tools

The instrument for the measurement of the gel strength: Texture Analyser TA-XT2i type (Stable Micro Systems, Great Britain); pH meter: Sentron pH meter with ISFET transistor probe (Sentron, the Netherlands) and Dry matter determination: hot-air oven HS 62 A Chirana (CR).

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**Raw material**

– Fresh hen eggs from laying hen farm No. I – Isa Brown hen breed (brown egg shell)
– Fresh hen eggs from laying hen farm No. II – Lohmann LSL hen breed (white egg shell)
– Hisex brown hen breed (brown egg shell)
– Fresh hen eggs from laying hen farm No. III – Isa Brown hen breed (brown egg shell)

Fresh eggs were purchased at the farms Nos. I, II and III. A day after being laid, the eggs were manually broken and the egg whites were carefully separated from the yolks. 60 eggs were used in each series of samples designed for the monitoring of the dependence of the egg white properties on the time of storage. The separated egg whites were cautiously mixed up with a perforated-head piston in a two-litre glass cylinder. Next to that, a sample (mixed white) was taken for the measurement of pH and the gel strength. The remaining white in the measuring cylinder was further homogenised with fifty vertical piston shifts while preventing the undesired air to whip into the white.

The analyses of the homogenised samples, i.e. the coagulated gel strength and pH determinations, were carried out on the day of the egg breaking and on the 6$^{th}$ (7$^{th}$), 13$^{th}$ (14$^{th}$) and 20$^{th}$ (21$^{st}$) days after that. The egg whites were kept in the refrigerator at a temperature below 5°C. The evaporation of water from the egg whites was prevented by covering the storage vessel with a tight lid.

The samples designated for the measurement of the gel strength were poured into a casing of 30 mm diameter and coagulated at the temperature of 90°C for 30 min. They were then cooled down in cold water. Beside that, we also determined the dry matter contents on the days 0, 13 (14), and 20 (21). The egg white samples were dried at 90°C for 21 h and further at 105°C for 3 h.

We further carried out an experiment explaining the change of properties (strength, pH, dry matter) in the dependence on the sample dilution with water. For this purpose, we used eggs from the farm No. I in a series of 60 eggs. The eggs were broken 13 days after laying (eggs had been kept in the refrigerator at 5°C since laying). We measured the properties of the non-homogenised egg white obtained, which was subsequently homogenised in the same way as described above. Next to that, we prepared samples in the following weight ratios (egg white:water): 100:0, 95:5, 90:10, 80:20, 70:30, 60:40 and 50:50. The measurements of the gel strength, pH, and dry matter contents were then carried out with all these samples.

**Methodology of strength measurement**

The measurement was carried out with a TA-TX2i texturometer programmed and set up to the following parameters: shift speed – 50 mm/min, measuring head – 5 kg. A cylindrical sample of 30 mm diameter and 30 mm length (without casing) was loaded with a circular shaft surface of 0.5 cm$^2$. The force used to achieve the first maximum on the force-time curve was considered to be the gel strength. We prepared 5 to 10 cylinders of each sample of the coagulated white, each of which was used for a single measurement. The results of the strength measurements were further analysed and statistically evaluated.

**Methodology of statistic evaluation**

a) **Exclusion of distant results**

We applied Grubbs test (Eckschlager *et al*. 1980) to exclude the distant results of the coagulated gel strength measurements prior to the statistic evaluation itself. The Grubbs test consists in the arrangement of the values measured upwards with $x_1$ being the lowest and $x_n$ the highest value of the data acquired. Next to this, we determined the values of the $T_1$ a $T_n$ ratios.

$$T_i = \frac{\bar{x} - x_i}{S_n} \qquad T_n = \frac{x_n - \bar{x}}{S_n} \tag{1}$$

The value of the $S_n$ variable is specified by the following formula:

$$S_n = \sqrt{\frac{\sum(x_n - \bar{x})^2}{n}} \tag{2}$$

where: $n$ – number of independent measurements
$\bar{x}$ – arithmetic mean

Further on, we compared the calculated values of the ratios with the tabelated critical values at the selected level of importance ($\alpha = 0.05$). If the $T_1$ or $T_n$ value calculated is equal or higher than the critical $T_\alpha$ value for the specific number of measurements $n$, we exclude $x_1$ or $x_n$, respectively. The results excluded with the Grubbs test using the critical values $T_\alpha$ ($\alpha = 0.05$) are distant with 95% reliability.

b) **Student's *t*-test**

After the exclusion of the distant values, the remaining data (5 to 10 for each sample) were subjected to the statistical evaluation of the coagulated gel strength. We used the statistical evaluation to demonstrate whether the samples differ from one another. For this purpose, we used the Student's *t*-test at the level of importance $\alpha = 0.05$ (Štěpánek 1975). By using this method of evaluation, we determined the average value and the standard deviation $\sigma$ for each repeated measurement of the gel strength value. After that, we determined a 95% interval of $\beta$ reliability, with limits defined by the formula (3):

$$\left\langle \bar{x} - \frac{t_{n1,\alpha} \cdot \sigma}{\sqrt{n}} ; \bar{x} + \frac{t_{n1,\alpha} \cdot \sigma}{\sqrt{n}} \right\rangle \qquad (3)$$

where: $n_1$ – number of degrees of freedom ($n_1 = n - 1$)
$n$ – number of repeated measurements
$\alpha$ – importance level (here selected as 0.05 = 5%)
$\sigma$ – standard deviation
$\bar{x}$ – means the mean of the number of measurements

## RESULTS AND DISCUSSION

The study focused on two directions. The first objective was to examine the changes in the properties of different samples (farms Nos. I, II, and III) of egg white depending on the time of storage. The measurements were carried out in the course of 21 days and the data acquired were statistically evaluated. For complete data, see Houška *et al*. (2002). This article introduces summarising tables and figures. For illustration, we have also included an example of the table representing the statistical evaluation (Table 1). Table 2 brings the comprehensive survey of the average strength values, the reliability intervals of all samples, and the Student's *t*-test determining whether the individual samples differ with statistical importance. Statistically indifferent samples are designated with the same letter. Samples marked with the letter "a" have the lowest strength while the samples marked with the letter "e" have the highest strength. The table shows that all the non-homogenised samples had a lower strength which subsequently rose after homogenisation. The strength also increased with the time of storage in the majority of samples, except for both samples of the egg white from the farm No. II. The eggs from the farms Nos. I and III showed comparable strengths, dry matter contents and pH values.

Figure 1 shows an example of the loading curves used for the gel strength measurement in the case of the egg white from the farm No. I. The first maximum value in the chart determines the gel strength. Figure 3 shows the dependence of the gel strength of the egg white samples on the time of storage. In the course of time, the gel strength was increasing over the first two weeks; the values acquired practically did not change or slightly decreased in the third week. The figure also demonstrates that the egg whites differ particularly with respect to

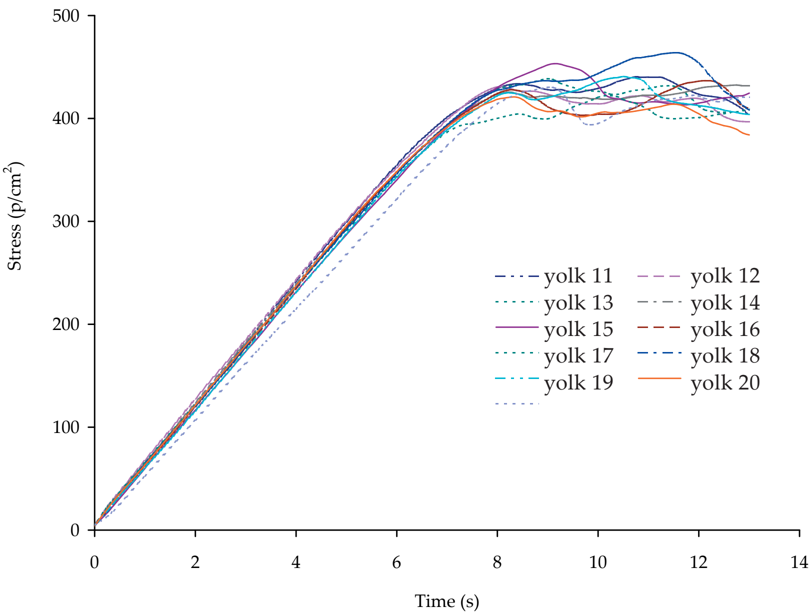


Figure 1. Compression stress as a function of compression time during penetration of circular shaft into the gel, sample from farm No. I, homogenised

Table 1. Non-homogenised egg white strength (0. day) – farm No. II

Sample: egg white from farm No. II, prepared from fresh eggs
Colour of egg shell: white

| Sample | Strength | |
|---|---|---|
| | *p/0.5 cm$^2$ | p/cm$^2$ |
| 1 | 157.0 | 314.0 |
| 2 | 130.2 | 260.4 |
| 3 | 137.1 | 274.2 |
| 4 | 118.2 | 236.4 |
| 5 | 126.4 | 252.8 |
| 6 | 137.4 | 274.8 |
| 7 | 163.9 | 327.8 |
| 8 | 135.0 | 270.0 |
| 9 | 143.4 | 286.8 |
| 10 | 135.1 | 270.2 |

*measured values

Grubbs test of exclusion of outlayed values of gel strength

Sample: non-homogenised

| Data $x_i$ | 10 values | |
|---|---|---|
| 314.0 | minimum $x_1$ | 236.4 |
| 260.4 | maximum $x_n$ | 327.8 |
| 274.2 | average $x_p$ | 276.74 |
| 236.4 | $S_n$ | 25.81 |
| 252.8 | $\boldsymbol{T_1}$ | **1.563** |
| 274.8 | $\boldsymbol{T_n}$ | **1.978** |
| 327.8 | $\boldsymbol{T_{\mathrm{krit}}}$ | **2.294** |
| 270.0 | | |
| 286.8 | | |
| 270.2 | | |

$T_1$, $T_n < T_{\mathrm{krit}}$
not necessary to exclude any measured value

Student $t$-test (10 samples)

| Sample | Non-homogenised |
|---|---|
| Strength (p/cm$^2$) | 314.0 |
| | 260.4 |
| | 274.2 |
| | 236.4 |
| | 252.8 |
| | 274.8 |
| | 327.8 |
| | 270.0 |
| | 286.8 |
| | 270.2 |
| Average | **276.74** |
| St. deviation | **27.21** |
| Variability σ$^2$ | **740.28** |
| Value of I | **19.46** |
| Reliability | |
| Interval β: | |
| Lower limit | **257.28** |
| Upper limit | **296.20** |

$$T_1 = \frac{x_p - x_i}{S_n} \qquad T_n = \frac{x_n - x_p}{S_n}$$

$$S_n = \sqrt{\frac{\sum_{i=1}^{n}(x_i - x_p)^2}{n}}$$

half of reliability interval

$$I = \frac{t_{n1,\alpha}\,\sigma}{\sqrt{n}}$$

95% reliability interval

$$\beta = \bar{x} \pm \frac{t_{n1,\alpha}\,\sigma}{\sqrt{n}}$$

where: $n$ – number of replication ($n$ = 10)
$n_1$ – freedom rate ($n$ – 1)
$t_{n1,\alpha}$ – critical value of Student distribution for level of reliability and freedom rate $n_1$

their origin. The egg whites from the farm No. II showed significantly lower strength compared to those from farms Nos. I and III.

The second part of the study examined the properties of one sample of homogenised egg white (from the farm No. I) as a function of the dilution

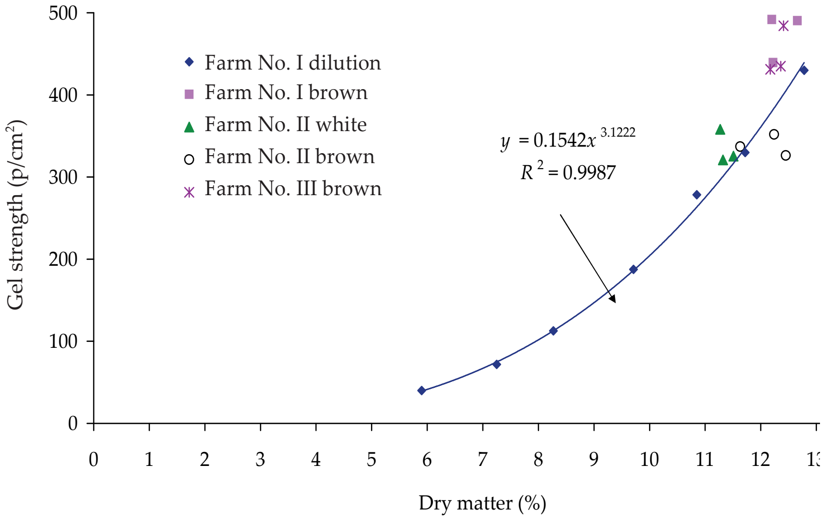


Figure 2. Dependence of gel strength on dry matter

with water. The measurements were carried out in a single day. The results of the Student's *t*-test included in Table 3 show that the dilution of the white with water affected the gel strength which was significantly decreasing as a result of the dilution. When using dilution in the 50:50 ratio, the gel strength reached approximately 1/10 of the non-diluted homogenised white gel strength. All the diluted egg white sub-samples showed statistically important differences (designation with the letters a, b, …g). That is why we were looking for the relation that would define this feature. Figure 2 describes the dependence of all the egg whites gel strengths (including the diluted ones) on the dry matter. Exponential ratio, the equation of which is shown in the same figure, was inlaid with the points obtained during the whites dilution. The dependence found apparently applies to the non-diluted

Table 2. Comprehensive summarisation of the average strength values and reliability intervals β (p/cm$^2$)

| Sample | | 0 day | | $6^{th}$–$7^{th}$ day | | $13^{th}$–$14^{th}$ day | | $20^{th}$–$21^{st}$ day | |
|---|---|---|---|---|---|---|---|---|---|
| | | average | interval β | average | interval β | average | interval β | average | interval β |
| Farm I brown | non-homogenised | 357.9 | 336.3–379.6 | – | | – | | – | |
| | homogenised | 439.3 | 432.9–445.8 | 443.8 | 416.3–471.3 | 491.7 | 477.8–505.6 | 490.3 | 485.3–495.3 |
| Farm I white | non-homogenised | 276.7 | 257.3–296.2 | – | | – | | – | |
| | homogenised | 325.4 | 312.8–337.9 | 335.1 | 327.8–342.5 | 358.1 | 347.2–369.0 | 320.9 | 310.5–331.3 |
| Farm II brown | non-homogenised | 252.8 | 231.8–273.9 | – | | – | | – | |
| | homogenised | 326.3 | 314.1–338.6 | 280.4 | 262.8–297.9 | 351.8 | 329.9–373.7 | 337.1 | 325.2–349.0 |
| Farm III brown | non-homogenised | 285.4 | 232.4–338.3 | – | | | | | |
| | homogenised | 431.2 | 403.9–458.4 | 415.2 | 388.3–441.9 | 434.9 | 407.6–464.1 | 484.16 | 454.7–513.6 |
| **Students *t*-test** | | | | | | | | | |
| Farm I brown | non-homogenised | b c | | – | | – | | – | |
| | homogenised | d | | d | | e | | e | |
| Farm I white | non-homogenised | a | | – | | – | | – | |
| | homogenised | b | | b | | c | | b | |
| Farm II brown | non-homogenised | a | | – | | - | | – | |
| | homogenised | b | | a | | b c | | b c | |
| Farm III brown | non-homogenised | a | | – | | – | | – | |
| | homogenised | d | | d | | d | | e | |

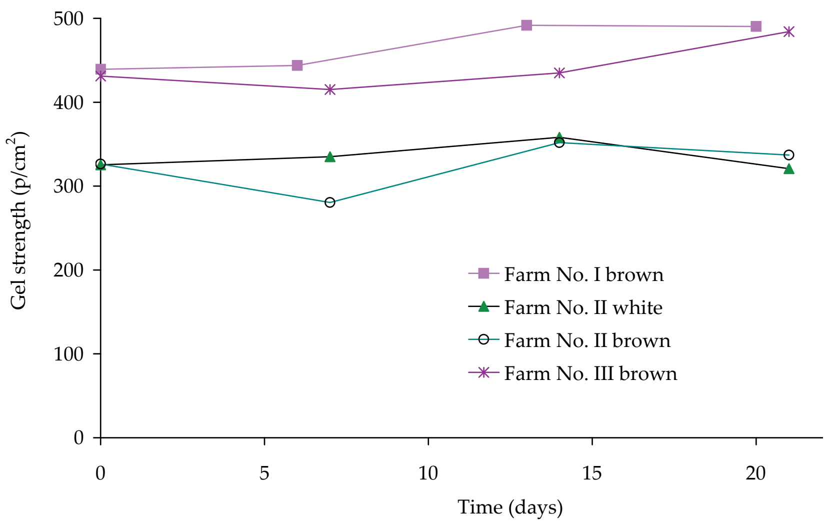


Figure 3. Dependence of gel strength on the storage time

whites, too. Lower strength of the egg whites from the farm No. II may be therefore greatly attributed to their lower content of dry matter.

Another quality parameter monitored was the egg white pH and its changes in the course of storage as well as its relation to the gel strength. Figure 4 shows the pH dependence on the time of storage. Two cases statistically proved a slightly increasing pH dependence on the time of storage (farm No. II brown eggs and farm No. III), where the correlation coefficient equalled or slightly exceeded the critical value of $R_{2;0.05}$ = 0.950. In the case of the farm II egg whites, there was just a weak dependence, in the case of the farm I it was even entirely unimportant.

The correlation between pH and the egg white gel strength regardless of its origin showed an interesting result (Figure 5). The correlation is statistically demonstrable as the correlation coefficient $R$ = 0.860 significantly exceeds the critical value of $R_{14;0.05}$ = 0.497. The pH dependence on the gel strength within the areas of individual farms

Table 3. Comprehensive survey of the average strength values and reliability intervals β of egg white from farm No. I – broken 13 days after laying

| Sample | | Non-homogenised | | Homogenised | |
|---|---|---|---|---|---|
| | | average | interval β | average | interval β |
| **Farm I** | | | | | |
| Undiluted | | 323.0 | 266.9–379.0 | 430.0 | 416.9–443.2 |
| Diluted | 95:5 | – | – | 329.8 | 320.8–338.9 |
| | 90:10 | – | – | 278.5 | 272.4–284.6 |
| | 80:20 | – | – | 187.6 | 178.0–197.3 |
| | 70:30 | – | – | 112.6 | 110.2–115.1 |
| | 60:40 | – | – | 71.8 | 69.5–74.0 |
| | 50:50 | – | – | 40.1 | 32.8–47.3 |
| **Farm II** | | | | | |
| Undiluted | | e f | | g | |
| Diluted | 95:5 | | | f | |
| | 90:10 | | | e | |
| | 80:20 | | | d | |
| | 70:30 | | | c | |
| | 60:40 | | | b | |
| | 50:50 | | | a | |

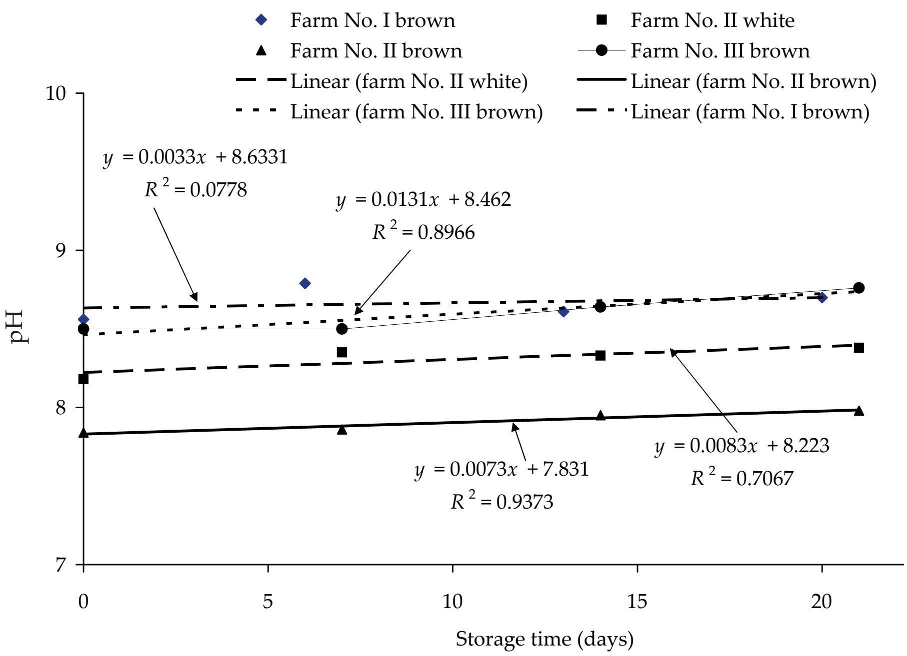


Figure 4. Dependence of the egg white pH on the storage time

(pH changes due to the storage) was not statistically demonstrable, while the wider pH changes due to mere application of eggs of different origin proved the pH effect on the gel strength.

Based on the existence of the statistically demonstrable correlations with the different parameters, we tried to find the general relation between the homogenised egg white gel strength and its dry matter, pH and the time of storage. Out of the series of models, we chose the following function as the optimum:

$$\text{Gel strength (p/cm}^2) = \exp[0.00674\text{*time (days)} + 0.289\text{*dry matter (\%)} + 0.1165\text{*pH} + 1.433] \quad (4)$$

where the correlation coefficient $R = 0.964$ exceeds the critical value $R_{15;0.05} = 0.482$

According to the Durbin-Watson statistics (Likeš & Laga 1978), $D = 1.269$ is lower than the critical value of 1.685. The variability of the values measured has therefore not been explained completely, the model, however, explains 93% of this variability. Figure 6 demonstrates the comparison of the measured and calculated values of the gel strength. The figure apparently shows that the maximum deviation of the calculated values from the measured ones is approximately 50 p/cm², making the calculation sufficient for a rough estimate.

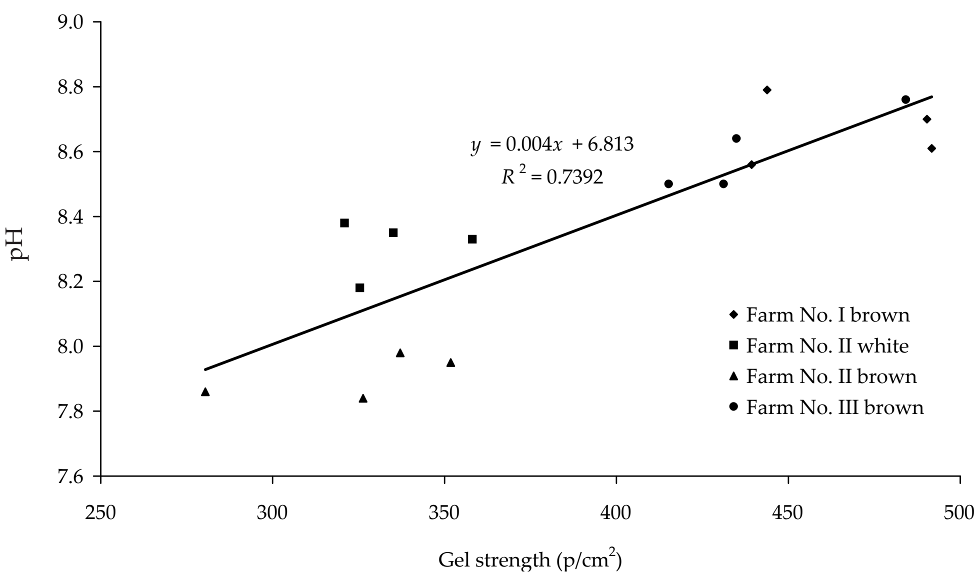


Figure 5. Correlation of the egg white pH with gel strength

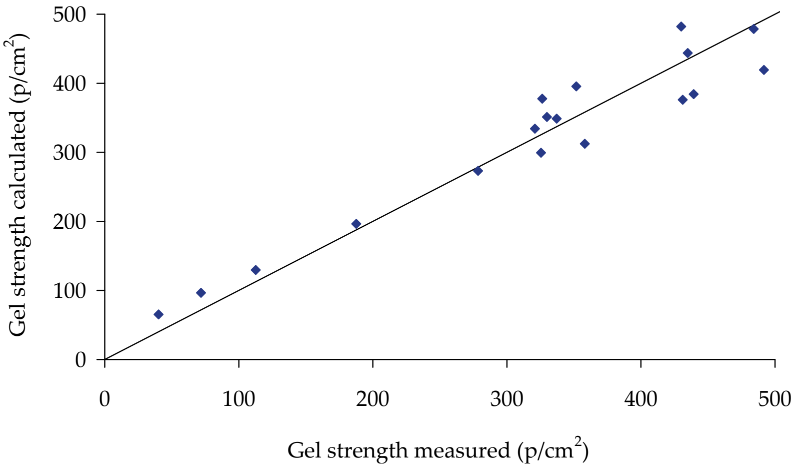


Figure 6. Comparison of measured and predicted values of the egg white gel strength (using mathematical function of dry matter, pH and storage time)

## Conclusion

The study was aimed at the verification of the basic relations between the gel strength and another quality parameters of the egg whites (origin, pH, the time of storage, dry matter). An effect on the gel strength was proven with all of these parameters. The origin of eggs may be partially estimated by different contents of dry matter and pH. The egg white strength increases with the rising content of dry matter. This dependence is described as a non-linear mathematical relation (Figure 2).

The egg white gel strength increases with rising pH (Figure 5). The egg white gel strength also slightly increases at first with the time of storage (over the first two weeks), and then it slightly decreases again (Figure 3).

The acquired general relation (4) demonstrates the influences of the aforementioned parameters at a time and confirms the trends of different parameters effects.

All the results obtained represent a good tool for the assessment of the aptness of the native egg white for the specific product series.

### List of symbols

| | | |
|---|---|---|
| $n$ | number of repeated measurements | (–) |
| $n_1$ | number of degrees of freedom | (–) |
| $t_{n1,\alpha}$ | critical values of the Student's $t$-test for the level of $\alpha$ importance and the number of degrees of freedom $n_1$ | (–) |
| $\bar{x}$ | average value of gel strength | p/cm$^2$ |
| $x_i$ | individual measured values value of gel strength | p/cm$^2$ |
| $I$ | half of the reliability interval | p/cm$^2$ |
| $R$ | correlation coefficient | (–) |
| $S_n$ | variables in relation (2) | p/cm$^2$ |
| $T_1$, $T_n$ | variables in relations (1) | (–) |
| $\alpha$ | importance level at the Student's method | (–) |
| $\beta$ | gel strength reliability interval | p/cm$^2$ |
| $\sigma$ | gel strength standard deviation | p/cm$^2$ |
| $\sigma^2$ | gel strength scatter | p$^2$/cm$^4$ |

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**Souhrn**

Houška M., Kýhos K., Novotná P., Landfeld A., Strohalm J. (2004): **Pevnost gelu vaječného bílku.** Czech J. Food Sci., **22**: 58–68.

Byla sledována závislost pevnosti gelu přírodního vaječného bílku jako funkce pH a sušiny. Bílek byl získán jednak z čerstvých vajec, jednak z vajec skladovaných různou dobu. Pevnost gelu byla měřena analyzátorem textury, typ TA-XT2i. Z výsledků je patrné, že pevnost gelu roste s rostoucí hodnotou pH a obsahem sušiny. Vliv doby skladování je komplikovanější. Pevnost gelu roste prvních 14 dnů po snesení vajec a pak pomalu klesá. Pevnost gelu byla vyjádřena jako matematická závislost nalezená regresí experimentálních dat ve tvaru: pevnost gelu (p/cm$^2$) = exp [0,00674*čas (dny) + 0,289*sušina (%) + 0,1165*pH + 1,433].


**Klíčová slova**: přírodní vaječný bílek; pevnost gelu; pH; sušina; doba skladování


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