Influence of drying temperature on the wet-milling performance and the proteins solubility indexes of corn kernels

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\textbf{A R T I C L E I N F O}

Article history:
Received 10 February 2009
Received in revised form 7 April 2009
Accepted 26 May 2009
Available online 31 May 2009

Keywords:
Wet-milling
Drying
Corn
Starch
Salt-soluble proteins
Albumin
Globulin
Zein
Logistic model
Polynomial model
Solubility

\textbf{A B S T R A C T}

The effects of air drying temperature on the wet-milling performance and the proteins solubility indexes were investigated for corn kernels dried between 54°C and 130°C. It was observed that when the drying temperature increases, the starch yield drops significantly. The gluten recovered increased abruptly for drying temperatures up to 80°C. The albumin, globulin and zein solubility indexes decreased continuously when corn drying temperatures increased. According to the temperatures used, the starch yield, the gluten recovered and the salt-soluble proteins solubility indexes were adjusted satisfactorily by using a two asymptotic logistic model. This model has the advantage of supplying information on the dynamic of the variation of described parameters. The solubility index of total salt-soluble proteins was shown to be a suitable indicator of the severity of the drying treatment in regard to the corn wet-milling performance.

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\textbf{1. Introduction}

Corn kernel is a near-perfect starch crop which is easily dried and yields over 85% of the starch produced in the world (Eckhoff, 2004). Globally, it contributes for 42 Mt of proteins a year, which corresponds to approximately 15% of the world annual production of food-crop protein (Li and Vassal, 2004).

In order to separate its major components, corn kernel is processed using the wet-milling process during which steeping and starch/gluten separations appear to be the most important operations. When dealing with corn dried at high-temperature, the wet-milling performance is severely affected. The impairment of wet-milling performance observed in this condition is reliable to physical and chemical changes occurred within the kernel’s matrix.

Watson and Hirata (1962) probably appear among the first authors who correlated the impairment of wet-milling performance of corn with the denaturation of their proteins. They theorized that a specific protein fraction that releases starch granules when dissolved in steep water is unsolubilized by high drying temperature. Lasseran (1973) assessed that the solubility index of both salt-soluble and alcohol-soluble proteins decrease when the corn drying temperature increases. Unfortunately, the procedure used in his studies did not allow estimating separately the solubility index of albumins, globulins and zein-like proteins.

According to Wall et al. (1975), Wight (1981a), Weller et al. (1988) reported that the combination of high drying temperature and high initial moisture content of grain can damage endosperm proteins and prevent their solubilization during steeping, so the starch granules cannot easily set free during the wet-milling process. Hence, the impairment of the starch/gluten separation could be attributed to the denaturation of endosperms’ proteins, which are mainly alcohol-solubles (Wolf et al., 1975). Haros and Suarez (1997) hypothesized that the difficulty in starch/gluten separation can results from a partial gelatinization of starch granules, a protein denaturation and an endogenous proteolytic enzyme denaturation. Based on this assertion, factors such as the denaturation of proteolytic enzymes, which are mainly hydro-soluble proteins, and partial gelatinization of starch granules would play a significant role in the wet-milling process.
None of the previous studies concerning the impairment of corn wet-milling performance has been based on the concomitant evaluation of the wet-milling performance and the denaturation of specific proteins extracted from kernels dried at more than four different drying temperatures. Neither the work published by Haros and Suarez (1997) nor the one of Haros et al. (2003) concerning the effect of drying temperature on the wet-milling performance of corn grains were focused on the effect of drying temperature on the denaturation of corn protein as the main cause of the impairment of the corn millability. Relationship between the protein solubility index and the wet-milling performance were not investigated in their studies and the small number of drying temperatures tested did not allow to develop a mathematical model describing the effect of drying temperature on the corn millability.

In the present study, in order to evaluate the influence of drying temperatures on the wet-milling performance and to correlate the impairment of the corn millability with the denaturation of specific corn proteins, a laboratory-scale wet-milling procedure and a sequential extraction of corn proteins were performed in parallel. Relationship between the fractions yield by these two fractionations procedures and the drying temperature were determined and fitted using polynomials and a two asymptotic logistic model.

2. Materials and methods

2.1. Materials and samples preparation

The Baltimore variety of flint corn was field grown in 2004 at CRA-Wallon Experimental Station (Gembloux, Belgium). The corn was harvested at approximately 47 g of water per 100 g of dry grain and shipped immediately to the laboratory where it was stored at −18 °C in sealed plastic bag until drying. Before drying, corn was equilibrated to ambient temperature over night. Drying was done in a laboratory fluidized-bed dryer. Approximately 700 g of wet corn were dried in a preheated cylindrical duct, with pulsed air flow. The air velocity was chosen to induce fluidization and ensure a maximal mass transfer between the air and the kernels to maintain all kernels at the same temperature.

Experiments were carried out at temperatures between 54 °C and 130 °C in triplicate and wet corn was used as a control. For each air drying temperature, a specific processing time was chosen in order to obtain final moisture content between 14.8% and 12% on dry basis. A constant drying temperature was regulated by a Proportional–Integral–Derivative (PID) system (Vulcanic, Model 30880, France) and recorded by copper/constant thermocouples connected to a data logger IMPS ORION 3530 (Sollatron-Schlumberger, UK). After drying, kernels were equilibrated at ambient temperature for 10 min and stored in sealed bags at 10 °C.

2.2. Laboratory wet-milling procedure and performance

The wet-milling procedure developed by Neryng and Reilly (1984) was performed with some modifications suggested by Haros and Suarez (1997), Perez et al. (2003), Singh and Eckhoff (1996) and Steinke and Johnson (1991) as previously described (Malumba et al., 2009).

Batches of 500 g of corn were steeped at 50 °C for 48 h in 1.2 L of a solution containing 0.6% (w/v) of bisulfite sodium and 0.05% of lactic acid. Steeped corn was finely ground at 3600 rpm, using a mikrocut grinder (Model MCV12, Stephan Machinery corp., Germany) and then sieved through 0.40 mm and 0.05 mm on a sieve shaker (Model Sweco, Belgium). The fractions that were held up by each sieve were washed with 1 L of distilled water in order to completely separate starch. According to the terminology used by Haros and Suarez (1997), fractions held up by the sieves of 0.4 mm and 0.05 mm were named respectively as “Fiber”, and “Gluten sieved”. In addition, the slurry sieved was decanted during one night at 2 °C and the supernatant was siphoned.

Approximately 2 L of settling residues were dispersed in water and centrifuged twice at 7333g (Sorval RC centrifuge 12BP, USA) for 10 min. After each centrifugation, a supernatant was eliminated; a brownish band of materials from the top layer of the settled starch was scrapped off (gluten scrapped). Therefore, water (1.5 L) was added to the partially cleaned starch, which was sieved again through a small nylon siever (0.40 mm of opening) in order to eliminate the agglomerated residual gluten.

After the freeze-drying and weighing, fractions scrapped off and the one held up by the sieve of 0.05 mm were combined as total gluten recovered. The starch slurry was decanted at 2 °C for 2 h. Settled starch was frozen at −20 °C, and then freeze-dried for 48 h at a pressure <0.1 mbar, using a freeze-dry system Heto (Model DW 8, Allerod, Denmark).

The wet-milling performance was analyzed on the basis of recovering fractions. Starch yield, gluten sieved, gluten scrapped, total gluten recovered, fiber and soluble material contained in all water recovered during the fractionation procedure were expressed as the percentage of dry material recovered from the total corn sample used.

2.3. Sequential extraction of corn protein

The sequential extraction of corn protein was developed by the combining methods which were described by Landry and Moureaux (1970) and Paulis (1982).

Before extraction, the air dried corn was first grounded in a Falling Number laboratory mill (Type 3100, Huddinge, Sweden). Freeze-dried corn was used as control. Twenty grams of ground meals were twice defatted by stirring with 180 mL of 80% hexane + 20% diethyl ether (v/v) for 1 h at ambient temperature and were finely decanted for 30 min. Supernatant was carefully
siphoned and filtered on a Buchner funnel. Solid residues were air dried at ambient temperature before the subsequent protein extractions.

Total water soluble nitrogen-containing substances were extracted by stirring the meal residue of dilapidation with 200 mL of distilled water at 4 °C for 90 min. After 30 min of centrifugation at 10,000g at 4 °C in a Beckman J2-21 centrifuge with a JA14 rotor, water soluble material was separated with residues. This operation was repeated twice with 150 mL of water and all supernatants were combined as the total water soluble nitrogen-containing substances. Albumin was separated with non protein nitrogen-containing materials by precipitation after adding trichloroacetic acid solution. Globulin was separated with non protein nitrogen-containing substances and the difference was considered as albumin material.

The meal residues from water soluble extraction were stirred for 90 min at 4 °C with 180 mL of NaCl 0.5 M and then centrifuged at 10,000g for 30 min. Next, residues were extracted twice under similar conditions. Globulin was separated with non protein nitrogen-containing material by precipitation with trichloroacetic acid as previously described. Subsequently to the sequential extraction of albumins and globulin, a direct extraction of total salt-soluble proteins was performed using the same procedure and solution as for the extraction of globulin. This fraction is a mixture of albumin and globulin extracted by one step procedure.

Next, the meal residues from the total salt-soluble protein extraction were used to extract zein and alcohol-soluble glutelins (also named Zein-like glutelin or glutelin-G1) following the procedure previously described by Malumba et al. (2008).

2.4. Chemical analysis

The kernel’s moisture contents were measured by oven drying at 105 ± 2 °C for 72 h. The moisture content of freeze-dried starches recovered from the extraction procedure was determined by measuring the weight loss of 5 g of the sample after 165 min at 130 °C (ISO 712:1998). Starch yields were calculated on a dry basis as the ratio of the weight of starch recovered to the total weight of the corn sample used on a wet-milling procedure. The starch recovery was calculated as a ratio of the starch yield to the total weight of starch present in the corn. Starch contents of dried kernels and wet-milled starch recovered were measured using the Ewers method (ISO 10520:1997).

The nitrogen contents of soluble from the sequential extraction of corn protein and the residual protein of the wet-milled starch were determined by the Kjeldahl method, with a 2020 Tecator Digester (Tecator, Sweden) and a 2100 Kjeltec distiller (Tecator, Sweden). Proteins were calculated using the general factor 6.25. The proteins solubility index of each specific protein family was calculated as the ratio of nitrogen material recovered in each extract over the total nitrogen contained in kernels.

2.5. Statistical analysis and modelling

Fractionation procedures were carried out at least in triplicate. Statistical analyses were performed using Minitab software (version 14, Minitab Inc., State College, PA). For the correlation analysis and one way ANOVA, a significance level of 95% has been used.

In order to describe the influence of drying temperature on the corn millability, fractions yield from the wet-milling procedure and the solubility indexes of specific corn proteins were fitted against the temperature used for the drying process. Two set of models were used:

- Polynomials model, including their linear, quadratic and cubic expression:

  Linear: $Y = a + bx$  \hspace{1cm} (1)

  Quadratic: $Y = a + bx + cx^2$  \hspace{1cm} (2)

  Cubic: $Y = a + bx + cx^2 + dx^3$  \hspace{1cm} (3)

- A two asymptotic logistic model:

  \begin{equation}
  Y = M_2 + \frac{M_1 - M_2}{1 + \exp([I - X]/r)}
  \end{equation}

With: $Y$ the fraction yield, $x$ the drying temperature; $a, b, c$ and $d$ the polynomial coefficient of the model; $M_1$ the highest asymptotic value of the fraction yield and $M_2$ the lowest asymptotic value, $I$ the temperature at the inflection point of transition and $r$ the range of temperature around the inflection point with significant change of the fraction yield.

Parameters of the models were adjusted by minimizing the root mean square (RMS)

\begin{equation}
\text{RMS} = \sqrt{\frac{\sum (Y_m - Y_p)^2}{n}}
\end{equation}

where $Y_m$ is the experimental value, $Y_p$ the predicted value and $n$ the number of experimental data used to fit the model.

3. Results and discussion

3.1. Influence of air drying temperature on the wet-milling performance

As it was reported by Vojnovich et al. (1975), Wight (1981a), Mistry et al. (1993) and Haros and Suarez (1997), the starch yield obtained by the wet-milling procedure decreased significantly when the drying temperature increased (Table 1). Comparing to the starch yields of undried corn the drop in starch yield was from 20% when the kernels were dried at 110 °C.

Haros and Suarez (1997) observed a decrease of 15.4% in starch yield when drying temperature reached 110 °C. Singh et al. 1998 observed that the drop in starch yields was from 5.8 to 18.2 depending on the corn hybrids variety and the initial moisture content of grain. High initial moisture content of the corn used in the present study may explain drastic decreasing in the starch yield observed.

Mistry et al. (1993) attributed the decreasing of starch yield to the combine effects of the partial gelatinization of embedded corn starch and the protein denaturation caused by the hot air drying. Weller et al. (1988) postulated that the combination of high-temperature and high-moisture conditions damage the endosperm protein and may prevent its solubilization during the steeping, such that the starch could not set free during the wet-milling. A denatured matrix protein may cause incomplete release of starch during the wet-milling process.

Table 1 indicates also that the Percentage of residual Protein in recovered Starch (PPS) increased slightly above 80 °C and was less than 1.5% for all samples analyzed. PPS measured by Haros and Suarez (1997) were generally higher (0.9–5.72 g/100 g of starch) than those observed in the present study (0.69–1.38 g/100 g). The increase of PPS could be explained by the denaturation of proteins from endosperm and their subsequent cross-linking at the surface of starch granules. Debet and Gidley (2007) found that the presence of proteins and lipids on the granule surface are determinant of gelatinized starch granules integrity and robustness, and might modulate the swelling phenomenon of starch during gelatinization.
Table 1
Influence of drying temperature on the yield (%) of various fractions and the percentage of residual protein in recovered starch (PPS) from the wet-milling procedure.

<table>
<thead>
<tr>
<th>Drying temperature (°C)</th>
<th>Drying time (min)</th>
<th>Final moisture content (dry basis)</th>
<th>Starch yield</th>
<th>Gluten sieved</th>
<th>Gluten scrapped</th>
<th>Fibre</th>
<th>Solubles</th>
<th>Total</th>
<th>PPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Untreated</td>
<td>Untreated</td>
<td>47.4 ± 0.6</td>
<td>64.4 ± 0.4</td>
<td>8.1 ± 0.8</td>
<td>9.0 ± 0.8</td>
<td>3.6 ± 0.2</td>
<td>94.8 ± 0.8</td>
<td>0.69 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>240</td>
<td>14.8 ± 0.0</td>
<td>61.4 ± 0.4</td>
<td>8.8 ± 0.3</td>
<td>9.6 ± 0.5</td>
<td>4.2 ± 0.7</td>
<td>94.4 ± 1.3</td>
<td>0.69 ± 0.01</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>180</td>
<td>14.3 ± 0.2</td>
<td>60.5 ± 0.4</td>
<td>10.0 ± 0.7</td>
<td>10.3 ± 0.1</td>
<td>4.9 ± 0.1</td>
<td>95.5 ± 0.1</td>
<td>0.69 ± 0.02</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>120</td>
<td>14.3 ± 0.0</td>
<td>57.8 ± 0.6</td>
<td>10.5 ± 0.1</td>
<td>10.0 ± 0.2</td>
<td>4.1 ± 0.3</td>
<td>91.8 ± 0.1</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>85</td>
<td>13.2 ± 0.0</td>
<td>55.5 ± 0.5</td>
<td>10.5 ± 0.6</td>
<td>11.1 ± 0.3</td>
<td>3.9 ± 0.4</td>
<td>92.0 ± 0.3</td>
<td>0.69 ± 0.00</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>70</td>
<td>14.6 ± 0.1</td>
<td>53.5 ± 0.4</td>
<td>21.3 ± 0.4</td>
<td>10.5 ± 0.3</td>
<td>3.7 ± 0.1</td>
<td>98.7 ± 0.2</td>
<td>na</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>50</td>
<td>11.4 ± 1.1</td>
<td>47.3 ± 0.8</td>
<td>23.2 ± 0.4</td>
<td>12.7 ± 0.8</td>
<td>3.8 ± 0.8</td>
<td>97.3 ± 0.8</td>
<td>0.79 ± 0.04</td>
<td></td>
</tr>
<tr>
<td>110</td>
<td>35</td>
<td>14.2 ± 0.2</td>
<td>44.7 ± 0.5</td>
<td>24.7 ± 2.0</td>
<td>12.5 ± 1.1</td>
<td>3.5 ± 0.1</td>
<td>95.9 ± 3.7</td>
<td>1.38 ± 0.03</td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>30</td>
<td>12.0 ± 0.7</td>
<td>44.5 ± 0.4</td>
<td>24.7 ± 2.0</td>
<td>12.8 ± 1.1</td>
<td>3.8 ± 0.2</td>
<td>94.5 ± 2.1</td>
<td>1.27 ± 0.09</td>
<td></td>
</tr>
<tr>
<td>130</td>
<td>20</td>
<td>14.2 ± 0.4</td>
<td>44.1 ± 0.1</td>
<td>24.1 ± 3.0</td>
<td>9.7 ± 0.5</td>
<td>3.6 ± 0.2</td>
<td>94.8 ± 0.8</td>
<td>0.69 ± 0.01</td>
<td></td>
</tr>
</tbody>
</table>

Table 2
Comparison of RMS of the models used for fitting the corn millability with the temperatures used for drying (n = 25).

<table>
<thead>
<tr>
<th></th>
<th>Two-asymptotic logistic</th>
<th>Cubic</th>
<th>Quadratic</th>
<th>Linear</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch yield</td>
<td>0.185</td>
<td>0.203</td>
<td>0.336</td>
<td>0.362</td>
</tr>
<tr>
<td>Starch recovery</td>
<td>0.365</td>
<td>0.421</td>
<td>0.471</td>
<td>0.487</td>
</tr>
<tr>
<td>Gluten sieved</td>
<td>0.244</td>
<td>0.466</td>
<td>0.623</td>
<td>0.734</td>
</tr>
<tr>
<td>Gluten scrapped</td>
<td>0.152</td>
<td>0.153</td>
<td>0.165</td>
<td>0.165</td>
</tr>
</tbody>
</table>

In contrast with Mistry et al. (1993), fiber fraction recovered in the present study did not vary significantly with the drying temperature. Haros and Suarez (1997) observed that the mean value of recovered fiber fraction of flint corn increased only in the range of 1% when drying temperature reached 110 °C.

3.2. Modelling of the influence of drying temperature on the wet-milling performance

Relationship between starch recovery and drying temperature was fitted using polynomial models and compared with the proposed two asymptotic logistic model (Table 2).

The RMS of models used to fit changes of the wet-milling performance against corn drying temperature showed the necessity of the cubic terms when polynomial models are used. However, a two asymptotic logistic model seems to do slightly better the forecasting of the influence of drying temperature on over the starch and gluten yield (Fig. 1).

Vojnovich et al. (1975) observed a significant correlation between the starch recovery and the drying temperature with a regression coefficient of approximately −0.27%/°C. Weller et al. (1988) observed that the decrease in starch recovery due to the increase of drying temperature was significant, not only linearly and quadratically but also cubically.

Parameters of logistic and polynomial cubic models used to fit relationship between the starch and gluten yield and the corn drying temperature are summarized in the Table 3. This model allows to appreciate the highest (M1) and the lowest (M2) value that the fraction yield can reach when the drying temperature vary. It include also the temperature at the inflection point of transition (I) and the range of temperature (r) around the inflection point which have influence significantly the change of the fraction yield.

It can be observed that the temperatures at the inflection points of fractions yields during the wet-milling were localized between 78 °C and 86 °C. Watson and Hitara (1962) observed that a corn sample dried above 82 °C gave a poor starch–protein separation during the wet-milling.

The smallest value of parameter r in the asymptotic logistic model of gluten sieved describes well the abrupt variation of the amount of this fraction when the drying temperature passes beyond 80 °C. This phenomenon, typical for thermal transitions, is better illustrated by a two asymptotic logistic model than by the polynomial model (Fig. 2).

The increase of gluten recovered, which is mainly composed by proteins when dealing with undried corn, with drying temperature corroborates the assertion that the protein denaturation causes incomplete release of starch granules embedded in the endosperm matrix.

3.3. Influence of drying temperature on the extractability of specific corn proteins

Fig. 3 presents the influence of drying temperature on the solubility index of albumin, globulin, zein and zein-like glutelin (glutelin-G1). The solubility index of albumin, globulin and zein dropped significantly as the drying temperature increased. These results are consistent with those of Wall et al. (1975), McGuire and Earle (1958) and Lasseran (1973).

Albumins appeared as the most readily denatured proteins when the drying temperature increases. The significant denaturation of albumins, even at the drying temperatures which do not affect significantly the corn wet-milling performance, does not allow the use of its solubility index as an indicator of the corn wet-milling performance (Wight, 1981b).

Comparatively to zein, the experimental results did not reveal significant decrease on the extractability of zein-like glutelin. On the other hand the loss of zein could not be explained by new disulfide bonds created when sulphydryl groups are oxidized. Other modifications of zein structure certainly occurred at a high drying
temperature and could contributed to the impairment of corn kernel millability.

3.4. Modelling of the influence of drying temperature on the extractability of proteins

The influence of drying temperature on the extractability of specific corn proteins was approximated using a polynomial cubic and a two asymptotic logistic model. Table 4 summarized parameters of models adjusted.

The RMS values indicate that a two asymptotic logistic model describe well the influence of drying temperature on the extractability of salt-soluble proteins. However, the effect of drying temperature on zein was slightly better described by the polynomial cubic model.

Albumins presented the lowest temperature on its inflexion point (I). According to Wight (1981b), this fact confirmed that albumins are the most readily heat-denatured proteins.

<table>
<thead>
<tr>
<th>Fraction yield</th>
<th>Logistic</th>
<th>Polynornial cubic</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$M_1$ (%)</td>
<td>$M_2$ (%)</td>
<td>I (°C)</td>
</tr>
<tr>
<td>Starch yield</td>
<td>64.26</td>
<td>42.42</td>
<td>85.05</td>
</tr>
<tr>
<td>Starch recovery</td>
<td>91.56</td>
<td>58.29</td>
<td>84.05</td>
</tr>
<tr>
<td>Gluten recovered</td>
<td>18.99</td>
<td>32.44</td>
<td>78.79</td>
</tr>
<tr>
<td>Gluten sieved</td>
<td>9.12</td>
<td>24.46</td>
<td>86.36</td>
</tr>
</tbody>
</table>

Fig. 2. Curve fitting % gluten sieved against drying air temperature.

Fig. 3. Influence of drying temperature on the solubility index of albumin (right-upper), globulin (left-upper), zein (right-lower) and zein-like glutelin (left-lower).
Salt-soluble nitrogen-containing material 18.2 6.3 75.3 15.4 0.016 14.80 0.2416
Starch yield
Globulin 4.3 0.0 101.0 21.9 0.034 3.49 0.0482
Albumin 4.2 1.4 66.8 9.6 0.065 3.56 0.0612
Zein 35.8 6.6 106.2 31.5 0.254 30.44 0.2368

Fig. 4. Relationship between total salt-soluble proteins and drying temperature.

The authors are grateful to Mr. Delimme and Mr. Filocco for their technical assistance. Corn seed used for cultivation were kindly supplied by CIPF (Centre indépendant de promotion fourragère).

4. Conclusion

High drying temperatures induces the insolubilization of the salt-soluble proteins and zein, causing difficulties in the separation of proteins and starch granules during the corn kernels' wet-milling process. According to the drying temperatures used, the corn-starch recovery and the salt-soluble proteins solubility index can be adjusted satisfactorily by using a two asymptotic logistic model. This model has the advantage of supplying information on the dynamic of the variation of described parameters. Correlation coefficients among different fractions extracted from the wet-milling process and the specific protein solubility indexes revealed that the solubility index of total salt-soluble proteins can be used as a suitable parameter to evaluate the severity of thermal treatment endured by the corn during the drying in regard to their wet-milling performance.

Acknowledgements

The authors are grateful to Mr. Delimme and Mr. Filocco for their technical assistance. Corn seed used for cultivation were kindly supplied by CIPF (Centre indépendant de promotion fourragère).

Table 4
Parameters of models used to fit relationships between the solubility of proteins and drying temperatures.

<table>
<thead>
<tr>
<th>Fraction yield</th>
<th>Logistic</th>
<th>Polynomial cubic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M1</td>
<td>M2</td>
</tr>
<tr>
<td>Salt-soluble protein</td>
<td>11.1</td>
<td>1.6</td>
</tr>
<tr>
<td>Albumin</td>
<td>4.2</td>
<td>1.4</td>
</tr>
<tr>
<td>Zein</td>
<td>35.8</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Matrix realized with 14 observations at significant level \( \alpha = 0.05 \).
ns: Non significant.
*** \( P \)-value \( \leq 0.001 \).
** \( P \)-value \( \leq 0.01 \).
\( * \) \( P \)-value \( \leq 0.05 \).

Table 5
Pearson correlation coefficients among different fractions extracted from the wet-milling process and the specific protein solubility indexes.

<table>
<thead>
<tr>
<th></th>
<th>Drying temperature</th>
<th>Starch yield</th>
<th>Gluten sieved</th>
<th>Gluten scrapped</th>
<th>Fibers</th>
<th>Solubles</th>
<th>Albumins</th>
<th>Globulins</th>
<th>Total salt-soluble proteins</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch yield</td>
<td>(-0.973^{***})</td>
<td>(-0.958^{***})</td>
<td>(-0.855^{**})</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gluten sieved</td>
<td>0.886***</td>
<td>(-0.914^{**})</td>
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References


