ESTIMATING THE RELATIVE EFFICIENCY OF SEPARATION BETWEEN ENDOSPERM AND BRAN IN THE WHEAT FLOUR MILLING PROCESS

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ABSTRACT

The aim of the wheat flour milling process, along with the size reduction, is to obtain the best possible dissociation of the starchy endosperm from the other parts of the kernel. Milling tends to concentrate various section of the kernel into different flour mill streams but the complete separation of the anatomic parts can not be achieved. The gradinets of ash, protein and cellulose content increase while the starch content decreases from the center portion to the outer portion of the kernel. Considering the significant differencies between the chemical composition of the kernel layers, distribution of chemical compounds in intermediate, final and subproducts of the milling process come as a result of the level of dissociation achieved during the milling process. These differences serve as a basis for the mill process control. Ash determination is probably the most widely used tool while even greater differencies exist in cellulose and especialy stach content. In this work mathematical model has been defined and used to evaluate the relative efficiency of the separation of endosperm from the outer pericarp leyers of the kernel. The model is based on quantity rates (flour extraction and subproducts yield) and qulitative analyses (starch and cellulose content in the wheat, flour and subproducts).

1. INTRODUCTION

Wheat flour milling is a complex process because, along with the size reduction, efficient removal of the bran and germ from the endosperm of the wheat kernel had to be achieved (Posner & Hibbs, 2005). This is possible due to differences in the structural and mechanical properties between the anatomic parts of the wheat kernel (these differences are exaggerated by adding water to the wheat prior to milling in process known as conditioning), a gradual reduction process consisting of repeated size reduction (roller milling) and separation (sifting) and appropriate adjustment of the roll parameters (Kent, 1975).

The aim of the milling process is to obtain the best possible dissociation of the starchy endosperm from the other parts of the grain to yield the white flour (Antoine et al, 2004). The separation should ideally occur at the level of the endosperm-aleurone layer interface. Although the aleurone layer is part of endosperm, it is separated as part of the bran during the milling process (Peyron et al., 2002).

However, it is impossible to mill flour completely free of bran contamination. Milling tends to concentrate various section of the kernel into different flour mill streams but the complete separation of the anatomic parts can not be achieved. The objective in efficient milling is to approach this goal as closely as possible (Posner & Hibbs, 2005).

Considering the significant differencies between the chemical composition of the kernel layers, distribution of chemical compounds in intermediate, final and by-products of the milling process come as a result of the level of dissociation achieved during the milling process. These differences serve as a basis for the mill process control.

Ash (mineral matter) is concentrated in the bran (with over half the total in the pericarp, testa and aleurone) (Kent,1975) and therefore ash determination is of great value to the miller because it is a relatively accurate index of the separation of endosperm from pericarp and germ in any particular flour. The most widely used single measurement of milling efficiency from a technical viewpoint is accumulated ash curve. This can be constructed form the flow rate, percentage of ash and moisture level of all the mill's intermediate flour streams. The individual flour streams are arranged according to ash content, with lowest-ash flour first. Starting with the two lowest ash streams, a series of calculations is made to determine ash content from blending two streams. (Posner & Hibbs, 2005).
The mill's intermediate flour streams also differ in protein quantity and quality (Nelson et al. 1977), the quantity and properties of the pentosans (Ciacco & D`Appolonia, 1982), contents of free lipids and their fatty acid composition (Prabhasankar et al., 1999; Prabhasankar et al., 2000a; Prabhasankar et al., 2000b), distribution of enzymes (Rani et al., 2001). Jensen et al. (1982) suggested the method for quantifying pericarp, aleurone, and endosperm in wheat milling fractions by their autofluorescence characteristics. Antoine et al. (2004) used starch, phytates, *p*-coumaric acid and dehydrotrimer of ferulic acid as markers to quantify the proportion of starchy endosperm, aleurone cell content, aleurone walls, intermediate layer and outer pericarp in bran products.
However, in the industrial conditions, dealing with day to day problems associated with commercial production, some of this analysis is still impracticable and expensive. Compared to ash content even greater differencies between the anatomic parts of the wheat kernel exist in cellulose and especialy starch content. The idea was to define the simplified model that is relatively easy applicable in industry.

2. BASIC MODEL FOR ESTIMATING THE EFFICIENCY OF SEPARATION BETWEEN TWO COMPONENTS

Assuming that material represents the mixture of two components (component 1 and 2) the aim of separation process is to obtain the best possible dissociation between them. Separation results in two fractions, fraction 1 mainly consist of component 1 and fraction 2 mainly consist of component 2 (Figure 1.).

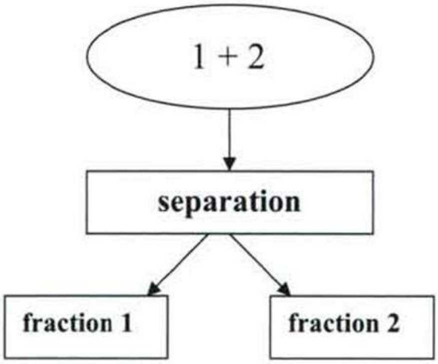

Figure 1. Simplified scheme of the separation process

In ideal situation (complete separation) fraction 1 contains only component 1 (without component 2) while fraction 2 contains only component 2 (without component 1). In reality the complete separation rarely occurs and certain amount of components 2 and 1 are present in fractions 1 and 2 respectively.

The following symbols represent:

Q – mass flow of the native feed
$a_{1/2}$ – content of the components 1 and 2 in native feed
$P_{1/2}$ – mass flow of the fractions 1 and 2
$B_{1/2}$ – yield of fractions 1 and 2 relative to the native feed
φ_{11} – content of the component 1 in fraction 1
φ_{21} – content of the component 2 in fraction 1
φ_{12} – content of the component 1 in fraction 2
φ_{22} – content of the component 2 in fraction 2

having: $a_1 + a_2 = 1$; $B_{1/2} = \frac{P_{1/2}}{Q}$; $B_1 + B_2 = 1$; $\varphi_{11} + \varphi_{21} = 1$; $\varphi_{12} + \varphi_{22} = 1$ (1)

Considering the fraction 1, the efficiency of separation increases with the increase of φ_{11} and decrease of φ_{21} with ideal situation having:

$$\varphi_{11}=1 \text{ and } \varphi_{21} = 0 \tag{2}$$

Considering the fraction 2, the efficiency of separation increases with the increase of φ_{22} and decrease of φ_{12} with ideal situation having:

$$\varphi_{22}=1 \text{ and } \varphi_{12} = 0 \tag{3}$$

The separation efficiency can be defined as a ratio of "achieved level of purity" relative to the "maximum level of purity" (ideal situation). For the fraction 1, achieved level of purity represent difference between φ_{11} and a_1, while for the fraction 2 can be defined as difference between φ_{22} and a_2:

$$\varphi_{11} - a_1;\ \varphi_{22} - a_2 \tag{4}$$

Maximum level of purity corresponds to ideal situation having:

$$1 - a_1;\ 1 - a_2 \tag{5}$$

Eqs. (6) and (7) define the separation efficiency considering fractions 1 and 2 respectively:

$$E_1 = \frac{\varphi_{11} - a_1}{1 - a_1} \tag{6}$$

$$E_2 = \frac{\varphi_{22} - a_2}{1 - a_2} \tag{7}$$

The overall separation efficiency also depends on the yield of fractions 1 and 2 (B_1 and B_2) because high level of purity can be achieved but with cost of low fraction yield. Following the increase of the fraction yield, the relative contribution of achieved separation efficiency considering the observed fraction (E_1 or E_2) to overall separation efficiency (E) also increases:

$$E = B_1 E_1 + B_2 E_2; \qquad E = B_1 \frac{\varphi_{11} - a_1}{1 - a_1} + B_2 \frac{\varphi_{22} - a_2}{1 - a_2} \tag{8}$$

Separation efficiency reaches its maximum with $E = 1$ (following $E_1 = 1$ and $E_2 = 1$) which corresponds to the ideal situation.

3. ESTIMATING THE RELATIVE EFFICIENCY OF SEPARATION BETWEEN ENDOSPERM AND BRAN

To study the effectiveness of the wheat flour milling process one needs quantity rates (break release, flour yield, particle size distribution of the output) and qualitative analyses (ash, protein, starch content in the flour or size fractions of the output etc) (Farrell & Ward, 1965).
Practically, the efficiency of the milling process is influenced both by the yields of the final (B_1) and by-products (B_2) as well as their "purity" or the absence of endosperm in by-products and bran in final products. Most of the approaches use some of the constituents as an indicator of presence of certain grain tissue in flour mill stream. Contrarily this model is based on an absence of certain constituent as an indicator of absence of tissue in the mill stream. Determination of the starch content in the by-products (bran) of the flour milling process serves as a measurement of the loss of endosperm in bran. Determination of flour cellulose content serves as a measurment of bran contamination of the flour.
This is reason why it is necessary first to know starch content (a_1) and cellulose content (a_1^*) in the wheat (native feed). Knowing a_1 and a_1^*, the values of a_2 and a_2^* defined as a content of all other components in the wheat except starch and cellulose respectively, are coming from eq.(1).
The absence of cellulose in flour indicates the high separation efficiency. Presuming ideal dissociation of endosperm and bran, cellulose content in flour is $\varphi_{11}^* = 0$, while the content of all other components in flour (except cellulose) is $\varphi_{21}^* = 1$. Considering flour (fraction 1) separation efficiency can be defined as:

$$E_1 = \frac{\varphi_{21}^* - a_2^*}{1 - a_2^*} \tag{9}$$

Complete separation of the anatomic parts of the wheat kernel also means that there are no endosperm particles in by-products (bran) with starch content $\varphi_{12} = 0$ while the content of all other components (except starch) is $\varphi_{22} = 1$. Considering bran (fraction 2) separation efficiency can be defined as:

$$E_2 = \frac{\varphi_{22} - a_a}{1 - a_2} \tag{10}$$

Having B_1 and B_2 as the yields of the final (flour) and by-products (bran) of the wheat milling process the overall separation efficiency (E) can be defined as:

$$E = B_1 \frac{\varphi_{21}^* - a_2^*}{1 - a_2^*} + B_2 \frac{\varphi_{22} - a_a}{1 - a_2} \tag{11}$$

Separation efficiency reaches its maximum with E = 1 (following $E_1 = 1$ and $E_2 = 1$) which coresponds to ideal situation that is complete separation between endosperm and bran.

Example:

$Starch\ content\ in\ the\ wheat - 65(\%) \Rightarrow a_1 = 0.65 \Rightarrow a_2 = 0.35$

$Cellulose\ content\ in\ the\ wheat - 3(\%) \Rightarrow a_1^* = 0.03 \Rightarrow a_2^* = 0.97$

$Cellulose\ content\ in\ the\ flour(\%) - 0.3(\%) \Rightarrow \varphi_{11}^* = 0{,}003 \Rightarrow \varphi_{21}^* = 0.997$

$Starch\ content\ in\ the\ by-products - 25(\%) \Rightarrow \varphi_{12} = 0.25 \Rightarrow \varphi_{22} = 0.75$

$Flour\ yield - 75(\%) \Rightarrow B_1 = 0.75$

$By-products\ yield - 25(\%) \Rightarrow B_2 = 0.25$

$$E = 0.75\frac{0.997 - 0.97}{1 - 0.97} + 0.25\frac{0.75 - 0.35}{1 - 0.35} = 0.82$$

4. CONCLUSION

The model is relatively easy applicable in milling industry. It is based on the data such as flour and bran yield that are practically determined on a daily bases. Also, today lot of the mills uses NIR technology for real-time, on-line control of the milling process. It can be attached to any spout in the mill for evaluation of the flowing material or flour qualitative characteristics that can influence milling performance. Using NIR it is relatively easy to monitor data such as starch and cellulose content of wheat and end-products. This model offers rapid relative measurement sensitive to changes in the mill in order to make a processing response to these changes.

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REFERENCES

1. Antoine, C., Peyron, S., Lullien-Pellerin, V., Abecassis, J., Rouau, X. (2004): Wheat bran tissue fractionation using biochemical markers. Journal of Cereal Science, 2004:39, 387-393 p.
2. Ciacco, C.F., D'Appolonia, B.L. (1982): Characterization and gelling capacity of water-soluble pentosans isolated from deifferent mill streams. Cereal Chemistry, 1982:59, 163-166 p.
3. Farrel, E.P., Ward, A.B. (1965): Flow rates and analyses for ash and protein of all streams in the Kansas State University pilot flour mill. Association of Operative Millers-Bulletin, 1965:March, 2842-2847 p.

4. Jensen, SV.A., Munck, L., Martens, H. (1982): The botanical constituents of wheat and wheat milling fractions. I. Quantification by autofluorescence. Cereal Chemistry, 1982:59, 477-484 p.
5. Kent, N.L. (1975): Technology of Cereals. Oxford, Pergamon press.
6. Nelson, P.N., McDonald, C.E. (1977): Properties of wheat flour protein in flour from selected mill streams. Cereal Chemistry, 1977:54, 1182-1191 p.
7. Peyron, S., Surget, A., Mabille, F., Autran, J.C., Rouau, X., Abecassis, J. (2002): Evaluation of tissue dissociation of durum wheat grain generated by the milling process. Journal of Cereal Science, 2002:36, 199-208 p.
8. Posner, E.S., Hibbs, A.N. (2005): Wheat Flour Milling. Minnesota, American Association of Cereal Chemists.
9. Prabhasankar, P., Haridas Rao, P. (1999): Lipids in wheat flour streams. Journal of Cereal Science, 1999:30, 315-322 p.
10. Prabhasankar, P., Sudha, M.L., Haridas Rao, P. (2000a): Quality characteristics of wheat flour milled streams. Food Research International, 2000:33, 381-386 p.
11. Prabhasankar, P., Vijaya Kumar, M., Lokesh, B.R., Haridas Rao, P. (2000b): Distribution of free lipids and their fractions in wheat flour milled streams. Food Chemistry, 2000:71, 97-103 p.
12. Rani, K.U., Prasada Rao, U.J.S., Leelavathi, K., Haridas Rao, P. (2001): Distribution of enzymes in wheat flour mill streams. Journal of Cereal Science, 2001:34, 233-242 p.