Effect of Mixing Conditions on the Quality of Dough and Biscuits[1]

A. S. CONTAMINE,[2,3] J. ABECASSIS,[4] M.-H. MOREL,[2] B. VERGNES,[5] and A. VEREL[3]

ABSTRACT

Cereal Chem. 72(6):516–522

The effect of energy input during mixing on the standard French biscuit *petit beurre* was observed by means of an experimental mixer fitted out with monitoring devices. Results showed an energy threshold of ≈60 kJ/kg, beyond which the biscuits retracted and grew thicker. This phenomenon was accurately studied by a rheological and physicochemical characterization of the dough. The viscoelastic properties of the biscuit dough were determined by dynamic measurements on a parallel plate rheometer The parameter tg δ (G''/G') decreased proportionally to the mixing energy, indicating an increase in the elasticity of the material. Consequently, doughs characterized by tg δ values >0.48 are of poor quality, producing short and thick biscuits that are unsuitable for packaging. For low strains, G' is higher than G'', whereas for high strains, the rheological behavior is modified ($G'' > G'$), indicating a change in the structure of the material. The value of the limit deformation D corresponding to the point of intersection of the curves G' and G'' depends on the energy input during mixing. The development of the gluten network was indirectly characterized by continuous measurements of the extractability of lipids by hexane. The more energy is absorbed by the dough and the more the gluten network develops, the smaller the amount of extractable lipids. Doughs that retain <80% of their lipids produce biscuits of poor dimensional stability.

Mixing is one of the key stages in biscuit making. Essentially, the gluten network formed during this phase is responsible for the viscoelastic properties of the dough and determines its machinability as well as the final quality of the biscuits. The quality of bread and biscuit dough depends on mixing conditions (mixer type, rotation speed, mixing time, and water content) and characteristics of the flour used (Wade and Davis 1964, Kilborn and Tipples 1972, Olewnik and Kulp 1984).

For semi-sweet biscuit dough, such as the French biscuit *petit beurre* (35% sugar, 17% fat, and 20% water, in proportion to the total flour weight), the development of the gluten network is limited (Wade 1988). Consequently, the doughs obtained are sufficiently extensible to be easily sheeted, without being so elastic that it prevents the biscuits from retracting after cutting. The absence of retraction is considered a factor of good quality; it determines the potential of the biscuits for packaging. This article assesses the effect of dough-making parameters on the dimensional stability of the biscuits and defines the relationship between the observed phenomena and the rheological characteristics of the dough, as well as the extractability of lipids by hexane, which is known to decrease in bread dough after water absorption and mixing (Olcott and Mecham 1947, Chung and Tsen 1975, Wood et al 1975).

MATERIALS AND METHODS

Flour

A soft wheat flour (cv. Apollo) of biscuit-making quality was provided by the Grands Moulins de Paris. Protein content (9.9% dwb) was determined by the Kjeldahl method; damaged starch content (7.6%) was measured by amperometry (SD4 Chopin, AACC units); water absorption capacity (54.4%) was determined on the Brabender Farinograph (AACC 1983); and alveographic Chopin measurements ($W = 138$, $G = 19.4$, $P = 54$, $P/L = 0.72$) were obtained by the standard method (AACC 1983). The levels of total (17% dwb) and water-soluble pentosans (0.46%) were obtained by adding the concentrates of water-free xylose and water-free arabinose and measuring by vapor phase chromatography (Blakeney et al 1983).

Equipment

An experimental, horizontal type, biscuit mixer capable of mixing 6 kg of dough (De Vuurslag, Roosendaal, The Netherlands), with a uniaxial arm and variable speeds (0–250 rpm), was used for the testing. The mixer was fitted out with a double jacket allowing temperature regulation by circulation of heated water, so that the bowl temperature was maintained at 27.5°C. Thermal and mechanical power consumption was measured by two thermocouplings set on the bottom of the bowl and a torque sensor (Beta N-1350, 100 daN) perpendicular to the floating motor axis. Data were relayed to a data acquisition system (AOIP SAM 80) linked to personal computer. The amount of specific mechanical energy absorbed by the dough (measured in J/kg) was calculated as:

$$E = CNt/M$$

where C is the average torque (N·m), N is the angular velocity (rad/sec), t is the mixing time (sec), and M is the weight of the mixed dough (kg). The amount of heat absorbed by the dough during mixing was determined by calculating the difference between the temperatures of the dough at the beginning and the end of the mixing (°C), multiplying by the heat capacity of the dough (calculated as the weighed sum of the heat capacity of each component: 1.90 J/g/°C) and multiplying by the weight of the mixed dough.

Method

The dough formula duplicated the French *petit beurre* biscuit formula (flour weight basis): 17.7% fat, 35% sugar, and 2.4% leavening agent. Technological parameters such as water content, mixer speed, and mixing time were varied. These factors were tested by an experimental central composite fractional design at three factors and two levels (Box et al 1978). Therefore, the water content of the doughs ranged between 16.3 and 23.1%, based on flour weight; the mixing speeds ranged from 53 to 187 rpm; and the mixing time varied from 200 to 700 sec. After mixing, doughs were sheeted 2-mm thick by a pilot-scale sheeter (R-Tech, Wigan, Great Britain), then punched out by hand using a rectangular cutter. The biscuits were baked at 250°C for 7 min in a domestic

---

[1] Supported by a grant of the French Research and Technology Ministry, Aliment Demain program.

[2] INRA-Laboratoire de Technologie des Céréales, Montpellier, France.

[3] BSN-Branche Biscuits, Athis-Mons, France

[4] Corresponding author: INRA-Laboratoire de Technologie des Céréales, 2 place Viala 34060 Montpellier, France. Fax: 67.52.20.94.

[5] CEMEF, Ecole des Mines de Paris. Sophia Antipolis, France.

oven (Arthur-Martin). The specific mechanical energy transferred to the dough and the temperature were measured during mixing. After mixing, about 20 g of dough were immediately frozen in liquid nitrogen and kept at −18°C for the lipid extraction by hexane. Viscoelastic characteristics of the dough were determined on samples of dough shaped by compression directly after mixing, or possibly after a given rest time. Finally, the biscuits were characterized by their size (length, width, thickness, and volumic mass).

Viscoelastic Properties of Doughs

The viscoelastic properties of the dough were measured in small deformations using a parallel plate rheometer (RMS 800, Rheometrics) at 20°C with parallel plate geometry (25-mm plate radius). The doughs were shaped by compression between two plates to obtain dough pieces of constant thickness (6.5 mm ± 0.5). Dynamic measurements were achieved by both frequency sweep (1–100 rad/sec at 0.2% deformation) and deformation sweep (0.2–20% at 1 rad/sec).

Lipid Content Extractable by Hexane

The frozen dough samples were thawed at ambient temperature. Dough (6 g) was weighed in a 50-ml centrifuge Teflon tube (Nalgène); 20 ml of *n*-hexane was added. The test tube was then spun in a rotating stirrer (30 rpm, position 2,) (Reax 2, Heildoplh) for 1 hr at 40°C and centrifuged at 1,000 × *g* for 10 min. The supernatant was gathered, then evaporated at 70°C until the hexane completely disappeared. The dry residue, corresponding to the soluble lipid content of the hexane (lipids added to the dough and flour lipids), was weighed. To normalize the extraction conditions, lipids were extracted from three samples (Table 1) obtained in different conditions, with different hexane volumes (10, 20, and 30 ml) and different spinning times (15, 60, and 120 min). The dough-to-solvent ratio (20:6), as well

TABLE I
Duplicating the Measurements of Fat Extractability on Three Samples from the Same Dough

Sample	Rate of Lipids Extracted (%)
1	36.7
2	41.2
3	38.8
Average	38.9
Standard deviation	1.9
Variation coefficient (%)	4.8

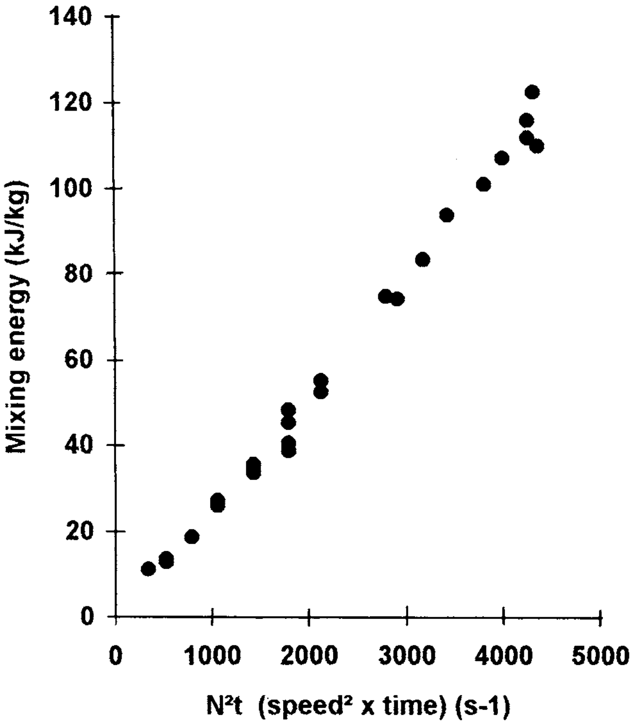

Fig. 1. Relationship between specific mixing energy (kJ/kg) and mixing time multiplied by the square of the rotation speed *(N ²t)*.

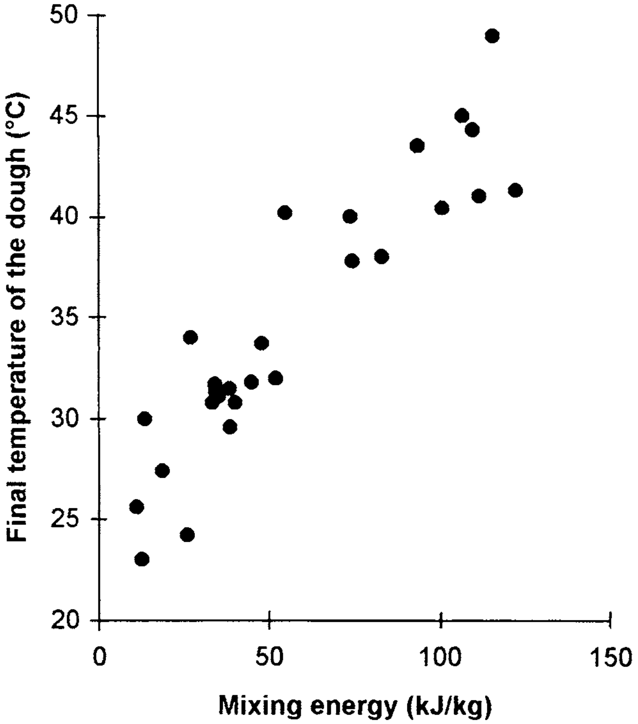

Fig. 2. Variation of the final temperature of the dough in relation to mixing energy.

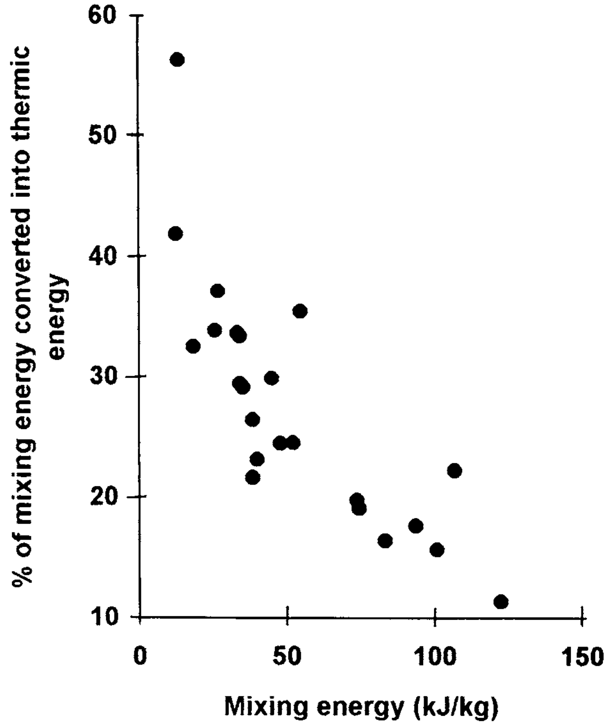

Fig. 3. Variation of the percentage of specific mechanical energy converted into thermal energy during mixing, in relation to specific mechanical energy.

as the spinning time (60 min), were determined for discriminant and duplicable results.

RESULTS AND DISCUSSION

Effect of Mixing Conditions on Specific Mechanical Energy

In our experimental conditions, the dough water content has virtually no effect on the specific mechanical energy absorbed during mixing; however, this parameter is strongly related to mixer speed and mixing time. The specific mechanical mixing energy increases steadily in proportion to mixing time, while its evolution is quadruple in proportion to mixer speed. This can be easily accounted for by considering dough as a viscous fluid. The deformation energy by volume unit is:

$$\eta\gamma^2 t$$

where η is the viscosity, t is the mixing time, and γ is the shear rate, which can be considered as directly proportional to the rotation speed N. Figure 1 shows that a fairly good linear correlation (r^2 = 0.989) effectively exists between the measured mixing energy and the N^2t factor. The final temperature is highly correlated with the mixing energy. For intense mixing, the latter can reach 45°C (≈20°C above the regulated mixer-bowl temperature) (Fig. 2). This calculation shows that 25–60% of the energy provided to the dough is turned into heat energy, thus participating in the heating of the dough (Fig. 3). The higher the specific energy, the more effective the mechanical energy is in making the dough and developing the protein network.

Effect of Mixing Energy on Biscuit Size

The effects of speed and mixing time were globally investigated through the influence of mixing energy on the final quality of the biscuits. As more energy is absorbed by the dough during mixing, the biscuits obtained are shorter and thicker (length 63–71.5 mm, thickness 5.6–12 mm). Width was virtually insensible to mixing conditions. The relationship is illustrated in Figure 4, which represents the variation of the length and thickness of the biscuits in proportion to the specific mixing energy. Whatever the water level, two different stages can be described: 1) at 10–60 kJ/kg the size of the biscuits remains unchanged; 2) beyond this threshold, a second stage produces short and thick biscuits unsuitable for packaging. Therefore, the dimensional stability of biscuits is strictly dependent on the energy absorbed by the dough. In all likelihood, these results are correlated to a given stage of the dough development. To identify this point, we tried to determine the evolution of the rheological properties in relation to mixing conditions.

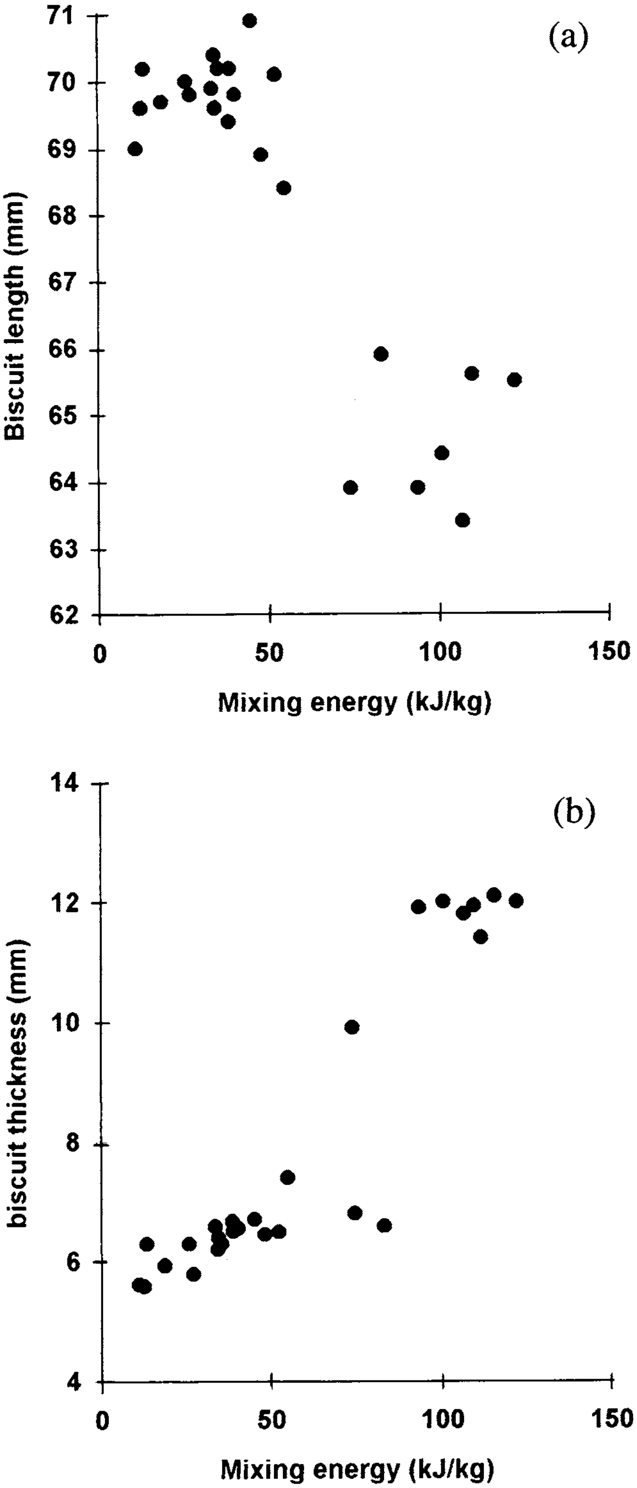

Fig. 4. Effect of the amount of energy absorbed by the dough on biscuit length (**a**) and thickness (**b**).

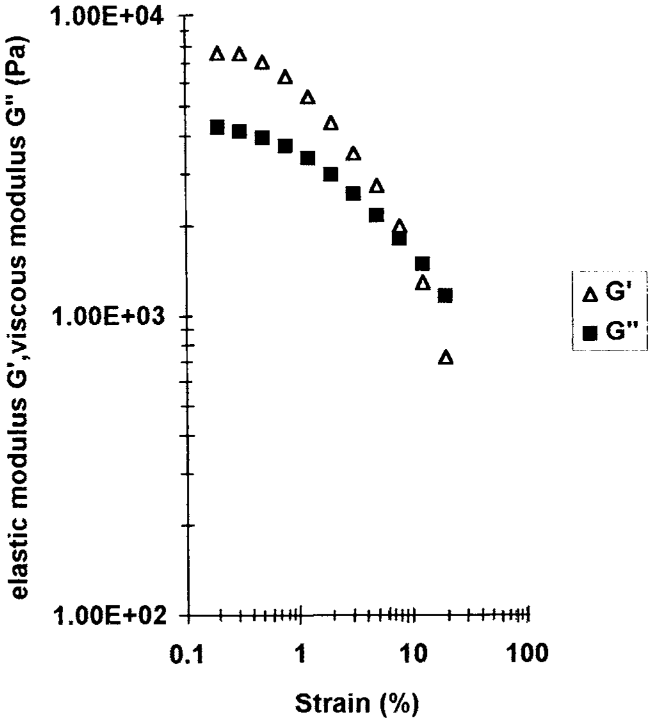

Fig. 5. Variation of the elastic (G') and viscous (G'') moduli with the deformation (ω = 1 rad/sec).

Rheological Behavior of Biscuit Dough

Because biscuit dough has a strong nonlinearity and lengthy evolution, the determination of its viscoelastic behavior poses a few experimental problems and must be done carefully. Dough rheological behavior constantly evolves during rest time, even for several hours. Such evolution may also go on during the measuring stage; therefore, the experimental protocol was dealt with very accurately, and the time of measurement was closely checked to determine the main characteristics of the rheological behavior precisely.

Linear region determination. Biscuit dough is characterized by highly nonlinear viscoelastic behavior. Actually, the dough shows almost linear behavior; G' and G'' values are independent from deformation in a region of very low strains (<0.25%) (Fig. 5). These results are very close to those already found for bread doughs (Dus and Kokini 1990, Weipert 1990, Berland and Launay 1992).

Evolution of G' and G'' moduli in relation to frequency. For any frequency applied in this range (1–100 rad/sec), the elastic modulus G' is always higher than the viscous modulus G''. Thus, the dough behaves as a viscoelastic structured body. When the applied frequency increases, the G' and G'' moduli increases, while the parameter tg $\delta = G''/G'$ reaches a minimum nearing 3 rad/sec before increasing again (Fig. 6). The complex viscosity η^* decreases together with the frequency (Fig. 7) following a power law with a pseudoplastic index m close to 0.25. This can also be compared to the behavior of bread doughs (Dus and Kokini 1990, Berland and Launay 1992).

Evolution of G' and G'' moduli in relation to strain. Beyond the linear region, G' and G'' decrease as the deformation increases. However, at low strains, G' is higher than G'', while at higher strains G'' becomes dominant (Fig. 5). It appears that the D point of intersection of the curves ($G' = G''$) can be relied on to assess the strength of the protein network as it corresponds to the turning point between a gel-like behavior and a fluid-like one. This structural change consequently leads to a loss of elasticity that could be due to the breaking of some bindings within the network. Then the dough becomes viscous and easily extensible, presenting minimum elastic retraction after deformation. Such a quality could be of value for the shaping of the dough after sheeting. This specific deformation D allows us to characterize the structural state of the dough. It is worth noting that for bread dough, D is close to 100% (Dus and Kokini 1990, Berland and Launay 1992), while it reaches only 22% for our biscuit dough.

Effects of Mixing Conditions on Dough Viscoelastic Properties

Even though the general behavior of the doughs remains constant for all the materials studied, the viscoelastic properties are strongly influenced by mixing conditions: when the water content increases, the G' and G'' moduli as well as the η^* viscosity decrease, which is in accordance with previous works (Dreese et al 1988, Berland and Launay 1992, Navickis et al 1992). On the whole, both viscosity and elasticity decrease as the dough water content increases. However, tg δ (the proportion between the viscous and elastic moduli at 10 rad/sec) decreases, indicating the development of some elastic network (the elastic modulus undergoes a slower decrease than the viscous one). Finally, the limit deformation D raises together with water content indicating a better resistance of the material to deformation, resulting in a stronger dough.

Other factors, such as speed rotation and mixing time also entail modifications of the previously quoted parameters. The G' and G'' moduli, as well as tg δ, decrease as either mixing time or speed increase. Therefore, the formed network appears to be more elastic. These results were also observed for bread doughs (Bohlin and Carlson 1980, Navickis 1989).

Among the viscoelastic characteristics we studied, tg δ is the most strictly correlated to the amount of energy absorbed during mixing. Thus, as the energy and water content increase, tg δ decreases (Fig. 8), indicating an increased elasticity of the dough. This must be due to the increasing development of the gluten network, which is usually prevented by the reduced water availability of biscuit doughs.

When the mixing energy is increased, resulting in a more elastic dough, the gluten network is also strengthened. As shown in Figure 9, the limit deformation D progresses almost in linear relationship with the amount of energy provided to the dough.

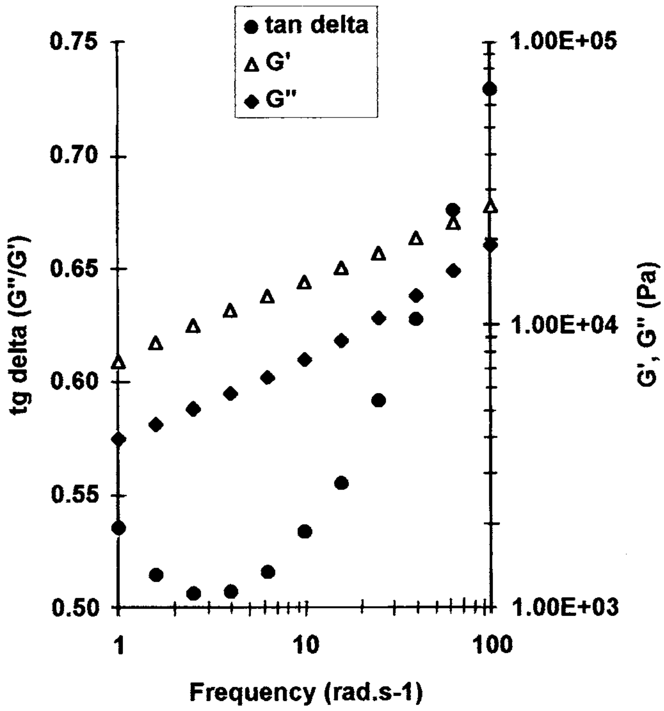

Fig. 6. Variation of the elastic (G') and viscous (G'') moduli as well as tg δ (phase lag angle) with the frequency $\gamma = 0.2\%$.

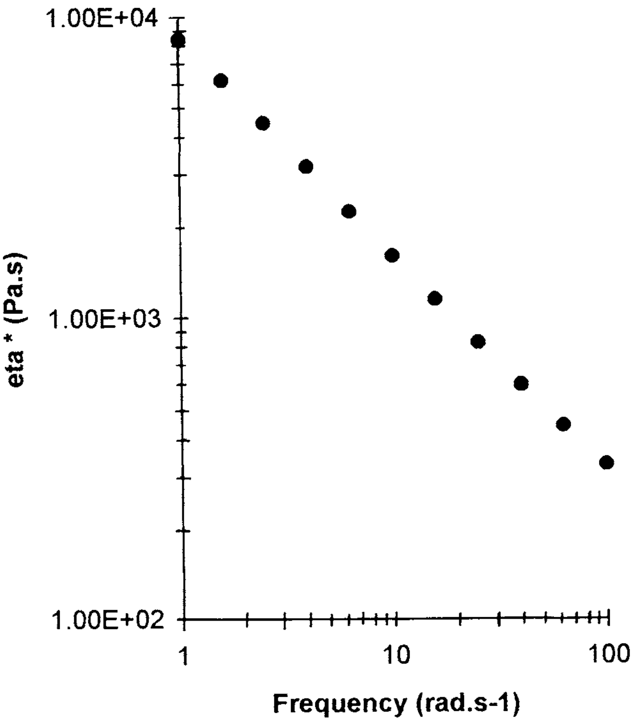

Fig. 7. Variation of complex viscosity η^* with the frequency $\gamma = 0.2\%$.

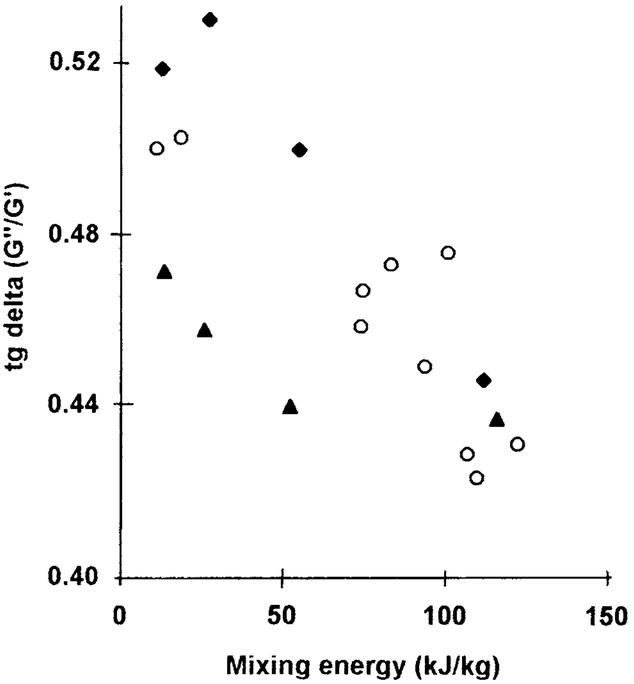

Fig. 8. Effect of mixing energy on tg δ in relation to dough water (♦ 17.7%, ○ 19.7%, ▲ 21.7%).

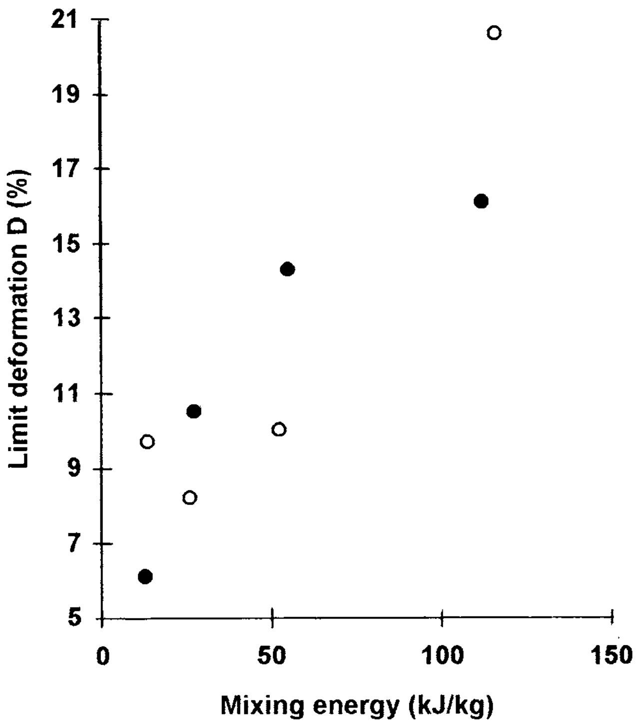

Fig. 9. Effect of mixing energy on the limit deformation *D* in relation to dough water (● 17.7%, ○ 21.7%).

Therefore, the structural state of the dough varies in relation with mixing conditions. Dough structural resistance to deformation is proportional to the energy transferred during mixing. Such properties will obviously have an important impact on the subsequent shaping of the material (sheeting and cutting).

Relationship Between Rheological Characteristics of Dough and Quality of Biscuits

The evolution of the biscuit length related to the proportion $G''/G' = \text{tg } \delta$ shows the existence of an elasticity threshold for the material corresponding to tg δ = 0.48, beyond which the biscuits retract significantly (Fig. 10) and become too thick. Remember that the increase of thickness only appears after baking, not after sheeting. These findings are due to the development of a gluten network presenting quite an important capacity for retaining the gas produced by the degradation of leavening agent during baking. The material can also become fixed in such a structural state that it remains very developed and expanded and does not collapse during the final stage of the baking as good quality biscuits normally do. Moreover, this gluten network is sufficiently elastic to bring about a longitudinal reaction of the biscuits when oriented under the effect of sheeting.

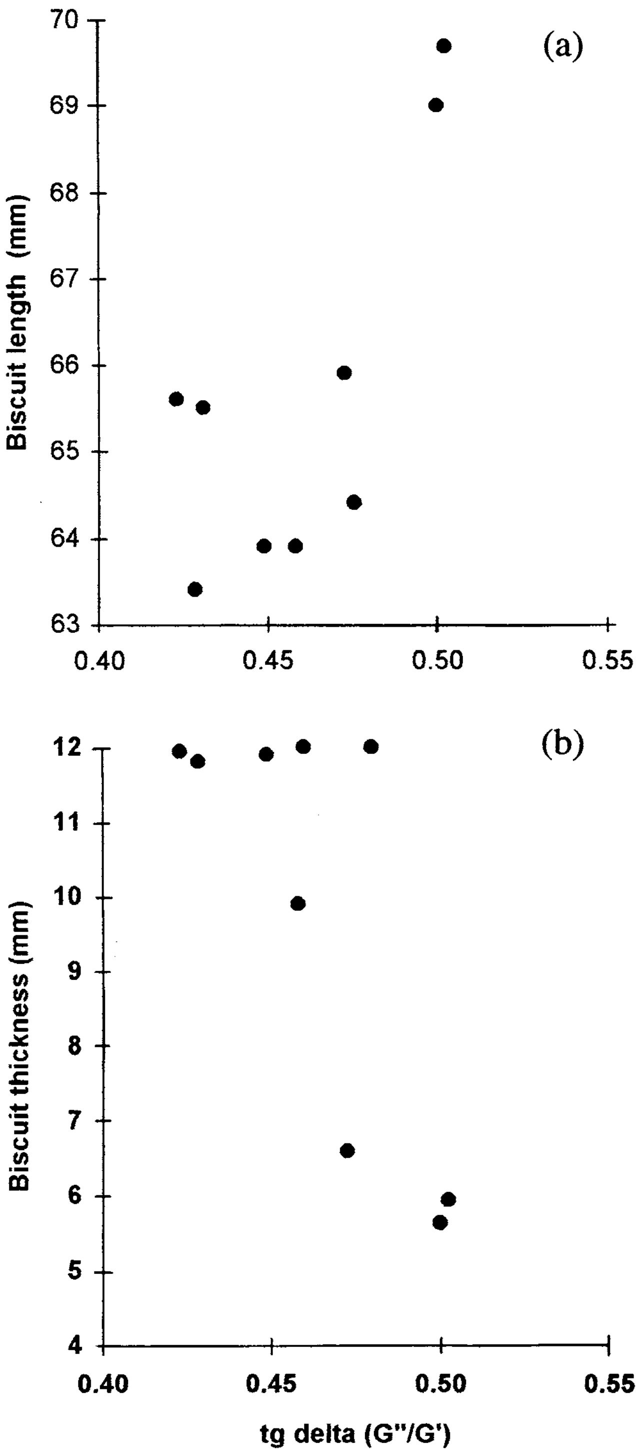

Fig. 10. Variation of biscuit length (**a**) and thickness (**b**) in relation to tg δ with constant added water (*H* = 19.7%).

Effect of Mixing Energy on Extractability of Lipids by Hexane

Lipids can be easily extracted from freeze-dried and ground doughs, but extraction from moistened dough (frozen immediately after mixing, then thawed before measurement) appeared to be dependent on mixing energy. Depending on mixing conditions, particularly on energy, the levels of lipids extracted in proportion to the quantity of lipids added to the dough ranged from 87% for a poorly mixed dough to 5% for an intensely mixed dough. Figure 11 shows that the percentage of extracted lipids decreases as the mixing energy is increased. The percentage continuously decreases, then the content of extracted lipids stabilizes at ≈10% for energy inputs of 60 kJ/kg and over. The comparison between these results and those of Figure 4 shows that good quality biscuits are produced by doughs retaining 40–75% of initial lipid content. Therefore, dough will produce good-sized biscuits as long as a decrease in bound lipids can be observed. But as soon as the quantity of bound lipids stops decreasing, whatever the energy input, the biscuits obtained will be both retracted and thick. These findings are in accordance with the results obtained in breadmaking technology by Chung and Tsen (1975), who found that approximately one third of the lipids remain free when the dough is mixed at optimum conditions and that proportion is not changed by increasing the mixing time. Similar results were also presented by Chiu and Pomeranz (1966).

The quantity of lipids extractable by hexane allows prediction of the final quality of the biscuits and can follow the development of the dough during mixing. The diminution of the extractability of lipids during mixing can be explained by three hypotheses. First, the lipids are physically trapped by the emergence of some network limiting the diffusion of both hexane and lipids. Second, strong interactions may take place between lipids and other flour constituents (especially proteins), as Frazier (1983) showed in a study on lipid-protein interactions during bread dough development. In a study on bread dough, Wood et al (1972) assumed that a better free water distribution during dough mixing could cause an increase in the ratio of bound lipids, consequently attributing a predominant part to the development of the gluten network to explain the decrease of free lipids content. Third, lipid emulsion may appear in the shape of small drops in a more or less continuous stage mainly constituted of water, proteins, and starch. Flint et al (1970) effectively showed that the more the gluten network develops, the more homogeneous is the distribution of the fat vesicles and the smaller their size. Investigations are being made to understand the process that takes place during the binding of lipids all through the mixing.

CONCLUSIONS

The amount of energy transferred to the dough appears to be an essential element of mixing, as its influence is determinant of the biscuits dimensions (length and thickness). Moreover, an energy input threshold of ≈60 kJ/kg has been identified. Beyond this threshold, the dimensional parameters become highly unpredictable and the biscuits produced are unsuitable for packaging. Such disruption in the biscuit quality is accompanied by alterations in the rheological behavior of the dough as well as modifications of the physicochemical parameters. The dough becomes more elastic (tg $\delta < 0.48$) and more resistant to strains, consequently losing its softness during sheeting due to the overdevelopment of the gluten network. Finally, continuous measurements of the extractability of lipids by hexane show that binding is proportional to the amount of energy provided to the dough during mixing. Therefore, a high lipid retention (85%) indicates a poor quality dough, producing biscuits of unacceptable standard. Conversely, good quality doughs are characterized by a lipid extractability of 40–75%.

On the whole, these findings confirm that a biscuit dough must be poorly elastic but sufficiently supple and extensible to allow an easy and stable shaping of the material. Accordingly, the gluten network is to be slightly developed for the dough to be cohesive without being too elastic.

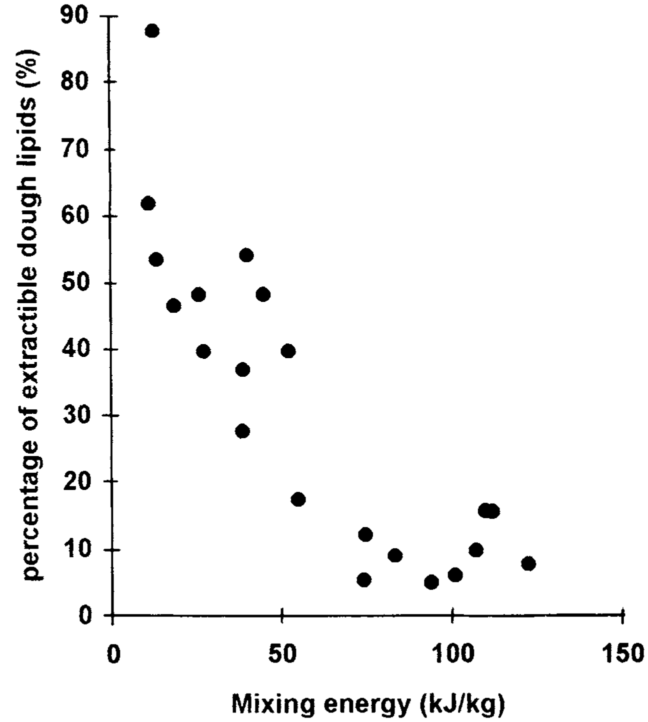

Fig. 11. Effect of mixing energy on the amount of lipids extractable by hexane (in percentage of lipids added to the dough).

LITERATURE CITED

AMERICAN ASSOCIATION OF CEREAL CHEMISTS. 1983. Approved Methods of the AACC, 8th ed. Method 54-21; Method 54-30. The Association: St Paul, MN.

BERLAND, S., and LAUNAY, B. 1992. Definition of a new structure parameter of dough from an extended Cox-Merz rule. Int. Cereal Bread Congress: Paris.

BLAKENEY, A. B., HARRIS, P. J., HENRY, R. J., and STONE, B. A. 1983. [Need title]. Carbohydr. Res. 113:291-299.

BOHLIN, L., and CARLSON, T. L. G. 1980. Dynamic viscoelastic properties of wheat flour dough: Dependence on mixing time. Cereal Chem. 57:174-177.

BOX, G., HUNTER, W., and HUNTER, J. 1978. Statistics for experimenters: An introduction to design, data analysis, and model building. John Wiley and Sons: New York.

CHIU, C. M., and POMERANZ, Y. 1966. Changes in extractability of lipids during breadmaking. J. Food Sci. 31:753.

CHUNG, O. K., and TSEN, C. C. 1975. Changes in lipid binding and distribution during dough mixing. Cereal Chem. 52:533-548.

DREESE, P. C., FAUBION, J. M., and HOSENEY, R. C. 1988. Dynamic rheological properties of flour, gluten, and gluten starch doughs. II: Effect of various processing and ingredient changes. Cereal Chem. 65:354-359.

DUS, S. J., and KOKINI, J. L. 1990. Prediction of the non-linear viscoelastic properties of hard wheat flour dough using the Bird-Carreau constitutive model. J. Rheol. 34:1069-1084.

FLINT, F. O., MOSS, R., and WADE, P. 1970. A comparative study of microstructure of different types of biscuits and their doughs. FMBRA Rep. 44.

FRAZIER, P. J. 1983. Lipid-protein interactions during dough development. In: Lipids in Cereal Technology. P. Barnes, ed. Academic Press: London.

KILBORN, R. H., and TIPPLES, K. H. 1972. Factors affecting mechanical dough development. I. Effect of mixing intensity and work input. Cereal Chem. 49:34-47.

NAVICKIS, L. L. 1989. Rheological changes of fortified wheat and corn flour doughs with mixing time. Cereal Chem. 66:321-324.

NAVICKIS, L. L., ANDERSON, R. A., BAGLEY, E. B., and JASBERG,

B. K. 1982. Viscoelastic properties of wheat flour doughs: Variation of dynamic moduli with water and protein content. J. Text. Stud. 13:249-264.

OLCOTT, H. S., and MECHAM, D. K., 1947. Characterization of wheat gluten. I. Protein-lipid complex during doughing of flours. Lipoprotein nature of the glutenin fraction. Cereal Chem. 24:407.

OLEWNIK, M. C., and KULP, K. 1984. The effect of mixing time and ingredient variation of farinograms of cookie doughs. Cereal Chem. 61:532-537.

WADE, P. 1988. The principles of the craft. In: Biscuits, Cookies and Crackers, Vol.1. Elsevier Applied Sciences: London.

WADE, P., and DAVIS, R. I. 1964. Energy requirements for the mixing of biscuit doughs under industrial conditions. BBIRA Rep. 71.

WEIPERT, D. 1990. The benefits of basic rheometry in studying dough rheology. Cereal Chem. 67:311-317.

WOOD, P. S., DANIELS, N. W. R., and GREENSHIELDS, R. N. 1972. The effect of water on lipid binding in dough mixed to low work levels. J. Food Technol. 7:183-189.

[Received December 19, 1994. Accepted June 13, 1995.]