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EFFECT OF VIBRATION FREQUENCY AND EXPOSURE TIME ON THE TECHNOLOGICAL USABILITY OF FRESH MILK

Magdalena Warmińska, Antoni Kruk, Waldemar Brandt

Department of Dairy Science and Quality Management, University of Warmia and Mazury in Olsztyn, Olsztyn

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A study was undertaken in order to monitor the effect of vibrations with variable frequency (10–60 Hz) and different times of exposure to vibrations (30 and 120 min) on changes in selected physicochemical properties of milk, especially those determining its technological usability.

Vibrations were found to negatively affect the properties of milk significant from the technological point of view, producing a slight increase in its acidity and conductance, a decrease in thermal and ethanolic stability as well as a reduction in the time of rennet coagulation of raw milk, among other effects.

The changes of the analysed milk traits as affected by vibrations were observed to depend on the frequency band applied and to intensify with an increasing frequency and elongated time of milk exposure to vibrations, thus exerting a significant, negative impact on its technological usability.

INTRODUCTION

A crucial element in determining the quality of raw milk is its transportation, since it results in a number of mechanical hazards, mainly vertical and horizontal vibrations of high frequencies. Through a negative effect on the main constituents of milk and its biostructure [Warmińska & Kruk, 2001b; Warmińska *et al.* 2003 a,b; Palich, 1993], these hazards may reduce, to various extents, the quality and technological usability of the raw material. This, in turn, may hinder technological processing and deteriorate the quality and shelf life of the finished products.

The significance of issues raised, as well as relatively sparse and the generally fragmentary studies carried out so far in this area point to the need to extend research into the effect of mechanical hazards, especially vibrations, on the properties of milk. A study was undertaken, therefore, to monitor the impact of the time of milk exposure to vibration with variables frequency ranging from 10 Hz to 60 Hz on changes in its selected physicochemical properties.

MATERIAL AND METHODS

Material. The experimental material was raw bulk milk with a regular chemical composition and of high microbiological quality, obtained from morning milking. The milk was sampled immediately after milking in a private farm located *ca.* 10 km from a laboratory of the Institute of Dairy Science Development, University of Warmia and Mazury in Olsztyn. The milk to be analysed was collected in a plastic container, each time filled up to the total volume (with no space left). Next, the milk was immediately transported to the laboratory and subjected to analyses.

Raw cowshed milk was subjected to preliminary physicochemical and microbiological evaluation, and then normalized to 3.5% fat content and preserved with a 2% solution of sodium azide applied at a dose of 1 mL per 1 L of milk.

Organization of the experiment. In the experiment into the effect of vertical vibration on the technological usability of milk, use was made of vibratory acceleration of 1 g and vibration frequency was changed in 10 Hz intervals from 10 to 60 Hz. These parameters were applied based on the results of previous investigations [Warmińska & Kruk, 2001a]. Vibration was run at a constant volume of the container (80%) and variable time of milk exposure to vibration – 30 and 120 min. One portion of milk not exposed to vibration served as a control sample.

Vibrations were simulated on an oscillator (VEB Schwingungstechnik und Akustik WIB), by differentiating the levels of vibration frequency with a decade frequency oscillator made in Poland (RC, type PW – 9), coupled with a power amplifier (Leistungsverstärker 3Ω, 50 W, 3 Hz – 40 kHz, type LV 102, made by VEB Metra Mess und Frequenztechnik). Measurements of vibrations were carried out with a KD 13/08 774 piezoelectric sensor cooperating with oscilloscopic vibration meter Schwingungsmessgerät type VM 6 (VEB Metra Mess und Frequenztechnik).

Range of analyses and analytical methods. Samples of vibrated and control milk were determined for: active acid-

Author's address for correspondence: Antoni Kruk, Department of Dairy Science and Quality Management, University of Warmia and Mazury, ul. Heweliusza 1, 10-957 Olsztyn, Poland; tel.: (48 89) 523 34 48; e-mail: antoni.kruk@uwm.edu.pl

ity with a CG 840 pH-meter and potential acidity °SH; conductance with an inoLab Cond Level 1 conductometer; ethanolic stability as the alcohol number by titration of 10 cm^3 of milk with 96% ethyl alcohol [Kruk *et al.*, 1979]; thermal stability as the time of thermal coagulation of milk at a temperature of 140°C [Kruk *et al.*, 1979], and rennet coagulation of milk with the method of Alais [1961].

The experimental data obtained were elaborated statistically. Changes in the analysed traits of milk depending on the frequency bands and exposure time applied were described with the use of the linear correlation coefficient of Pearson and the analysis of regression which demonstrated that in each case the changes of the traits analysed may be described with the following function: $y=a+bx$. The strength of the relationship between variables was expressed by means of correlation and determination coefficients.

RESULTS AND DISCUSSION

The research was aimed at evaluating the effect of vibrations on changes in selected properties of milk, with special attention paid to those that affect its technological usability.

The impact of vibrations on milk properties is reflected in changes in milk acidity which is one of the key technological factors determining the behavior of milk in different production processes. The potential acidity of the examined milk samples exposed to vibrations was observed to increase with an increasing vibration frequency and elongated time of exposure, reaching values higher than the initial ones by 0.8 °SH on average after 120 min of milk exposure to vibrations with a frequency of 60 Hz (Figure 1A).

Changes in the active acidity of milk subjected to vibration were the living image of the changes in the potential acidity, since pH values of milk were reported to decrease with an increased frequency of vibration and extended exposure time. Vibrations decreased the pH values at higher frequencies After 30-min vibration at a frequency of 60 Hz, the pH value of milk dropped to 6.70, whereas in the control sample it accounted for 6.78. The elongation of the time of exposure to vibration up to 120 min resulted in a successive pH decrease, *i.e.* to a value of 6.64 (Figure 1B).

The reason for changes in milk acidity, as affected by its exposure to mechanical hazard, is probably the unfolding of protein molecules and the resulting exposure of the polar group. All negatively-charged groups exposed outside the protein molecules determine the potential of the system and, consequently, its stability. The unfolding of protein structure is accompanied by interactions of proteins and the formation of new bonds. The unfolded protein may form new hydrogen and hydrophobic bonds between several protein molecules. As a result of these interactions, the surface of micelles is covered with whey proteins or aggregates of these proteins. This results in an increased number of positive charges of protein and decreases the availability of the polar groups of colloidal calcium caseinate [Singh & Creamer, 1991; Palich, 1993].

The changes in milk acidity observed in the study are also likely to result from alterations in the salt system as affected by vibrations [Warmińska *et al.,* 2001b]. The level and proportions of soluble salts in milk affect, to a great extent, its acidity. A special role is ascribed to the level of soluble phosphates and citrates as well as Ca^{2+} ions. A part of micellar calcium phosphate, while being transferred to a soluble phase as a result of vibrations, increases the concentration of Ca^{2+} ions and, by breaking the structure of micelles, considerably affects the acidity of milk.

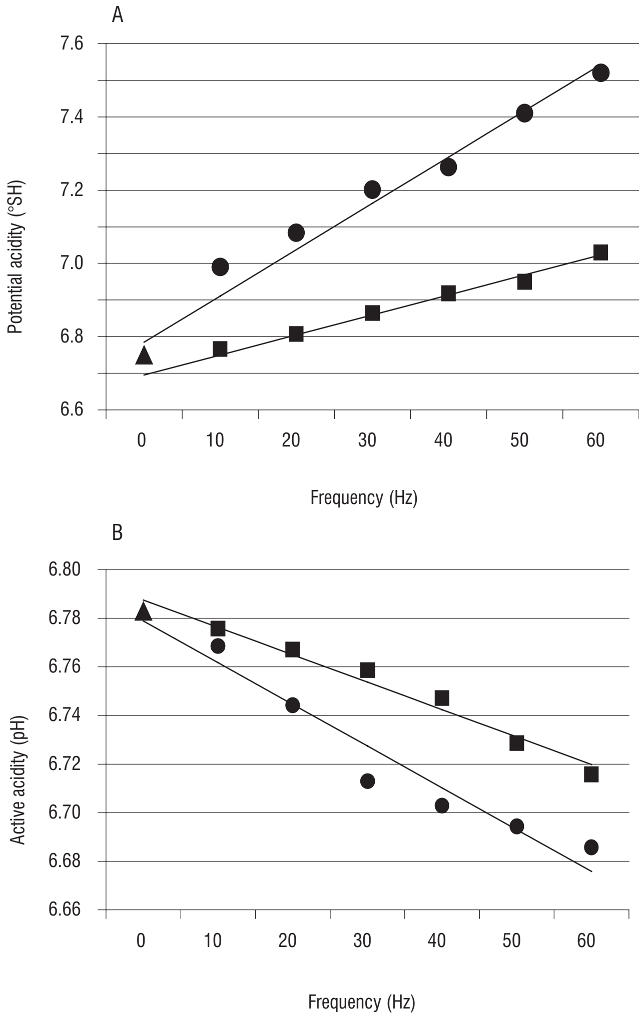

FIGURE 1. Changes in acidity depending on vibration frequency and time of milk exposure to vibration (■ exposure time 30 min, ● exposure time 120 min, ▲ control sample).

One of milk quality attributes, in respect of its technological usability, may be its conductance (electrical conductivity). This property of milk is the converse of resistance encountered by the electric current flowing through a solution in which ionic migration enables the transfer of some electrical load [Mabrook & Petty, 2003].

It was demonstrated that the effect of a mechanical stimulus on milk may also increase its conductivity. The changes observed in conductivity values were relatively small at low vibration frequencies and intensified with increasing frequency of vibrations, yet their higher values were observed at longer exposure times. After milk exposure to vibrations at a frequency of 60 Hz, the value of conductivity increased from 4.13 mS/cm in the control sample to 4.69 mS/cm in milk after 30 min of vibrations and to 4.81 mS/cm in milk exposed to vibration for 120 min (Figure

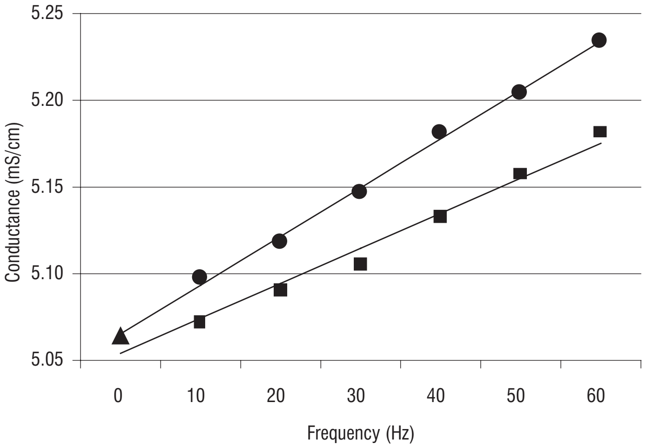

FIGURE 2. Changes in electrical conductivity depending on vibration frequency and time of milk exposure to vibration (■ exposure time 30 min, ● exposure time 120 min, ▲ control sample).

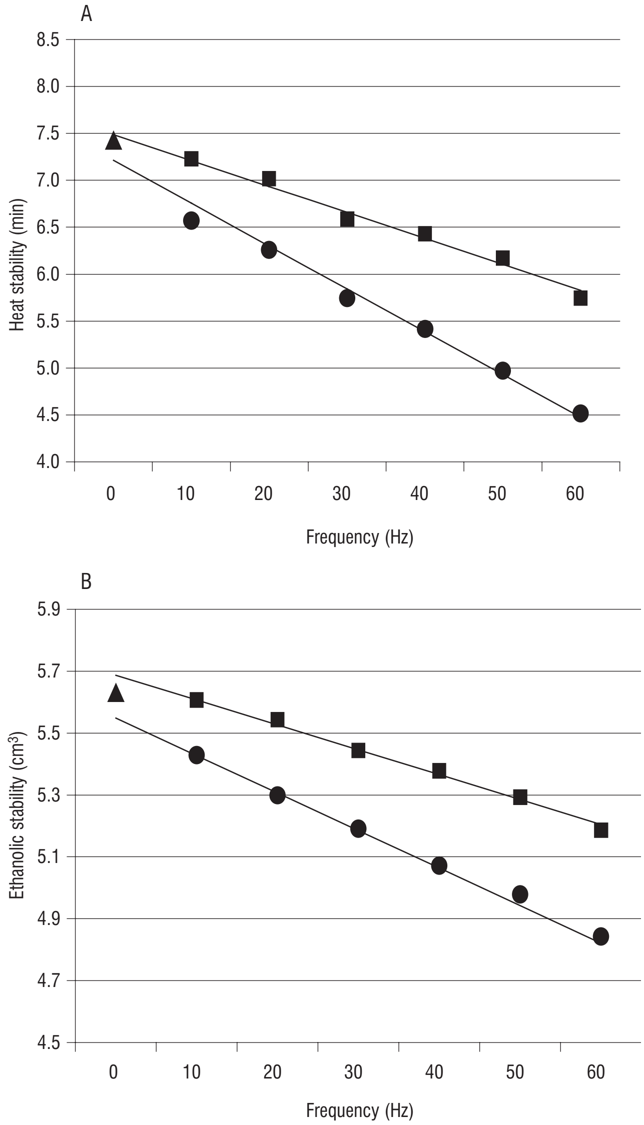

FIGURE 3. Changes in heat stability (A) and ethanolic stability (B) depending on vibration frequency and time of milk exposure to vibration (■ exposure time 30 min, ● exposure time 120 min, ▲ control sample).

2). The changes in milk conductivity as affected by vibrations result from the increased acidity of milk [Chmielowski & Rak, 1996] and alterations in the salt system (a higher concentration of Ca^{2+} ions) [Warmińska *et al.,* 2003b].

The next stage of the experiment was aimed at monitoring changes in heat and ethanolic stability of milk as a result of milk exposure to vibrations.

The results obtained clearly point to the negative effect of vibrations on the heat stability of milk proteins. With an increasing frequency of vibrations and extended time of exposure, its initial value was subject to a systematic decline. Vibrations spanning 120 min at a frequency of 60 Hz resulted in a reduction of the time of milk coagulation by as mach as 40% on average (Figure 3A).

Similar relationships were reported for the ethanolic stability. The increased vibration frequency caused a systematic decrease in the alcoholic value (Figure 4B).

The heat and ethanolic stability of fresh raw milk are determined by a number of factors, including: ionic concentration (H^+, Na^+, Ca^{2+}, Mg^{2+}, citrate and phosphate ions), ratios and contents of nitrogen compounds (casein and its fractions, whey proteins, non-protein compounds) and the total content and composition of salts (calcium, magnesium, citrates, phosphates). These properties are not affected by the natural acidity of milk, however, any change in its value (especially an increase) results in a significant decrease in milk stability [Czerniewicz *et al.*, 1999, 2000].

The changes in the ethanolic and heat stability observed in the research were significantly correlated with changes in the acidity of milk exposed to vibrations. A part of micellar calcium phosphate, while being transferred to a soluble phase as a result of vibrations, increases the concentration of Ca^{2+} ions, breaks the structure of micelles and reduces the degree of their hydration [Warmińska *et al.*, 2003 a, b]. An extremely important constituent of milk, determining its stability, are whey proteins which under the influence of alcohol and temperature are subject to denaturation, form aggregates and react with casein. Their significance in the coagulation process is linked with their impact on casein's structure and depends on the initial pH of milk. A change in pH leads to alterations in hydrophobic interactions, consequently resulting in changes of casein stability [Czerniewicz *et al.,* 1999].

In this study, an attempt was made to determine the changes in rennet coagulation of milk exposed to vibrations. The time of rennet coagulation of milk appeared to shorten with an increasing frequency and extended time of vibration. At the highest vibration parameters, *i.e.* a frequency of 60 Hz and a 120-min exposure, the reduction in rennet coagulation time was considerable and reached 52.5% on average (Figure 4).

The coagulation process of milk is affected by multiple factors, mainly by the presence and concentration of calcium ions, active acidity, the size of casein micelles and contribution of their particular fractions. In the rennet coagulation of milk, a significant function is also ascribed to mineral compounds and forms they occur in, whereas medium pH has a direct link with the balance between salts bound with casein and ionized salts. An increase in milk acidity results in the stepwise ionization of calcium that is transferred to a solution and affects the shortening of milk coagulation time [Singh & Creamer, 1991].

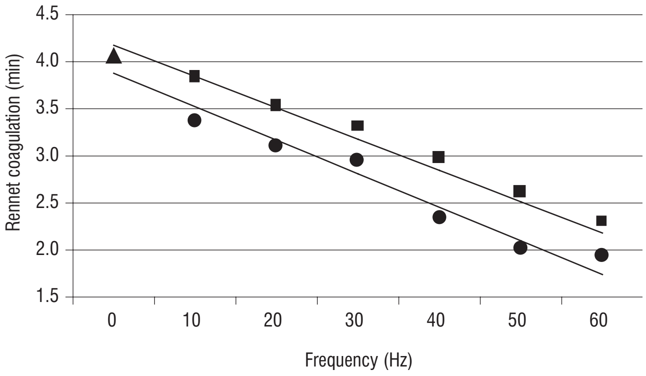

FIGURE 4. Changes in rennet coagulation depending on vibration frequency and time of milk exposure to vibration (■ exposure time 30 min, ● exposure time 120 min, ▲ control sample).

The results obtained clearly indicate the negative impact of vibrations on the physicochemical properties of milk assayed, *i.e.* potential and active acidity, conductivity, and typical indicators of the technological usability of milk, including: heat and ethanolic stability as well as coagulation under the influence of rennet.

High coefficients of correlation and determination confirm strong correlations between the traits examined as well as frequency band and exposure time applied (Table 1).

TABLE 1. Regression analysis of the selected traits of milk exposed to vibration.

Milk traits	Exposure time (min)	Correlation coefficient	Determination coefficient
Potential acidity (°SH)	30	0.99	0.99
	120	0.93	0.87
Active acidity (pH)	30	-0.98	0.97
	120	-0.97	0.95
Electrolytic conductivity	30	0.98	0.97
(mS/cm)	120	0.99	0.99
Heat stability (min)	30	-0.99	0.98
	120	-0.99	0.98
Ethanolic stability (cm^3)	30	-0.99	0.99
	120	-0.96	0.92
Rennet coagulation (min)	30	-0.99	0.99
	120	-0.97	0.95

CONCLUSIONS

1. Changes in the physicochemical properties of milk affected by vibrations are determined by the frequency band applied and intensify with an increasing frequency and extended time of milk exposure to vibration.

2. Vibration exerted an unfavorable effect on the basic physicochemical properties of milk, thus negatively affecting its technological usability.

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WPŁYW CZĘSTOTLIWOŚCI I CZASU EKSPOZYCJI WIBRACJI NA PRZYDATNOŚĆ TECHNOLOGICZNĄ MLEKA SUROWEGO

Magdalena Warmińska, Antoni Kruk, Waldemar Brandt

Katedra Mleczarstwa i Zarządzania Jakością, Uniwersytet Warmińsko-Mazurski w Olsztynie, Olsztyn

Transport mleka i wynikające z niego narażenia mechaniczne różnego typu, w istotny sposób kształtuje jakość mleka surowego, Wibracje niekorzystnie oddziaływując na składniki i właściwości mleka, mogą w różnym stopniu wpływać na obniżenie jakości i przydatności technologicznej tego surowca, co z kolei wiązać się będzie z utrudnieniami w procesie technologicznym oraz pogorszeniem jakości i trwałości gotowych wyrobów. W związku z tym celem pracy było prześledzenie wpływu wibracji o zmiennej częstotliwości (10–60 Hz) i zmiennym czasie ekspozycji wibracji (30 i 120 min) na zmiany wybranych właściwości fizykochemicznych mleka, w szczególności tych rzutujących na jego przydatność technologiczną.

Stwierdzono, że wibracja powoduje niewielki wzrost jego kwasowości (rys. 1). Wraz ze wzrostem częstotliwości od 10 do 60 Hz i wydłużaniem czasu wibracji z 30 do 120 minut wartość pH mleka ulegała obniżeniu. Przeprowadzone badania dowiodły, że działanie bodźca mechanicznego na mleko może również podwyższyć jego konduktywność. Stwierdzone zmiany konduktywności były stosunkowo małe przy niskich częstotliwościach wibracji i nasilały się wraz ze wzrostem częstotliwości drgań (rys. 2).

W dalszym etapie doświadczenia stwierdzono obniżanie się stabilności etanolowej i cieplnej (rys. 3), a także skracanie czasu krzepnięcia podpuszczkowego mleka surowego (rys. 4). Wykazane zmiany zależne były od zastosowanego pasma częstotliwości i pogłębiały się w miarę jej zwiększania oraz wraz z wydłużeniem czasu ekspozycji mleka na wibrację, wywierając w efekcie istotny, negatywny wpływ na jego przydatność technologiczną.