J. Agric. Sci. Mansoura Univ., 25 (7): 4369 - 4379, 2000.

RELATIONSHIP BETWEEN TYPE OF BUTTER AND ITS RHEOLOGICAL PROPERTIES

El-Senaity, M. H.[1] and M. Zin El-Din[2]
[1]Department of Food Technology and Dairying, National Research Centre, Dokki, Cairo, Egypt.
[2]Dairy Dept., Fac. of Agric., Mansoura Univ., Mansoura, Egypt.

ABSTRACT

Fresh whole buffaloe, cow, mixed of buffaloe and cow, ewe and goat milk were separated to cream. Cream was divided into two parts, the first part was churned into sweet cream butter while the second part was fermented using starter and churned to fermented cream butter. Rheological properties of the resultant butter were studied. Results showed that buffaloe butter was harder than other types of butter, and it was able to resist more shearing forces than the others at the same level of shear rate. Goat butter gave the lowest shear stress for the upward curve at the same shear rate, while buffaloe butter can suffer high value of stress than the others at the same shear rate. In fermented cream butter, fermentation process decreased shear stress of the resultant butter. Yield value of sweet cream butter was higher than that of fermented cream butter. Buffaloe butter gave high yield, whereas the lowest yield was observed in butter made from goat milk. It means that goat butter requires low values of stress to flow while buffaloe butter needs high values of stress to flow and was able to reform or rebuild more strongly than goat butter. Structural viscosity of buffaloe sweet butter was higher than the other types of butter at all shear rate, while it was lower in fermented cream butter also for all shear rates. Changes in deforming and reforming of butter can be divided into the following: 1) main changes would happened on rate level of 5 – 12.5 (sec^{-1}), 2) at shear rate 12.5 – 25 (sec^{-1}) changes would be slowly mild., 3) between rates 25 – 50 (sec^{-1}) changes showing a very slight differences., and 4) sequence of butter flowing and then reforming for different types as follows:- Buffaloe > Ewe > Mixed (buffaloe and cow) > Cow > Goat. Correlation coefficient (r) between iodine value and structural viscosity was calculated and showed that in either sweet or fermented cream butter there were negatively highly significant ($P < 0.01$) at different shear rates. It means that when iodine value of butter increased structural viscosity decreased.

Key words: Rheology, fermented cream butter, sweet cream butter.

INTRODUCTION

Butter and other fatty plastic materials consists of many small crystals of the order of a few micron or less, enmeshing a considerable proportion of liquid oil within their texture, (Sone, *et al*., 1962). Rheology is a branch of physics which deals with deformation and flow of materials both solids and fluids, (Scott-Blair, 1954 and Reiner, 1960). Muller (1973) stated that the physical approach to mechanical behaviour of matter is called " Rheology ". Knoop, (1964) reported that butter should not be considered as a solid body but as a liquid of high viscosity. Shama and Sherman, (1970) considered butter as a diluted emulsion made of water droplets embedded in semi-solid oil matrix. Sone, *et al.* (1962) mentioned that butter exhibits the Non-Newtonian character and therefore butter phenomenologically can be called a thixotrophic substance. Knoop (1964) stated that the viscosity of butter expresses sectility hardness. Finney (1972) concluded that viscosity is a characteristic property, which determines the rate of flow of any fluid, he defined viscosity as the internal friction of fluid or its resistance to flow. Warner, (1976) defined viscosity as the tendency of a fluid to cohere, to hold together and to resist forces causing it to flow or change shape. Dolby, (1941) recorded that butter hardness depends mainly on the structural viscosity. Kassem, *et al.* (1969) reported that in the case of plastic material (such as butter), the viscosity is not a function of the internal friction, but it is also determined by the stability of the solid phase structures, it is termed structural viscosity and it changes with the rate of shear. Finney, (1972) mentioned that the shear stress is a stress in which its components are tangentially to the plane on which the force components act.

In this paper, rheological properties of different types of butter made from buffaloe; cow; mixed of buffaloe and cow; ewe and goat milk, and effect of fermentation process on rheological properties were studied. Correlation between iodine value and structural viscosity of butter was estimated as a parameter of hardness and finally quality.

MATERIALS AND METHODS

Fresh buffaloe and cow milk were obtained from the Institute of Animal Production, Dokki, Giza, Egypt. Ewe and goat milk were collected from a private farm in Dakahliah Governorate. Samples were transported to the Laboratory of Dairying, National Research Centre in stainless steel containers under cooling conditions. Milk from every type of animal (buffaloe; cow, ewe and goat) were divided in two portions. The first portion of each was separated to cream by using a mechanical separator then cooled at 5°C for 12 hrs. and churned to sweet cream butter.

The second portion of milk was separated, then cream was pasteurized at 75°C for 5 min., cooled immediately to 30°C. Starter contained (1 : 1, V/V) *S. lactis* and S. *cremoris* (Chr. Hansens, Copenhagen, Denmark), added to the cream at the rate of 20 ml/1 kg, then incubated at 30°C for 24 hrs., aged in the refrigerator at 5°C overnight and churned into butter (fermented cream butter).

The resultant sweet cream from buffaloe and cow milk were mixed together with ratio of 1:1 (w/w) and divided into two portions. The first portion churned into butter (mixed sweet cream butter), while the second portion of mixed sweet cream was fermented by the same above method of fermentation, churned to butter (mixed fermented cream butter). Three replicates were carried out.

Rheological properties

Shear stress, shear rate and structural viscosity were conducted using Rotational Viscometer (Coaxial Viscometer) type RN as follows:

Butter samples were tightly placed into cylinder, air bubbles should be excluded. The temperature of the viscometer was thermostatically controlled at 20°C. The sample was subjected to shear at rates of 50; 25; 12.5 and 5 sec.$^{-1}$, respectively, for the upward curve. The same shearing rates in the reverse direction of the downward curve were adopted. The scale reading (α) was recorded after a shearing time of 10 sec. at each of the above mentioned rates. The (α) reading obtained by the instrument scale was used for calculation of shearing stress according to Scurlock (1986) with the following formula:

1- Shear stress

$= z \times \alpha$ (dyne/cm^2).

Where:

z = Cylinder constant given with the instrument (102.11).

α= Scale reading (skt).

Regarding the flow curve, it was worked out by plotting shear stress values against different shear rates between (5 sec.$^{-1}$ to 50 sec.$^{-1}$).

2- Viscosity:

$\wp = K \times N \times \alpha$ (centi-pose)

Where

$\wp$= dynamic viscosity (centi-poise).

K= constant (cp/skt)= 204.22

N= shear rate at every speed factor (1=50; 2=25; 4=12.5 and 10=5 sec.$^{-1}$)

α- scale reading (skt)

3- Structural viscosity:

The obtained shearing stress values at different shear rates were used to calculate structural viscosity. The following equation given with the instrument was used:

$$\text{Structural viscosity} = \frac{\text{Shear stress}}{\text{Shear rate}} = \quad \text{(poise)}$$

Where:

Shear stress = z x α (dyne/cm2).

Z= constant (102.11).

α= reading scale (skt).

Shear rate = (50; 25; 12.5 and 5 sec.$^{-1}$). (Kassem *et al.*, 1969).

4- Yield value:

It was obtained by the extrapolation of the straight-line part of the flow curve (down ward) to the stress axis, the cross point thus obtained given yield value (Kassem *et al.* 1969).

5- Iodine value:

Iodine value (I.V.) was determined using the method described by the British Pharmacopoeia (1963).

6- Statistical analysis:

Correlation coefficient (r) was calculated by the method of (Snedecor and Cochran), 1982).

RESULTS AND DISCUSSION

Rheological properties of butter from different types of milk:

1) Shear stress and flow curve:

Sweet cream butter:

Shear stress is favourable measure for structure breakdown phenomena and it is a good parameter for the resistance to deformation consequently indicates the butter hardness.

Results in Table (1) and Fig. (1) proof that buffaloe butter was harder than the other types of butter and was able to resist more shearing force than the others at the same level of shear rate.

Table (1): Yield value, shear stress of sweet cream butter at different shear rates.

Type of butter	Yield value	Shear rate ($sec.^{-1}$).				
	Dyne/cm^2	Ward	50	25	12.5	5
Buffaloe	3250	Up	4901.28	3880.18	3165.41	2859.10
		Down	3471.74	3267.52	3063.33	2859.10
Cow	1925	Up	2654.86	2348.53	1940.09	1735.87
		Down	2144.31	2042.20	1837.98	1735.87
Mixed (buffaloe + cow)	2700	Up	4084.40	3369.63	2859.08	2552.75
		Down	3165.41	2961.19	2654.86	2552.75
Ewe	3200	Up	4395.73	3573.85	3063.33	2654.86
		Down	3369.63	3165.41	2961.19	2654.86
Goat	850	Up	1327.43	1225.32	918.99	714.77
		Down	1123.21	1021.10	816.88	714.77

Shear stress = expressed as dyne/cm^2

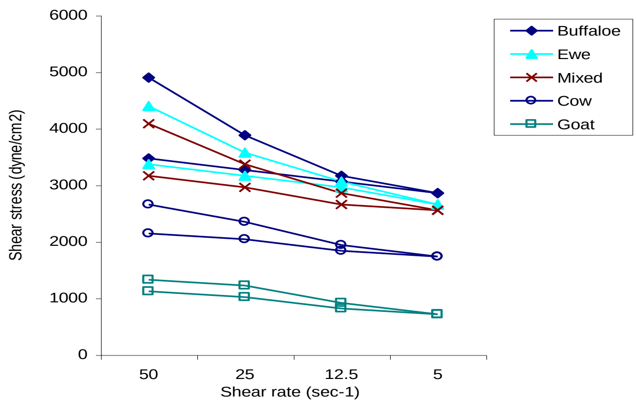

Fig. (1): Flow curve of different types of sweet cream butter.

Goat butter was of the lowest shear stress for upward curve at the same shear rate. It could also be noticed that every flow curves (Figs. 1 & 2) can be divided into two parts, one is over the 12.5 to 50 $sec.^{-1}$ being non linear, and the other over the upper range of the shear rate (12.5 to 5 $sec.^{-1}$) being approximately linear, which are in accordance with results of El-Nimr, *et al.* (1982) and Sone, *et al.* (1962).

From the obtained results, it could be concluded that buffaloe butter can suffer high value of stress than the other four types of butter at the same level of the shear rate. These results were in agreement with those reported by El-Nimr, *et al.* (1982) for buffaloe and cow sweet cream butter. It could be concluded that shear stress is a good indicator of structure breakdown as affected by the type of butter and fat content (%) in different types of its milk. Generally, shear stress of buffaloe butter is the highest compared with the other investigated types of butter.

Fermented cream butter:

Results in table (2) and Fig. (2), indicated that shear stress value was higher in buffaloe butter than in other types of butter. These results indicated that fermentation of cream before churning decreases shear stress of butter, due to the action of the starter which was used. Results are in accordance with that reported by (Hofi *et al.* 1982; Bindal and Wadhwa, 1993), who demonstrated that goat ghee has a higher liquid fraction (69%) compared with cow ghee (30.5%) or buffaloe ghee (36%). Levels of glycerides were also higher in goat ghee (64.5%); (54.5%) for cow ghee and (56%) for buffaloe ghee, respectively, this trend is in agreement with our work.

Table (2): Yield value, shear stress of fermented cream butter at different shear rates.

Type of butter	Yield value Dyne/cm^2	Ward	Shear rate ($sec.^{-1}$). 50	25	12.5	5
Buffaloe	2875	Up	4186.51	3408.74	2961.19	2552.75
		Down	3267.52	3063.30	2756.97	2552.75
Cow	1125	Up	2654.86	1940.09	1429.54	1327.43
		Down	1531.65	1429.54	1225.32	1327.43
Mixed (buffaloe + cow)	1925	Up	3267.52	2552.75	2042.20	1735.87
		Down	2450.64	2246.42	1837.98	1735.87
Ewe	2675	Up	3982.29	3165.41	2654.86	2348.53
		Down	3063.30	2859.08	2552.75	2348.53
Goat	600	Up	918.99	816.88	612.66	408.44
		Down	816.88	714.77	510.55	408.44

Shear stress = expressed as dyne/cm^2

2- Yield values:

Yield value is a critical stress after which the material exhibits flowing. Yield value is a good index concerning how far the substance must exhibit irreversible deformation without the application of excessive forces, in meantime it should retain its form, (Kassem, *et al.* 1969 and Finney 1972).

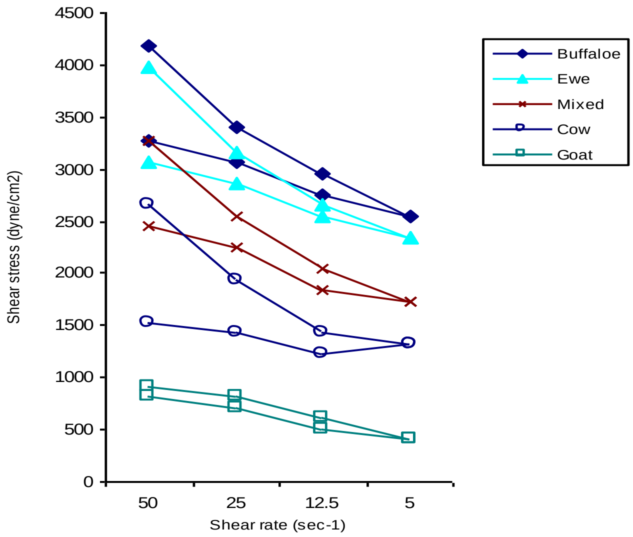

Fig. (2): Flow curve of different types of sour cream butter.

Sweet and fermented cream butter:

Tables (1 & 2) indicated that, yield value took the same trend in both sweet and fermented butter, but it was lower than that of sweet cream butter. Goat butter gave the lowest yield value while buffaloe butter gave the highest yield value. This difference in yield value is due to the fermentation process, which means that goat butter needs low value of stress to rebuild, while buffaloe butter needs high values. Sone, *et al.* (1962) showed that measurements of yield value is one of the factors which evaluate degree of crystallization of the system. Accordingly, it could be concluded that buffaloe butter has more crystal net-work than cow butter. Moreover, buffaloe butter was able to reform or rebuild more strongly than cow butter and the interlinks between fat crystals in cow butter were weaker. These results were in accordance to Sone *et al.* (1962) and El-Hofi *et al.* (1982).

3- Structural viscosity:

In the case of plastic material, the viscosity is not only a function of the internal friction, but it is also determined by the stability of the solid phase structure, (Kassem, *et al.* 1969).

Sweet cream butter:

Results in table (3) and Fig. (3) revealed that structural viscosity values of buffaloe; cow; mixed (buffaloe + cow); ewe and goat sweet cream butter at all shear rates. Data illustrated that the changes in structural viscosity values of these butter types, buffaloe butter had a higher structural viscosity value than others at all shear rates.

Table (3): Structural viscosity of different types of sweet cream butter at different shear rates.

Type of butter	Shear rate ($sec.^{-1}$).			
	50	**25**	**12.5**	**5**
Buffaloe	98.03	155.21	253.23	571.82
Cow	53.09	93.94	155.21	347.17
Mixed (buffaloe + cow)	81.69	134.79	228.73	510.55
Ewe	87.81	142.95	245.06	530.97
Goat	18.38	32.68	49.01	102.11

Structural viscosity value = expressed as poise

Fig. (3): Structural viscosity of sweet cream butter at different shear rates

Fermented cream butter:

Data in table (4) and Fig. (4) showed that structural viscosity values were lower than that of sweet cream butter. It is obvious that most of structural viscosity reduction was occurred at the first period of shearing at low shear rates while at high shear rates, the response of butter (sweet and fermented) was slight. The trend of structural viscosity at low as well as at high shear rate indicates that it behaved similarly to shear stress and yield values.

Dolby (1959), stated that butter hardness depends mainly on the structural viscosity. Our results were in agreement with that reported by Hofi, *et al.* (1982), who found this trend for buffaloe and cow butter. On the other hand, our results for structural viscosity indicated that power law as formulated:

$$\sigma = K^{n-1}.Y \qquad \text{(millipascals)}$$

Where:

σ = Shear stress (as millipascals);
Y = Shear rate (per second^{-1}).
K = Consistency coefficient index (millipascals) seconds $^{n-1}$
n = rate index.

Could be applied and confirmed in case of butter and can use the termination (consistency coefficient index) instead of structural viscosity where calculated values in all cases were the same, (Kristensen, *et al.* 1997).

Table (4): Structural viscosity of different types of fermented cream butter at different shear rates.

Type of butter	**Shear rate (sec.$^{-1}$).**			
	50	**25**	**12.5**	**5**
Buffaloe	83.73	138.87	236.90	510.55
Cow	53.09	77.60	114.36	265.49
Mixed (buffaloe + cow)	65.35	102.11	163.38	347.17
Ewe	79.64	126.62	212.39	469.71
Goat	26.55	49.01	81.69	183.80

Structural viscosity value = expressed as poise

Fig. (4): Structural viscosity of fermented cream butter at different shear rates

Interrelationship between iodine value (I.V.) and structural viscosity of butter:

Results of I.V. illustrated that in buffaloe it was 30.72; 33.0 for cow; 32.0 for mixed (buffaloe + cow) sweet cream butter 1:1 (w/w); 31.8 for ewe and 34.90 for sweet goat cream butter. Correlation coefficient (r) between

I.V. and structural viscosity of butter (sweet cream butter) was - 0.95 at 50 sec.$^{-1}$; - 090 at 25 sec.$^{-1}$; -0.85 at 12.5 sec.-1 and - 0.85 at 5 sec.$^{-1}$ shear rate, were negative highly significant ($P < 0.01$). It could be concluded that from these results, when I.V. was increased the structural viscosity decreased, and it was clear at high shear rate. This is due to the hardness of butter when the butter more hard, I.V. decreased, these results were in accordance with those reported by (Zegarska, 1988), who showed negative highly significant correlation between I.V. and viscosity of butter (hardness). Rohm and Ulberth, 1996 found an inverse relationship between oil viscosities and the iodine value (I.V.) which is a measure for the absolute number of double bonds.

In the case of fermented cream butter, the correlation between I.V. and structural viscosity of butter at different shear rates took the same trend but the (r) correlation coefficient was low. Iodine values (I.V.) were 31.50 for buffaloe; 34.0 for cow; 33.0 for mixed (buffaloe + cow), 32.3 for ewe; and 36.65 for goat fermented cream butter. Correlation coefficient between I.V. and structural viscosity at different shear rates (r) were –0.92 at (50 sec.$^{-1}$); -0.90 at (25 sec.$^{-1}$); -0.88 (12.5 sec.$^{-1}$) and –0.86 at shear rate of (5 sec.$^{-1}$) also negative highly significant correlation ($P < 0.01$).

In our opinion and as the former correlation results indicated, quality of butter specially its predicting for oxidation would affect its structure and vise versa, though keeping quality and shelf life of butter more or less would be affected by its structure.

CONCLUSION

Rheological properties of butter is highly influenced by the type of butter and cream ripening process (fermentation process). There was a clear difference in iodine value for every type of butter, it was lower for buffaloe sweet or fermented cream butter and was higher for goat sweet or fermented cream butter. This difference reflects a large variations in the rheological behaviour of both buffaloe; cow; mixed (buffaloe + cow 1:1 (w/w); ewe and goat butter, where the buffaloe butter possessed high value of shearing stress; yielding and structural viscosity than those of other types of butter (sweet or fermented butter). The buffaloe butter was harder than that of cow and goat butter were soft. Cream ripening for 24 hrs., gave butter with the lowest values of shearing stress, yield value and structural viscosity.

From all above described experimental results we may draw some conclusions about the fine structure and the rheological properties of butter. The rheological properties are largely dependent upon the rate of shear and the shearing stress exhibits the Non Neutantian character. Though we can divide changes in deforming and reforming of butter into the following:

1- Main changes would happened on rate level of 5 – 12.5 (sec^{-1}).
2- At shear rate 12.5 – 25 (sec^{-1}) changes would be slowly mild.

3- Between rates 25 – 50 (sec^{-1}) changes showing a very slight differences.

4- Sequence of butter flowing and then reforming for different types as follows:- Buffaloe > Ewe > Mixed (buffaloe and cow) > Cow > Goat.

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العلاقة بين نوع الزبد وخواصه الريولوجية

محمود حمزة السنيطى[1] - محمد زين الدين[2]
[1،3] قسم الصناعات الغذائية والألبان – المركز القومى للبحوث – الدقى – القاهرة - مصر .
[2] قسم الألبان – كلية الزراعة – جامعة المنصورة – المنصورة - مصر .

يهدف هذا البحث إلى دراسة الخواص الريولوجية للزبد الناتج من قشدة طازجة (غير متخمرة) وقشدة متخمرة بإستخدام البادئ وذلك من أنواع مختلفة من اللبن (الجاموسى – البقرى – الخليط من الجاموسى والبقرى – الغنم – الماعز) ، ومن أهم النتائج التى تم التوصل إليها فى البحث :

- الزبد الجاموسى الناتج من القشدة الطازجة (غير المتخمرة) كان أكثر صلابة وله القدرة على مقاومة الـ shearing stress أكثر منه فى جميع أنواع الزبد الأخرى وعلى نفس مستوى الـ shear rate بينما كان زبد الماعز أقل صلابة وقدرته أقل على مقاومة الـ shearing stress.
- بدراسة الـ yield value إتضح أن أعلى قيمة له كانت فى الزبد الجاموسى الطازج بينما كانت أقل قيمة له فى زبد الماعز الطازج وهذا يعنى أن الزبد الجاموسى يحتاج إلى قوة كبيرة للإسالة بعكس زبد الماعز الذى يحتاج إلى قوة أقل .
- أظهر البحث أن لزوجة الزبد الجاموسى الطازج كانت أعلى قيمة بينما كانت أقلها قيمة لزوجة زبد الماعز الطازج وهذا يرتبط إلى حد كبير بحجم حبيبات الدهن فى اللبن المستخدم .
- أما فى حالة الزبد المتخمر fermented كانت أقل فى النتائج ولكن بنفس الترتيب السابق أى أن عملية التخمر تؤدى إلى تقليل الـ shear stress ، الـ yield value ، الـ structural viscosity عنه فى الزبد الطازج (الغير متخمر) .
- وبدراسة منحنى الـ structural viscosity للأنواع المختلفة من الزبد سواء كان طازج أو متخمر إتضح الآتى :
  1. التغيرات كانت واضحة جداً وملموسة عند قيم shear rate من 5 – 12.5 (ثانية $^{-1}$) .
  2. عند قيم من 12.5– 25 (ثانية $^{-1}$) كانت التغيرات فيها أقل من المرحلة الأولى .
  3. كانت التغيرات قليلة وبسيطة عند قيم shear rate من 25 – 50 (ثانية $^{-1}$) .
  4. وبالنسبة لترتيب أنواع الزبد المختلفة من الناحية الريولوجية flowing ، yield value ، structural viscosity ، كان الترتيب تنازلياً كالآتى : الجاموسى – الغنم– الخليط من الجاموسى والبقرى – البقرى - الماعز
- وبدراسة معامل الإرتباط (r) بين الرقم اليودى iodine value واللزوجة structural viscosity فى جميع أنواع الزبد المستخدم سواء كان طازج أو متخمر إتضح أنه معنوى جداً (سالب) على جميع مستويات الـ shear rate وهذا يوضح أن اللزوجة تتناسب عكسياً مع الرقم اليودى .