Determination of meat cutting properties through the analysis of Warner Bratzler curve

Keywords
- Cutting works
- Warner Bratzler curve
- Compression
- Friction
- Disintegration

Investigations on beef, pork and back fat under chilled temperature and low speed for energy saving

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The measurement of cutting forces in meat was carried out to define the degree of constituting forces: compression, friction and disintegration forces in dependence on internal (fibre orientation, type of material) and external factors (cutting speed and temperature). In this experiment, a Warner Bratzler knife with 3 mm width of the blade edge was used to puncture meat and fat samples at three different temperatures and two feed speeds. Triangular shape was used to minimise friction for more accurate interpretation of the curve. Total cutting works for beef, pork and back fat increased with decreasing temperature and increasing speed. Average compression works reached a maximum at 0 °C and intensified with cutting speed. In meat, compression works were higher at chilled temperature (4 and 0 °C) than at frozen temperature (–4 °C). For back fat, the occurrence was the opposite. Average friction work reached its maximum value at 4 °C, and its value at frozen temperature was lower than that at chilled temperature. The friction works in back fat were lower than those in beef and pork. Disintegration works exhibited maximum value at frozen temperature; and lengthwise beef cuts produced the highest value of total works while perpendicular produced the least. Cutting forces were influenced by many factors such as type of material, temperature, cutting speed and fibre orientation. The variability of meat material and its anisotropic characteristics gave rise to marked inconsistency; nevertheless the tendency could still be discerned.

Grinding is an important and complex operation in meat industry which includes compression, shearing, extruding, rubbing, and size reduction. According to KAMDEM and HARDY (1994), there is a correlation between grinding parameters and cutting forces by shear blade, thus this high correlation can be used to predict energy requirement for grinding. A cutting test with Warner Bratzler blade which consists of compression, friction and disintegration force can also be regarded as simplified grinding operations. The presence and intensity of those cutting forces are not only influenced by the properties of the cutting machine i.e. meat grinder, but are also influenced by the characteristics of meat being cut such as type of meat, part of meat, fat tissues and connective tissues. On the other hand, the behaviour of meat cutting properties in relation with external factors such as meat temperature and cutting speed should also be analysed. The purpose of this research is to determine the cutting properties of meat and back fat in dependence on different factors such as sample type, temperature and cutting speed by analysing the contribution of different types of forces occurring during cutting. By understanding the relationships among those factors and cutting properties of meat, an effort to optimise the meat mincing process can be done. This is important to know as the grinding operation is a highly energy consuming process in the meat industry.

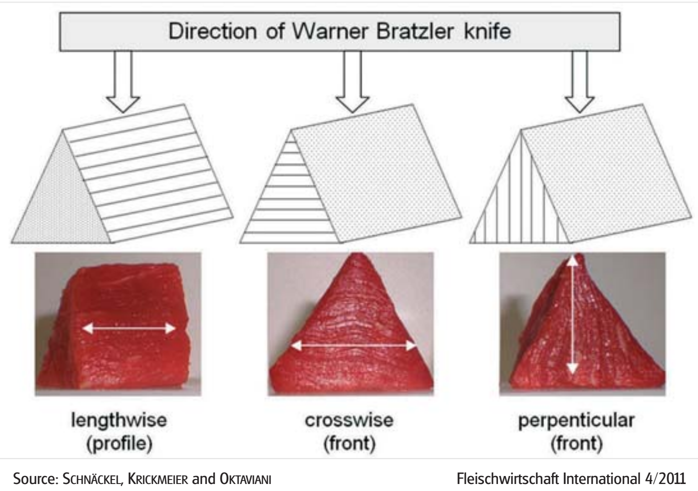

Fig. 1: Lengthwise, crosswise and perpendicular fibre orientation

Materials and methods

▶ Food materials

There were two types of meat selected for measurements: beef topside and silverside, and pork shoulder; furthermore, pork back fat was used. The refrigerated meat and back fat were purchased three days after slaughter from Flepro Fleisch und Wurstwaren GmbH, Bernburg, Germany. The samples were stored in a refrigerator at 0 °C before further use.

▶ Sample preparation

Fat and connective tissues were trimmed off the meat when necessary, then meat was cut to get a piece of meat with defined fibre orientations: lengthwise, crosswise and perpendicular (Fig. 1) by cutting into equilateral triangular area of 3 x 3 x 3 cm with certain width. Back fat was also cut to the same size. The samples were then wrapped to avoid moisture loss put in Styrofoam box and were conditioned in a refrigerator (0 °C) or freezer (–20 °C) until it reached the desired temperature (4, 0, –4 °C). The temperature was checked before and after cutting by IR thermometer to assure there were no considerable temperature changes.

▶ Equipment preparation

The Warner Bratzler measurement was carried out by placing a heavy duty platform on the base of the machine and the slotted blade

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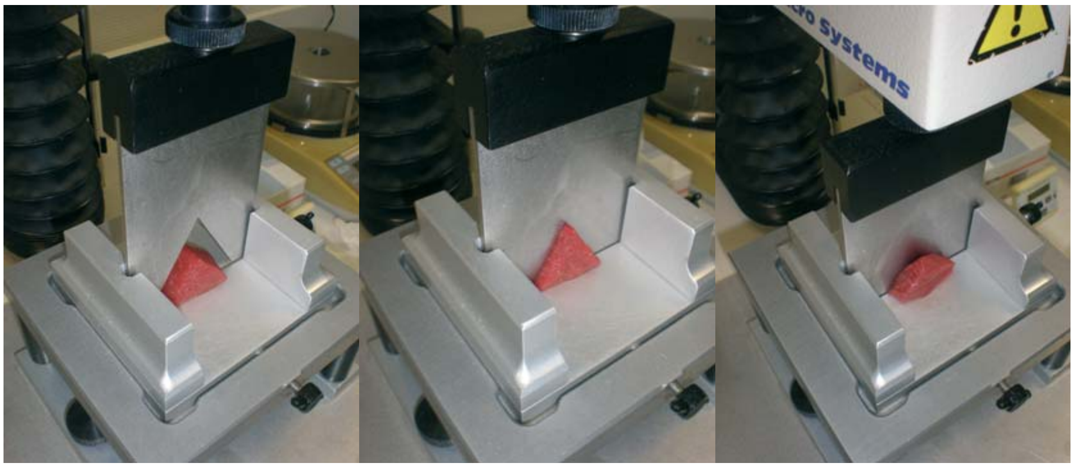

Fig. 2: The use of Warner Bratzler device in forces measurement

plate was inserted into this platform. The samples were centre justified under the blade and the blade was moved towards the slotted blade insert by a TA-XT Plus Texture Analyzer (Stable Micro Systems, Surrey, UK) fitted with a 30 kg load cell. The distance was set at 42 mm as this is the actual height of the triangular area of Warner Bratzler knife (Fig. 2). The speed of the Warner Bratzler knife was set at 2.0 and 20.0 mm/s.

▶ Data measurement and interpretation

The initial step was to determine points in which compression starts and maximum of compression occurs. This step was done by running the Warner Bratzler knife until the triangular edge of the blade were fully in contact with the meat surfaces. This point was called as start of compression (X3) and it was determined by visual observation and verified by analysing the Force-Distance-curve where it changed the steepness during the beginning of cutting. The point of maximum compression (X1) was determined afterwards by observing at which depth the knife started to cut. When the applied force exceeded the limit that meat could bear, the meat would be cut and this is called as maximum compression. Compression force would start to decrease as the knife entered deeper into the meat, on the other hand the friction force would start to increase because there would be increased contacts between the blade and the sample. Consequently, at the end of the cutting force, point of maximum friction could be obtained.

In every measurement, a Warner Bratzler curve would give the value of maximum friction force (N), maximum compression force (N), maximum total force (N), and the total area below the curve (Ncm). Figure 3 shows the Warner Bratzler curve which was produced from meat cutting. From the curve, the total area (Ncm), the area from start of compression until maximum compression (A1), force at start of compression (F1), force at maximum compression (F2), and force at maximum friction (F3) could be obtained by texture analyser. From the data above, equations for friction and compression could be derived (Fig. 4). These curves are created in order to determine the area under the curve. The total of friction work is represented by the area of A3 while the value of compression work is the sum of area A1 and A2. For disintegration work, the area is denoted by A4. By measuring the area under the curve through integral calculation, the work of compression, friction, disintegration, and total work could be obtained.

Every treatment combination was measured ten times, and the data were statistically analysed using analysis of variance (one way) to test for the significance of parameter effects at the 5% probability level ($P<0.05$).

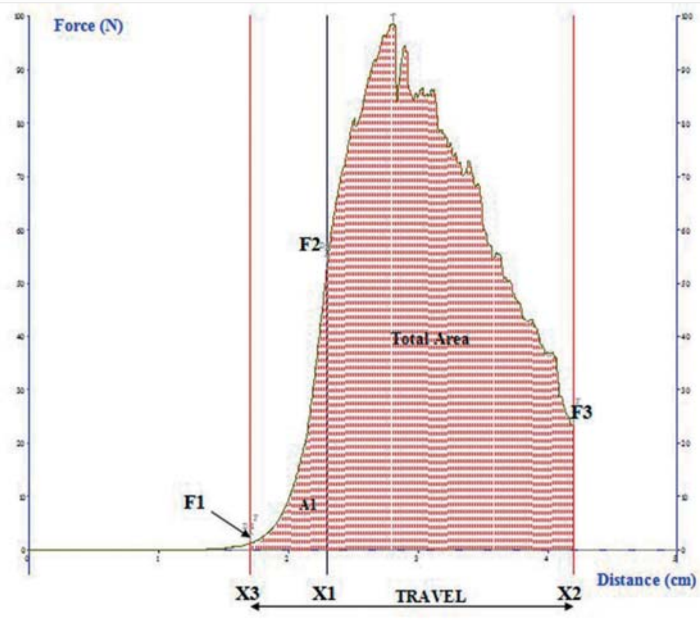

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Fig. 3: Typical plot of Warner Bratzler curve produced from pork meat

Results and discussion

Cutting forces may comprise of compression, friction and disintegration forces. In this experiment, a Warner Bratzler knife with 3 mm width of the edge blade was used to simulate the cutting forces occurring during meat grinding. Though it does not absolutely represent the actual condition during meat grinding, this can give an indication regarding the comparison of forces needed in relation with types of meat material, sample temperature and cutting speed. To illustrate the trends of data, the cutting works per area in three different fibre orientations are presented in Figures 5 to 10. Cutting works were calculated per cutting area (Ncm/cm^2) which was the surface area of the triangular meat cut.

▶ Meat cutting properties

Compression

Compression works in beef – lengthwise and crosswise – reached their maximum value at 0 °C and they intensified with cutting speed. The average compression works in pork also attained the maximum value at 0 °C and increased with cutting speed. At low cutting speed, compression works produced in pork cutting were considerably higher than works produced in beef cutting regardless of fibre orientation (Fig. 5). The relatively softer texture of pork compared to beef might have caused pork to require more compression before the knife started to cut. Higher cutting speed caused different tendencies of compression works compared to what occurred at 2 mm/s cutting speed

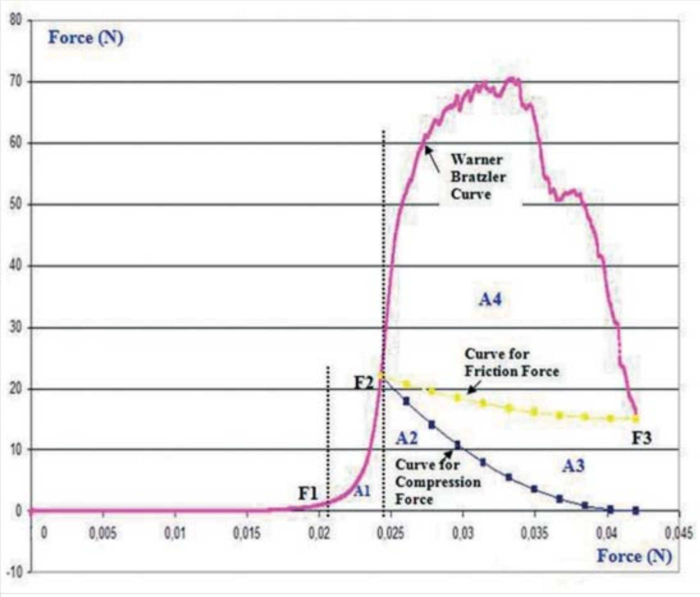

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Fig. 4: Curves for compression and friction Force

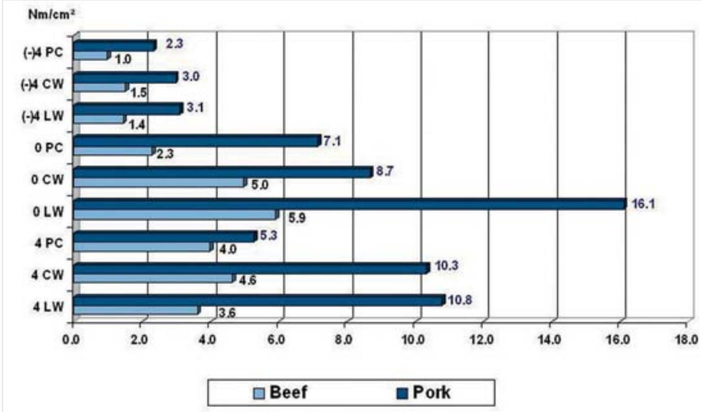

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Fig. 5: Compression works of beef and pork at different fibre orientations and temperatures at 2 mm/s (n=10)

(Fig. 6). In general, beef showed higher compression works than pork within three different temperature treatments (–4, 0, 4 °C). Nonetheless, crosswise pork at 4 °C and perpendicular pork at 0 °C showed higher compression work than the corresponding cuts of beef.

Compression would be the first force imposed on the product before it started to cut. Meat as a material with flexible fibrous structure requires compression force which is pointing to the centre. This force will be spent on elastic and plastic deformation before friction and disintegration force come to pass. During the compression, the product would be deformed along the line of the blade edge. When the compression force was more than the ability of the meat to bear, the meat will be cut. As stated by Fellows (2000), meat is usually tempered just below the freezing point to improve the efficiency of cutting. However, according to this study, there will be more works spent in meat cutting at 0 °C than at 4 °C. The slightly rigid structure of meat at 0 °C would produce more compression force.

The compression works in beef and pork at chilled temperature were greater than at frozen temperature. In frozen state, meat with its solid structure would not change shape in a great extent. Instead, it would require much disintegration force. According to Gac (1976, as quoted by Faraq et al., 2009), increasing percentage of frozen water may decrease plasticity and increase shear resistance at low temperature; at –5 °C, 75 to 80% of the water in meat is frozen.

Friction

The friction work in beef and pork reached its maximum value at 4 °C, slightly decreased at 0 °C, and dropped off at –4 °C. There was significant reduction of friction works in beef at frozen temperature compared to those at chilled temperature (0 and 4 °C). This could be attributed to melting ice which formed during cutting and can act as friction-reducing substance. Frictional force depends on the type of surfaces, in this case of meat and knife, and how hard the surfaces are pressed together. The knife which cuts the frozen sample would melt the ice along the line of the blade edge, thus water which emerged would reduce the friction work due to less interaction between the surfaces. As stated by Fellows (2000), water will act as a lubricant in some food products.

At low cutting speed, friction works in pork cutting were consistently lower than friction works produced in beef cutting at chilled temperature (Fig. 7). Beef tended to stronger attach to the knife than pork did. This might happen, because the fat content of beef is relatively lower than that of pork. The intramuscular fat content of beef *longissimus* with slight marbling was approximately 3.4% (Savell et

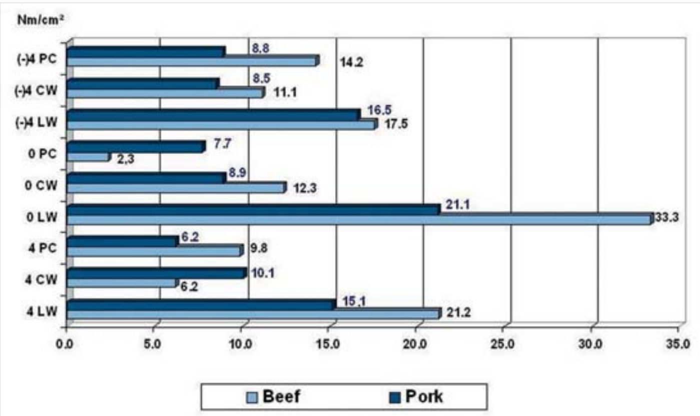

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Fig. 6: Compression works of beef and pork at different fibre orientations and temperatures at 20 mm/s (n=10)

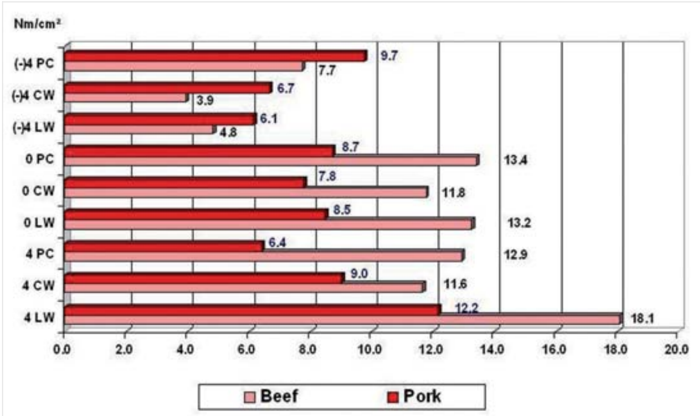

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Fig. 7: Friction works of beef and pork at different fibre orientations and temperatures at 2 mm/s (n=10)

al., 1986) while fat content of pork *longissimus* muscle ranged from 1.23 to 5.18% (PRUSAI et al., 1988). It is also said that pork contains less muscle tissue than beef (LAWRIE, 2006). At frozen temperature, the friction works of pork were higher than with beef. The relatively firmer texture of frozen beef could make it more liable to breaking which caused much lesser friction.

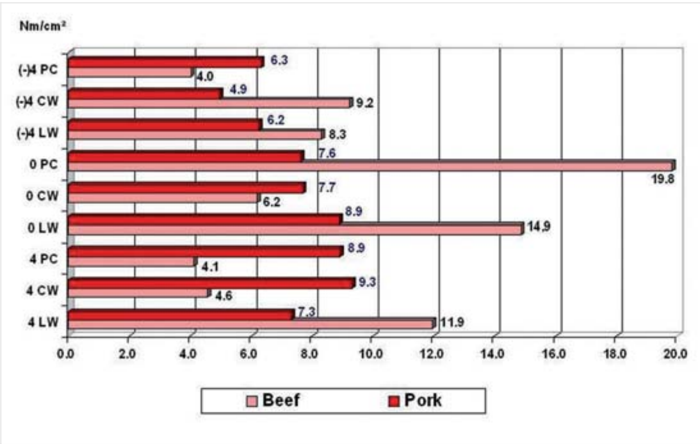

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Fig. 8: Friction works of beef and pork at different fibre orientations and temperatures at 20 mm/s (n=10)

At higher speed, friction works of beef is partly higher than of pork (Fig. 8). Four pork samples from nine treatments showed higher friction works compared to beef. Even so, the highest friction works were produced by beef samples at 0 °C. At 4 °C, it consistently showed that the friction work in beef decreased with cutting speed. Besides, in pork lengthwise, the friction work at 4 °C also decreased at higher cutting speed. This might happen, because the muscle fibre has less time to respond or attach toward moving blade at higher speed. Even so, at frozen temperature, the friction in beef increased with cutting speed. This could be attributed to the stronger holding effect due to the rigid structure. The meat is, however, cut under open condition (without any holder) by a vertically moving blade. The result may not be comparable to other studies which did cutting under motionless condition.

Disintegration

Disintegration works in beef and pork showed a clear trend over different fibre orientations and cutting speeds. The higher the cutting speed and the lower the temperature, the higher the disintegration works would be required. This finding is aligned with a study done by KING (1999), he found that the increase in feed speed would cause an increase in cutting force, and at –1.5 and 5 °C, cutting force increased by approximately 10% for each doubling of feed velocity.

At low cutting speed, the disintegration works of beef were almost entirely higher than pork across all temperatures and fibre orientations (Fig. 9). Only at 4 and –4 °C, the disintegration works between lengthwise beef and pork were not significantly different. At higher cutting speed, the disintegration work diagram entirely displayed consistent inclination that beef produced higher works than pork and the total disintegration works at frozen temperature were the most intensive (Fig. 10).

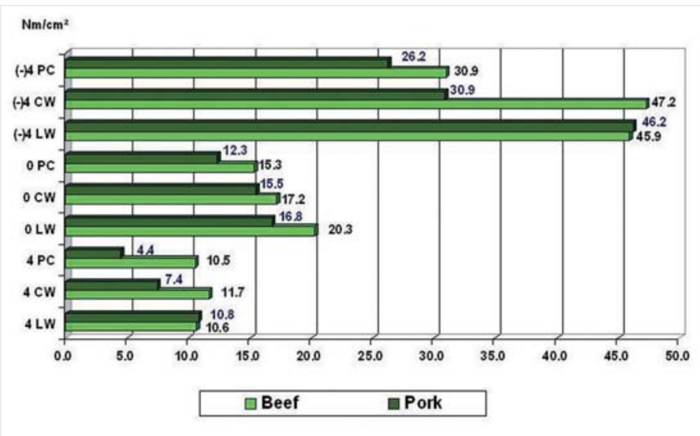

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Fig. 9: Disintegration works of beef and pork at different fibre orientations and temperatures at 2 mm/s (n=10)

Total works

Total works were the overall works required in meat or back fat cutting. Increasing speed and decreasing temperature produced higher total works in beef and pork. Higher speed (20 mm/s) would produce almost double works than those at 2 mm/s. Change of speed influenced the total works more intensively than change of temperature did. This result is comparable with a study done by BROWN et al. (2004) which showed that cutting force in beef at –5 °C is higher than at 5 and 15 °C, respectively, and force increases with cutting speed. They also concluded that the temperature difference from 15 to 5 °C had little effect on the maximum cutting force.

Lengthwise cuts of beef produced the highest value while perpendicular cuts of pork produced the lowest. As stated by FARAQ et al. (2009), there was much greater force required to cleave samples to cut across the fibre than other fibre orientations. There were obvious differences between different fibre orientations. Perpendicular fibre orientation possessed the lowest amount of works required in cutting. It is unstable to endure any type of forces imposed during cutting. Anisotropic characteristics of meat are the reason for the differences of works as a result of different fibre orientation. It has been steadily shown that cutting in lengthwise direction would require the highest works. In this orientation, the blade would need to cut across the muscle fibre. Consequently, it would need higher force than required to cut in perpendicular direction which is more fragile. According to SACKS et al. (1988), the stress transmitted through perpendicular cut is supported only by connective tissues, while cutting meat of lengthwise cut is closely related to myofibrillar components of meat (CROSS et al., 1973).

Cutting works in dependence on fibre orientation would be important in meat industry, particularly for slicing processes. The perpendicular direction will require less works which is necessary to lower the energy requirement during cutting. Nevertheless, to improve the tenderness, meat is usually cut across the grain.

▶ Back fat cutting properties

Back fat from pork has been generally used in sausage making. In this study, the cutting properties of back fat were also investigated with Warner Bratzler for three different temperatures (–4, 0, 4 °C) and two levels of cutting speeds (2 mm/s and 20 mm/s). Figure 11 shows obvious pattern; higher temperature would lead to higher compression, destruction and total works. The friction work was not significantly influenced by temperature at low speed. So, there was no difference of friction work noticed between frozen and chilled pork back fat at 2 mm/s. However, at 20 mm/s, there is a slight decrease of friction work of frozen beef compared to chilled beef. Higher cutting speed produced increased compression work only at –4 °C,

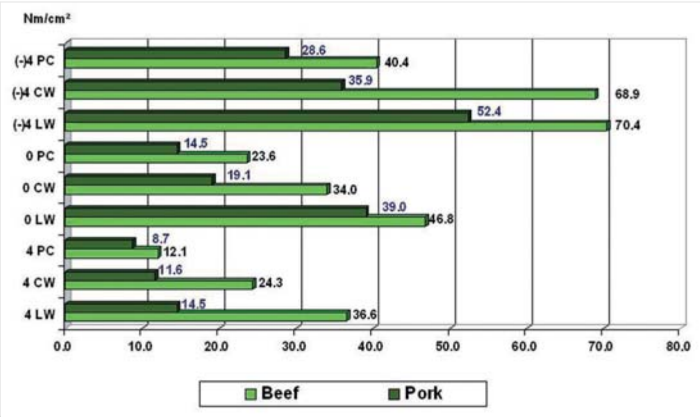

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Fig. 10: Disintegration works of beef and pork at different fibre orientations and temperatures at 20 mm/s (n=10)

whereas at 4 and 0 °C, there was no considerable difference.

Friction works decreased significantly with increasing speed in three different temperatures. For practical uses, that means in a mincer the effect of smearing can be influenced and minimised by increasing the number of knife rotations. Accordingly, cutting speed influenced compression works in frozen back fat while it influenced friction works in chilled and frozen back fat. The disintegration work increased significantly with decreasing temperatures, and so did the total work. Likewise, disintegration works increased significantly with cutting speed for samples kept at 0 and –4 °C. For total works, the value increased consistently with cutting speed.

▶ Comparison of cutting properties among beef, pork and pork back fat

Back fat or subcutaneous adipose tissue is an irregular connective tissue in which fat cells are the principal component (DRANSFIELD and JONES, 1984). There is no fibre orientation in fat as in meat muscles. In this study, it is observed that, at chilled temperature and low speed, the compression works of back fat was lower than with pork, but higher than with beef. At chilled temperature and high speed, the

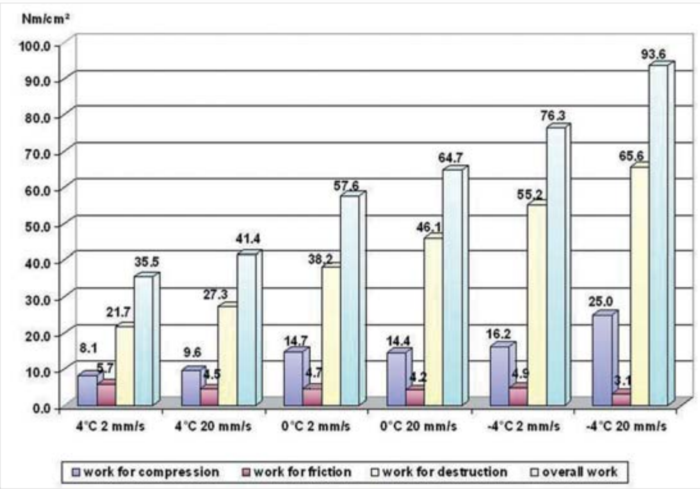

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Fig. 11: Cutting works of pork back fat at different temperatures and speeds (n=10)

compression force of back fat was lower than that of pork and beef. The relatively compact and less flexible structure might cause less deformation, thus less compression in back fat sample. Conversely, at frozen temperature, the compression value of back fat was higher than pork than beef regardless the speed; hence the first point where knife started to cut frozen back fat required relatively higher force than that of frozen meat.

The friction works of back fat were entirely lower than the friction works of beef and fat. Animal fat has been used to reduce the coefficient of friction in some applications. Friction is lower, because there is less interaction between two moving surfaces. The total works of back fat were almost completely higher than with pork except for the lengthwise cut at 0 °C and 20 mm/s cutting speed. For beef, the total works of back fat were higher excluding lengthwise cut beef which was treated at higher speed.

Pork back fat has high rigidity to endure the cutting forces. Furthermore, there might be some variances due to two layers present in pork back fat. Pork subcutaneous back fat has two main layers. The outer layer, in which the supporting connective tissue appears to be a continuous three dimensional network with branching to the dermis, is separated from the inner layer by a thin layer of connective tissue (HAUSMAN, 1978). These complex structures will impart anisotropy in mechanical properties of back fat. Apart from this, connective tissue is also a major contributor to breaking stress under tension and is related to firmness in pig back fat (WOOD et al., 1984). However, it can be generally concluded that the total works of back fat were higher than with pork but less than lengthwise cut beef, only at higher speed.

Conclusions

The Warner Bratzler measurement is a combination of compression, friction and disintegration forces. Its curve is generated by measuring the force as blade is pulled at a constant speed through a sample of meat. The curve depicts a plot of the resultant force F(x), against distance (x) covered by the blade. The measured shear force can be divided into three constituting forces. Expression of compression force (f-comp(x)) and friction force (f-friction(x)) as functions of x were calculated through determining points (point of maximum compression and point of maximum friction force/end of cutting force).

This study displayed apparent trends; decreasing temperature and increasing speed resulted in higher total cutting works. Cutting works are influenced by many factors such as temperature, cutting speed, fibre orientation in meat, type of material (meat or fat) and type of meat (beef or pork). From the method used, there could be some deviation due to sample movement during measurement.

Practical importance

Mincing, chopping and cutting are very important processes for preparation of meat for further uses. Necessary is a high amount of energy in dependence of kind of meat and cutting conditions. Otherwise the input of energy influence the quality of disintegrated meat. So there can be effected for instance smearing processes during mincing or too high destruction during slicing processes. The practical importance of this work is to find a method for evaluation the different forces during cutting processes and on base of this to create a data base for effected forces by different cutting conditions. On base of this there can be optimised conditions of mincing, cutting or chopping in dependence of requirements of specific finished products or there can developed specific knifes for specific equipment.

From this study, high friction could be obtained under chilled temperature (4 °C) and at low speed (2 mm/s). On the other hand, the production of meat mincing requires less friction so that it maintains good appearance in terms of colour. Less friction could be generated by cutting at high speed (20 mm/s) under chilled temperature (4 °C) or at any speed under low temperature (0 and –4 °C).

Fibre orientation for instance is important especially for mincing processes, because in dependence of flow conditions there could be found in meat mincers a less or more lengthwise fibre orientation.

Higher total works will be produced at frozen temperature (–4 °C) and higher speed (20 mm/s). Thus it is reasonable to perform meat cutting under chilled temperature and low speed for energy saving purposes when it is not necessary to reduce friction.

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