Modelling of Mincing Process by Determination of Meat Cutting Properties through the Analysis of Warner Bratzler Curve

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Abstract— **An integral operation in the production of many meat products is the necessary size reduction in particle size undertaken by meat mincers. Mincing machines work by rotating shear. The meat is sheared between the knife edge and perforated grinding plates while under pressure.**

This model seeks to describe the forces and necessary work required for compression, friction and disintegration of meat pieces during shearing, when mincing is undertaken at different cutting speeds and temperature.

In this experiment, a Warner Bratzler system with a 3 mm edge was used to puncture meat at 3 different temperatures and two feed speeds. Conditions in a Warner Bratzler system are comparable with a simple one holed grinding operation.

Total cutting work increased with decreasing temperature and increasing speed. Average compression work reached its maximum at 0°C and intensified with cutting speed. Compression was higher at chilled temperature than when frozen. Average friction reached its maximum value at 4°C, with frozen meat showing lower friction than chilled meat. Disintegration exhibited its maximum value with frozen meat.

It is concluded that cutting forces were influenced by many factors such as type of meat, temperature and cutting speed.

Keywords— **Cutting Work, Warner Bratzler system, Grinding**

I. INTRODUCTION

Grinding is an important and complex operation in the meat industry, which includes compression, shearing, extruding, rubbing and size reduction. According to Kamdem & Hardy [1], there is a correlation between grinding parameters and cutting force. This correlation can be used to predict the energy requirement for grinding. Cutting tests conducted with a Warner Bratzler blade; which employs compression, friction and disintegration force can be regarded as a simplified grinding operation. The difference between conditions in a grinder and Warner Bratzler system is that meat in a Warner Bratzler system is not under pressure. Conditions for shearing in a Warner Bratzler system are in principle comparable with the practical conditions involving a grinder featuring one knife and a grinding plate with one hole. The presence and intensity of different cutting forces are not only influenced by the properties of the cutting machine, i.e. meat grinder. Another influence can be the physical characteristics of meat being cut; such as type of meat, part of meat, fat and connective tissues percentage and muscle fibre orientation. The purpose of this research is to determine the cutting properties of meat with variation in factors such as type of meat, temperature and cutting speed by analysing the contribution of the different types of force that occur during cutting. By understanding the relationship between these factors and the cutting properties of meat, the meat mincing process can be optimised. This is important, as the grinding operation is an energy expensive process in the meat industry.

II. MATERIALS AND METHODS

A. Sample preparation

Four kinds of meat were selected for measurement: beef (topside and silverside), pork (shoulder), turkey (breast part) and pork backfat. Three days post-slaughter cooled meat was sourced from Flepro Fleisch und Wurstwaren GmbH, Bernburg, a regional meat processor. Fat and connective tissues were trimmed from meat where necessary, then cut to achieve a triangular piece of meat with an area of 3 x 3 x 3 cm (Fig. 3). The samples were then wrapped to avoid moisture loss and placed in a Styrofoam box and stored in the refrigerator (0°C) or freezer (-20°C) until the required temperature was obtained (4, 0, -4°C). The temperature was checked before and after cutting by IR thermometer to assure there was no considerable temperature change.

B. Equipment preparation

The Warner Bratzler measurements were undertaken when the samples were centrally placed under the blade, then 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 a Warner Bratzler knife (Fig. 1). The speed of the Warner Bratzler knife was set at 2 and 20 mm/s.

Fig. 1: The use of a Warner Bratzler device in force measurement

C. Data measurement and interpretation

Data measurement and interpretation was done according to Schnaeckel et al. [2].

The initial step in this experiment was to determine the point at which compression starts and when maximum compression occurs. This step was done by running the Warner Bratzler knife until the triangular edge of the blade was in full contact with the meat surface. This point is the start of compression (*X3*, Fig. 2a) and was determined by visual observation and verified by analysing the Force-Distance-curve. The point of maximum compression (*X1*, Fig. 2a) was determined afterwards by observing at which depth the knife started to cut into the sample. When the applied force exceeded resistance, the meat would be cut. This is the point of maximum compression. Compression force starts to decrease as the knife enters deeper into the meat, while friction force begins to increase at this point, as there is increased contact between blade and meat. Consequently, at the end of cutting, the point of maximum friction could be obtained.

Fig. 2a presents the Warner Bratzler curve produced from meat cutting. From the curve, the total area (Ncm), the area from start of compression until max compression (*A1*), force at start of compression (*F1*), force at maximum compression (*F2)* and force at maximum friction (*F3*) could be obtained by Texture Analyzer. Using the above data, equations for friction and compression could be derived (Fig. 2b).

These curves are created in order to determine the area under the curve. The total 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, compression, friction, disintegration and overall work was obtained.
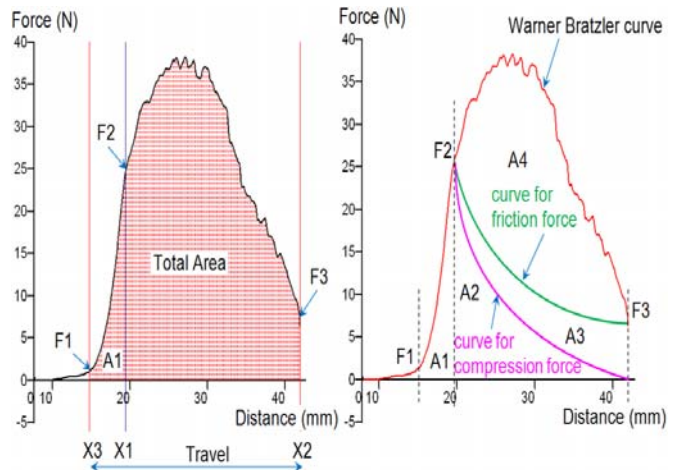

Fig. 2a-b: Typical plot of Warner Bratzler curve for pork meat (2a, left) and calculated curves for compression and friction force (2b, right)

Every treatment combination was measured 30 times, selected by fibre orientation. 10 samples were cut lengthwise, 10 crosswise and 10 perpendicular to fibre orientation (Fig. 3). This was done to simulate the uncontrolled fibre direction in meat mincing machines. The data was statistically analysed by use of Analysis of Variance (One Way) to test the significance of parameter effects at the 5% probability level ($P < 0.05$).
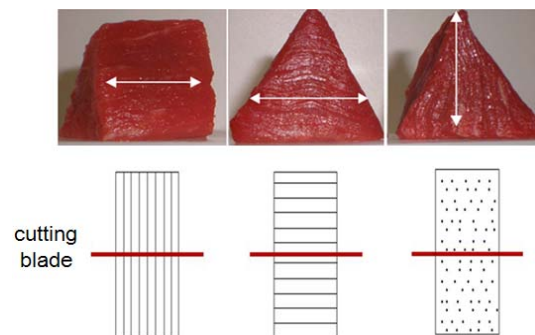

Fig. 3: lengthwise, crosswise and perpendicular fibre orientation

III. RESULTS AND DISCUSSION

Figure 4 shows the results for meat cut by a Warner Bratzler knife with varying temperature and blade speed of 2 mm/s. Figure 5 shows the results for 20 mm/s.
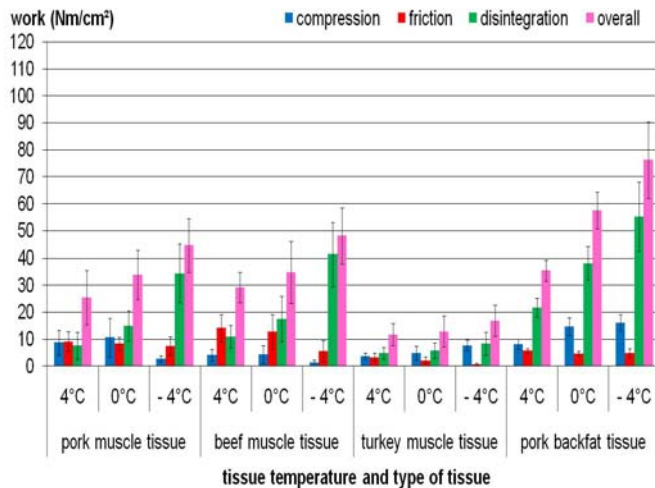

Fig. 4: Cutting work for a Warner Bratzler knife with 2 mm/s cutting speed for different meat temperatures and meat from different species (n = 30 per treatment)
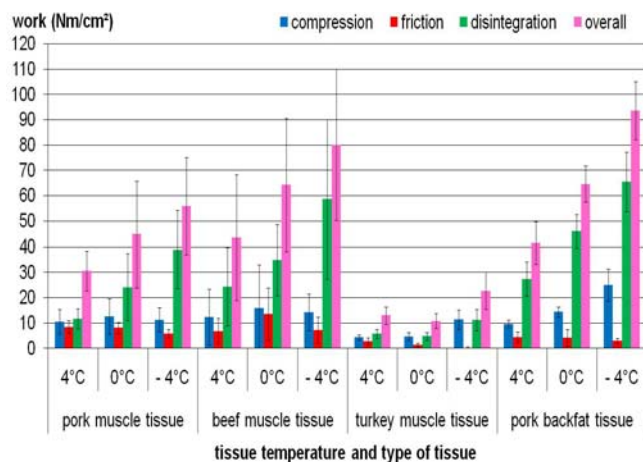

Fig.5: Cutting work for a Warner Bratzler knife with 20 mm/s cutting speed for different meat temperatures and meat from different species (n = 30 per treatment)

Figure 4 and 5 show that for different meat types the cutting properties are different by value for compression, friction and disintegration. The influence of temperature and cutting speed is the same for every type of tissue. With decreasing temperature a decrease of compression and friction during cutting was observed, as well as an increase of disintegration and the overall cutting force required.

Meat is a material with a flexible fibrous structure that requires compression force directed at its centre to be cut. This force will be spent on elastic and plastic deformation before friction and disintegration force come to pass. During compression, the product will initially deform in line with the blade edge. When the compression force exceeds the resistance of the meat, the meat will be cut. As stated by Fellows [3], meat is usually tempered just below freezing point to improve cutting efficiency. According to Gac (1976), as quoted by Faraq et al. [4], increasing the percentage of frozen water may decrease plasticity and increase shear resistance at low temperature; at -5°C the water in meat is 75-80% frozen.

Frictional force depends on what type of surfaces are involved, in this case meat and knife, and how hard the surfaces are pressed together. The knife which cuts a frozen sample will melt ice along its edge, thus emerging water will lessen the friction work due to reduced interaction between surfaces. As stated by Fellows [3], water will act as a lubricant in some food products. This can explain the decrease in friction seen at lower temperature.

Disintegration in the different types of tissue showed a clear trend across different temperatures and cutting speeds. The higher the cutting speed and the lower the temperature, the higher the disintegration work required. This finding is aligned with a study done by King [5]. King found that an 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 in feed velocity.

Overall work was correlated with disintegration. Increasing speed and decreasing temperature required higher overall work in beef and pork. This result is comparable with a study done by Brown et al. [6] which showed, that cutting force in beef at -5°C is higher than at 5 and 15°C, and that force increases with cutting speed. Brown also concluded that the temperature difference from 15 to 5°C had little effect on the maximum cutting force.

In Figure 4 and 5 a relatively high standard deviation is evident. This is caused by the three fibre orientations used. In Figure 6 the data for pork selected by fibre orientation is shown.

According to Figure 6, compression forces are highest when cutting in a lengthwise fibre orientation, lowest when cutting in a perpendicular fibre orientation. The same result was found for necessary disintegration work.
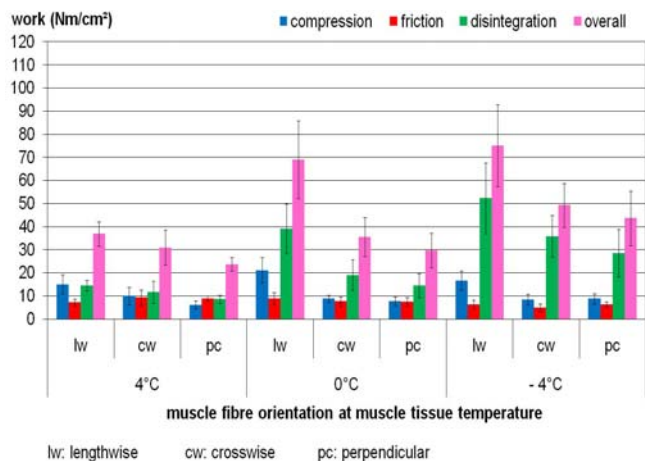
Fig. 6: Cutting work for a Warner Bratzler knife at 20 mm/s cutting speed for pork at varying temperatures and fibre orientations (n = 10 per treatment)

Friction during cutting is not influenced by fibre orientation, but by temperature. Frozen meat resulted in less friction than chilled meat. Temperature also influenced disintegration and overall work for cutting. The highest value for cutting work was found for frozen meat. As stated by Faraq et al. [4], a much greater force is required to cleave samples cut across fibre than the other fibre orientations.

Under practical conditions an inhomogeneous flow of meat from the grinder output can be observed (Fig. 7).

Fig.7: View of a grinder output (last plate). The differences in length of meat pieces are visible.

Due to the constant pressure in the "cutting room" (the area between the two plates that contains the rotating knife) inhomogeneous flow can be explained only by the inconsistent texture properties of the meat pieces.

Variations in texture can be caused by differences in the type of tissue or by fibre orientation.

IV. CONCLUSION

The Warner Bratzler measurement system examines and identifies a combination of compression, friction and disintegration forces. Its curve is generated by measuring force as a blade is pulled at a constant speed through a sample of meat. Conditions in a Warner Bratzler system are comparable with a simple one holed grinding operation.

This study displayed that apparent trends: decreasing temperature and increasing speed result in higher overall cutting work. Cutting work is influenced by many factors such as temperature, cutting speed, fibre orientation in meat and type of meat (beef, pork, turkey or pork backfat). A potential area of deviation in this experiments methodology is potential meat sample movement during the measurement process.

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