ELECTRICAL MEASUREMENT FOR DETECTING EARLY POSTMORTEM CHANGES IN PORCINE MUSCLE

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S-IVB.24

Introduction

In a recent study by Kauffman et al. (1992), a survey of 14 U.S. pork plants revealed that only 16% of the carcasses were considered to have ideal quality on the basis of color, firmness, and water holding capacity. Pale, soft, and exudative (PSE) lean was found in 16% of the carcasses, 10% were dark, firm, and dry (DFD), and over 50% of the carcasses were normal in color, but the muscles were soft and exudative. If the incidence of problems such as PSE is to be effectively controlled, quality parameters must be incorporated into the market price of a hog. Therefore, it is important to develop sensitive and accurate instrumentation to detect quality abnormalities on line before carcasses are lodged in the chill cooler.

Low frequency electrical impedance measurements can provide insight into the structure and viability of muscle tissue. Relationships between pork quality and its electrical properties have been studied by several investigators, who have shown that low frequency electrical conductivity and capacitance of muscle is related to water holding capacity (Swatland, 1981,1982; Pfutzner and Fialik, 1982). Since PSE formation is linked to higher rates of pH change, cellular breakdown, and an increase in extracellular fluid, the hypothesis that conductivity of PSE muscle should be higher than normal muscle seems valid. However, there are many authors with conflicting reports on the ability of commercial conductivity sensors to detect carcasses with poor water holding capacity and ultimate quality in the early postmortem stage. Typically, PSE meat yields higher average conductivity values at 45 and 60 minutes postmortem, but the standard deviation of the measurements have been too large to allow adequate differentiation between normal and abnormal quality (Fortin and Raymond, 1988; Warriss et al., 1991).

Accurate measurement of low frequency biological impedances is difficult due to the interface between the electrodes and the electrolytic material being measured. This interface is referred to as electrode polarization and its magnitude and phase depend on both measurement frequency and current density. In muscle tissue, electrode impedances are usually on the order of a few kilo ohms _ and the impedance of tissue is usually a few hundred ohms. Bipolar electrical measurements in biological materials may be subject to large impedance errors due to electrode polarization. Use of a constant current, tetrapolar circuit permits the highest accuracy in measurement of biological impedance at low frequencies because complications due to electrode polarization are avoided. Current is injected through two outer electrodes, and the potential is measured between the two inner electrodes using a differential oscilloscope with high input impedance. If the input impedance of the oscilloscope is high with respect to the sum of the two electrode interface impedances and the impedance of the tissue, negligible current flows into the inner electrodes, minimizing polarization.

This study focused on fundamental relationships between electrical properties of muscle and meat with other variables, such as time postmortem, pH, frequency, and electrode configuration, with a goal of identifying optimum conditions needed to predict muscle cell membrane and ionic changes in the early postmortem stages.

Materials and Methods

Twenty-five randomly selected hogs were stunned on the left side, with one electrode placed posterior to the base of the ear and the second approximately 36 cm caudal, using 60 Hz, 300 V, for approximately 10 seconds, shackled by the right hind leg, and exsanguinated. After exsanguination, a section of the longissimus muscle (LM) was excised from the last rib to the 2nd lumbar vertebra. This sample was used to monitor rigor shortening patterns and complex impedance behavior.

Excised Muscle Measurements

Rigor shortening patterns were monitored using methods and the apparatus described by Forrest et al. (1969). Two muscle strips were taken from the LM running parallel to the muscle fibers and immersed in mineral oil in jacketed temperature chambers held at 37 C. The rigor patterns and tension development were monitored by a data acquisition system for a period of 10 hours, with measurements taken every 20 seconds. The time of rigor onset, rigor completion, total time of onset to completion, and rate of muscle shortening were extracted from the shortening patterns.

A tetrapolar electrode circuit was used in the complex (i.e., magnitude and phase angle) impedance measurements as described by Littwitz et al. (1990). The LM sample was wrapped tightly in saran with low oxygen permeability, and four needle electrodes spaced 1 cm apart were placed perpendicular to the muscle fibers 4 cm deep into the muscle. The muscle sample was held at 37 C and impedance and phase angle were recorded using a 1 kHz sinusoidal current of 0.156 mA rms over a period of 10 hours. A cell constant was used to convert resistance measurements to resistivity and was calculated by comparison of measured resistances of saline solutions with conductivities measured by a YSI conductance probe (Yellow Springs, OH). Repeated calculations of cell constant were performed before and after each muscle measurement to determine if characteristics of the measurement technique were changing over time. A variation in the electrical circuit affected the magnitude of the measured impedance in the first nine muscle samples. In addition, small variations in electrode orientation with respect to fiber orientation may have caused large differences in measured transverse impedance. Therefore, relative magnitudes were calculated by normalizing both impedance (Z) and phase angle(θ) to the value of the initial postmortem measurement.

Early Postmortem Carcass Measurements

At 15, 45, and 90 minutes postmortem, conductivity measurements of the right side intact LM muscle were taken at the last rib using the Tecpro PQM probe. The parallel electrodes of the probe were inserted between the exposed vertebrae on the midline of the split carcass opposite the last rib.

At 15, 45, and 90 minutes postmortem, LM samples were taken from the 12th, 10th, and 8th ribs , respectively, from the right side. The ATP/IMP absorbance ratio and pH were evaluated using this sample. The ATP/IMP absorbance ratio assay (R-value) as described by Honikel and Fischer (1977) was performed in duplicate. pH was measured in duplicate by homogenizing 1 gram of muscle tissue in distilled water for 10 seconds and measuring the pH with an Orion glass electrode.

24 Hour Carcass Measurements

At 24 hours postmortem, one section of longissimus was taken from the 8th to the 10th rib on the left side. Water holding capacity, pH, R-value, color and subjective quality scores were measured.

Water holding capacity (WHC) was measured by the filter paper press method (FPP) using 0.3 grams of muscle tissue and Whatman #41 filter paper. A pressure of approximately 700 kPa was applied for 30 seconds using a Carver Press. 3 replications of this measurement were completed at 24 hours postmortem. The total area was divided by the area of the thin meat film to obtain a measurement of exudativeness.

A section of the LM muscle 2.5 cm in thickness was allowed to bloom for 30 minutes after excision from the carcass. Hunter Color L*a*b measurements were made on the tissue sample at 5 different locations on the muscle surface and averaged. Subjective color, marbling, and firmness were evaluated using 5 point scales set by NPPC standards (Kauffman, 1992).

Results and Discussion

Relationships between lean exudativeness, color, and marbling with some of the postmortem predictors of quality are shown in Table 1. Increased exudation as measured by the Filter Paper Press method (FPP) was related to increased ATP depletion at 90 minutes, low pH_{90}, faster rates of pH decline, lower pHu, and faster rates of rigor onset and completion with a correlation coefficient of approximately 0.4. At 90 minutes and 24 hours postmortem, conductivity measured by the Tecpro PQM probe had the highest correlations with FPP. The Hunter Color value of "a" was significantly correlated to early postmortem measurements. Muscles with rapid pH declines, ATP depletion, and onset and completion of rigor resulted in a lean with redder hue. These results demonstrate that color is not a good indicator of exudativeness due to the existence of carcasses with red, soft, exudative (RSE) lean. Marbling scores were lower for carcasses with faster postmortem glycolytic rates. The presence of marbling may lead to lower conductivity (or higher impedance) measurements due to fat's insulative properties, which may attribute to the negative correlations between marbling and PQM measurements.

Table 2 shows correlations between pH, R, and PQM measurements at different times postmortem. PQM measurements become more correlated with pH and R as the postmortem period progresses, indicating that 90 minutes may be the earliest time that the Tecpro PQM probe is sensitive to changes in muscle structure. Another important observation is the lack of correlation between ultimate pH and any other measurements of pH, R, and PQM. This observation may be partially explained by the fact that 5 hogs in the study were known to be homozygotes (nn) for the stress gene. pH in homozygotes has been observed to return to normal pH_u levels (van Laack et al., 1993).

The average value of measured impedance at 37 C was 1445 216 ohm-cm and the average value of the phase angle was 8.251.84 degrees. These values are comparable to impedance and phase angles reported by Zheng et al. (1984) for excised porcine muscle at 37 C. The magnitudes of impedance and phase angle changed as a function of time. Since wide variation in impedance and phase angle magnitudes existed between muscle samples, the measurements were normalized for each sample by dividing by the initial measurement of impedance and phase. A summary of the relationships between measured relative impedance (Z) and phase angle (θ) values with postmortem pH, R-values, and rigor patterns measured on the excised LM is shown in Table 3. Relative impedance and phase angle measurements were characterized by the following variables: Time of initial low Z and θ value, Time of peak Z and θ value, Relative magnitude of Z and θ peak value, Relative magnitude of Z and_θ at 15, 45, 90, and 120 minutes postmortem, and the change in Z and θ between different times postmortem.

In muscle samples with high postmortem metabolism, the relative magnitude of impedance and phase angle initially increased rapidly, peaked within the first hour postmortem, and then both Z and θ began to decrease. This relationship is illustrated by positive correlations of approximately 0.68 between time of Z peak and time of rigor completion. One carcass in the study which exhibited an extremely fast decline in pH and onset of rigor showed an immediate decrease in Z and θ. In muscle samples which exhibited slower postmortem changes, Z and θ initially decreased slightly, and then began to increase. This increase in Z and θ tended to be slower and resulted in higher relative peak values shown by a negative correlation of nearly -0.6 between Zpeak and θpeak with rate of rigor completion. Correlations between pH, R, and muscle shortening with electrical properties of the muscle were slightly higher for the θ measurements. θ values reflect both the changes in muscle resistance and the change in muscle capacitance.

The 25 carcasses were divided into two groups based on FPP, with 17 carcasses classified as normal WHC (FPP<1.95) and 8 classified as abnormal WHC (FPP>1.95). Table 4 is a summary of measurement mean values for normal and abnormal WHC. Mean values of pH and R at 45 and 90 minutes, rate of pH fall, time of rigor onset and completion are all significantly different. Ultimate pH value was not significantly different between the two groups. The abnormal WHC group had significantly lower marbling scores and a higher Hunter Color "a" value. Conductivity measured by the PQM probe on the intact carcass was significantly higher for the abnormal WHC group at both 90 minutes and 24 hours, but was not different at 15 or 45 minutes.

Relative impedance began to increase in a shorter period of time following excision in the abnormal WHC group. Mean values of Z and θ were higher for the abnormal group at 15 minutes postmortem, but began to decrease more rapidly between 15 and 90 minutes, leading to lower mean values of Z and θ at 90 minutes postmortem. The mean value of θ at 90 minutes was significantly lower for the abnormal WHC group, indicating that muscle capacitance was decreasing more rapidly in this group between 15 and 90 minutes postmortem.

Conclusions

Tecpro PQM probe had the highest success in indentifying carcasses with low water holding capacity at 90 minutes and 24 hours postmortem, but had little success at 45 or 15 minutes postmortem. Impedance and phase angle measurements on excised muscle samples showed that muscles in the abnormal WHC group had a more rapid increase in impedance and phase angle in the first 60 minutes postmortem, while many samples in the normal WHC exhibited a short decrease in impedance and phase angle in the first 15 or 20 minutes. Therefore, measurements of the rate of change of conductivity or impedance and phase angle may be more successful before 1 hour postmortem. In addition, measurement of the phase angle may be more effective in identifying carcasses with abnormal water holding capacity.

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