CONSTANT CURRENT ELECTRONARCOSIS OF MARKET POULTRY

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(ABSTRACT)

This study was conducted to optimize the parameters involved in the electronarcosis of market chicken and turkeys. A prototype constant current stunner designed at the Department of Electrical Engineering of Virginia Polytechnic Institute and State University was used. Broilers were electrically stunned with 8, 29 and 50 mA per bird. Turkeys were electrically stunned with 10, 30 and 50 mA per bird. Three weight classes, controlled by age, were used as treatment levels. Broiler males were grown for 36, 43 and 50 days while females were grown for 37, 44 and 51 days. Turkey hens were grown for 84, 98 and 112 days, while toms were grown for 112, 126 and 140 days. Pre-stun levels of 3, 5 and 8 hours of feed and water withdrawal were used for each weight class and sex. The effect of sex, weight and feed and water withdrawal on stunning efficiency, recovery time, blood splatter, bone breakage, color and pH of the breast meat was determined. The experimental unit for each specie, sex, weight and feed withdrawal class used was a "pen" comprised of 10 birds. A total of 130 birds, by gender and specie are used for each repetition. Two repetitions of all experiments were accomplished. A third repetition was done in turkeys, but this time a cooping time of three hours prior to slaughter was added. All data was statistically analyzed with ANOVA and a Box-Behnken response surface design was used to optimize the current for the different experimental variables. Results indicated a significant ($p \leq 0.0001$) gender difference in resistance, recovery time and prevalence of defects in both broilers and turkeys. Optimization of the stunning process parameters was not achieved due to inability of the model to express logistic regression equations at the levels used in this study.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

There are several reasons for the stunning of poultry prior to slaughter, one being the humane need for a process that will reliably render an animal insensible to pain and sensation prior to death, another to render the bird motionless to facilitate head capture for bleeding and also to reduce struggle during bleed-out. Among the stunning methods available for use, electrical stunning is the method of choice used by the poultry industry (Stadelman et al., 1988).

In the United Kingdom, the Farm Animal Welfare Coordinating Executive (1980), quoted by Heath (1984b), reported that electrical stunning of poultry is particularly unreliable where the water bath method is used, indicating that "in a test of significant size, one third of the birds emerged dead from the water bath and another third were understunned".

Live production and bird handling practices have been incriminated among the factors contributing to the occurrence of bruises and hemorrhages; however, a more significant number of these defects are thought to occur during the slaughter process (Bilgili, 1992). Ineffective electronarcosis results in defects which cause downgrading of the poultry carcasses, decreasing their value and increasing the cost of production. According to Gregory et al. (1990) electrical stunning is one of the most important causes of bone breakage during processing of turkey hens. Application of an excessively high voltage during stunning has been associated with a high incidence of quality defects. These include broken bones (Gregory and Wilkins, 1989a), exploded or damaged viscera (Heath, 1984a), bloody wing joints, red wing tips (Heath, 1984a), blood splattering in the breast meat (Veerkamp and de Vries, 1983), shoulder hemorrhages (Gregory and Wilkins, 1989b) and inadequate bleed-out from major blood vessels (Gregory and Wilkins, 1989c). All of these result in a decrease in the value of the meat products.

This study was performed to optimize the stunning of market age chickens and turkeys, utilizing an electronarcosis system that applies constant electrical current by adjusting voltage to compensate for the bird-to-bird variability in resistance.

II. REVIEW OF LITERATURE

A. REASONS FOR STUNNING

1. Regulations

As stated in the *Humane Methods of Slaughter Act of 1958* all livestock under U.S.D.A. inspection must be humanely slaughtered (National Research Council, 1985). Though the law does not include poultry in its definition of livestock, the Poultry Inspection Regulations of the U.S.D.A. (Code of Federal Regulations, 1992) state that "Poultry should be slaughtered in accordance with good commercial practices in a manner that will result in thorough bleeding of the carcasses; assuring that breathing has stopped prior to scalding".

The nature of the method used for the stunning of poultry prior to slaughter can be chemical, mechanical or electrical; with electrical stunning being the method chosen by this industry to induce unconsciousness in the birds. In electrical stunning a sufficient amount of electricity must pass through the brain of the bird for a given amount of time to produce instant unconsciousness (American Veterinary Medical Association, 1978) and induce a reversible state of insensibility for a short period of time. If the time required to induce unconsciousness from bleeding exceeds the length of the insensibility period induced by the stunner, feel pain and suffer (Grandin, 1989; Gregory and Wotton, 1986).

The sensation of pain is initiated when damage or intense stimulation of tissue occurs. Substances such as histamine, angiotonin, serotonin, prostaglandin, bradykinin, adenosine triphosphate, and H^+ and K^+ ions, are released from the damaged tissue and modulate or stimulate pain receptors that send impulses to the thalamus and cerebral cortex resulting in the recognition of pain by the animal. For pain to be experienced, the cerebral cortex and subcortical structures must be functional. An unconscious animal does not experience pain because the cerebral cortex is not functioning as a result of treatments such as hypoxia, depression by drugs, electrical shock or concussion (A.M.V.A., 1978).

2. Carcass quality

The use of electrical stunning not only allows for the performance of humane slaughter practices but also has the benefit of facilitating the slaughtering operation through the physiological conditioning of the birds that results from the relaxation of the muscles of the neck and contraction of the wings which permits a proper cutting of the veins during exsanguination. Wing flapping and bird struggling is diminished during bleed-out (Dickens and Shackelford, 1988). In addition, blood pressure, heart beat and respiration, are stabilized during stunning and picking is made easier (Wabeck, 1987).

B. THE TECHNIQUE OF ELECTRICAL STUNNING

According to the wide variation in resistance from bird to bird, reported by Schutt-Abraham et al. (1983) and Heath (1984b), stunning at low voltage would allow some birds to regain consciousness before venesection and some would go sentient into the scalder.

To reliably induce instantaneous insensibility after stunning, a sufficient current (amperage) must pass through the brain of the animal (Croft, 1952); therefore enough voltage (pressure) must be applied since only a small portion of the total current will follow the brain path and the rest will remain on the surface of the body (Grandin, 1989). The use of a power supply that maintains a constant current flow has been recommended (Grandin, 1989; Heath, 1984b; Ingling and Kuenzel, 1978, Sparrey et al., 1992) since the current is what induces unconsciousness and the voltage is the pressure that pushes the current through the animal. With constant current, the voltage is the parameter which fluctuates depending on the resistance of the animal.

In the past, electrified knives and contact grids and plates have been used to achieve stunning, none of these methods are being currently used with the exception of hand-held stunner knives which continue to be effective in small scale operations (Gregory and Wotton, 1990a). At present, the most common electrical stunning method used in commercial operations is a brine water bath.

1. Review of electricity and electrical circuits

Usually electricity is expressed in terms of amperes. One ampere (A) is the flow of one coulomb of electricity (6.28 billion electrons) through a single point during one second:

$$I(\text{current, amperes}) = \frac{\Delta Q \text{ (charge, coulombs)}}{\Delta t \text{ (time, seconds)}}$$

The amount of force required to move one coulomb of electricity through a resistance of one ohm is termed one volt. Ohm's Law expresses these relationships as:

$$\mathbf{V}(\text{voltage,volts}) = \mathbf{I}(\text{current, amperes}) \times \mathbf{R}(\text{resistance, ohms})$$

Thus, as voltage increases, the current moved through the circuit for a given resistance, increases as well.

Electrical power is measured in watts and one watt is consumed when one ampere of current flows through one point to another under the pressure of one volt (Bilgili, 1992).

An alternating current or voltage is defined as one which varies, repeating its pattern at regular intervals of time called the period, and whose time averaged value over a period is zero (Kuenzel and Ingling, 1977). To produce an alternate current (AC), electrons in the coil are driven in opposite directions. A direct current or voltage is one which is always in the same direction (positive or negative) with respect to a reference level. In a direct current (DC), electrons flow from a steady source in the same direction through a circuit in a constant or pulsatile way. In both types of current, frequency refers to the number of cycles per second and is expressed as Hertz (Hz), household currents alternate at 60 Hz. Both AC and pulsed DC currents, can be modified to alternate at higher frequencies (Tippens, 1989).

The resistance of a conductor is an inherent property and it is independent of current and voltage. The resistance of a wire of uniform cross-sectional area is determined by (Tippens, 1989):

- **the kind of material:** different materials offer varying amounts of resistance to the flow of electrons.

- **the length:** the resistance of a conductor is directly proportional to its length.
- **the cross-sectional area:** the resistance of a wire is inversely proportional to its cross-sectional area.
- **the temperature:** for most metallic conductors, the resistance increases directly with temperature. However, the resistance of most liquids and nonmetallic conductors decreases with a raise in temperature.

Regardless of current or circuit type, in brine-bath stunners the birds suspended by their legs on shackles represent a parallel set of resistors with each bird acting as a separate circuit. The total current flowing through this parallel arrangement in the stunner is the sum of all individual currents (Bilgili, 1992). The resistance of the system includes the inherent resistance of the stunner as well as the resistance of the birds (Ingling and Kuenzel, 1978).

2. Commercial stunners

Ingling and Kuenzel (1978) reported that a variety of electrical systems are presently available and in use in processing plants to stun poultry prior to slaughter. However, they also mentioned that no detailed description of the stunning circuits have been published, the type of circuit used at a determined plant being unknown.

Regardless of the current type, electrical stunning results from the interaction of electrical force (voltage), current (amperes) and resistance (ohms).

In the assumption that all commercial stunner have similar design and operating principles, Sparrey et al.(1992) describes them as a moving line with birds suspended by their legs from shackles going above a water bath maintained between 80-120 volts. The birds are submerged in the charged bath for a determined time dependent upon the type of bird being processed.
Bilgili (1992), discussed the importance of factors such as proper control of brine solution, adequate contact between bird and stunner, provision of enough stunning time (approximately 7seconds) and a close monitoring of the process, when using a brine-bath stunner.

Brine stunners have lower inherent resistance (less than the bird), and fresh-water stunners have higher inherent resistance than the bird. The plate stunner has a resistance intermediate between the brine and fresh water stunner and also has a greater variability in resistance (Ingling and Kuenzel, 1978; Kuenzel and Ingling, 1977).

3. Current path on electrical stunning

Woolley et al. (1986a) have reported differences in the proportion of current flowing through the various tissues of a bird for a given current level. They reported a higher proportion of the total stunning current flowed through the paths of least resistance e.g; breast muscle, cardiac muscle and brain. Under commercial conditions, electrical currents applied to broilers in a head-to-feet direction, enters the brain through either the optic nerve, the spinal cord or the skull bone (Woolley et al., 1986b).

4. Conditions used in electrical stunning

In Germany, Schutt-Abraham et al. (1983), using a water bath stunner, measured the current flow in individual broilers when applying a range of 40 - 120 volts for 4 seconds and found that at 70 volts an average of 46 milliamps was obtained which resulted in adequate stunning in 62% of the birds, but at lower amperages only 19% were properly stunned. Birds "stunned" at less than 20 milliamps squawked and flapped as they left the stunner and tried to escape immediately after removal from the shackles. It was observed that stunning was improved by submerging the birds into the water at least up to the base of their wings. Veerkamp (1988) reported that a minimum of 20 milliamps/bird are required to achieve stunning, although 45 milliamps/bird is recommended for effective immobilization.

A survey done in 12 processing plants in Australia showed a line speed varying from 25 - 125 birds/minute; voltage of the bath from 55 to 165 volts; duration of stunning from 2 to 75 seconds and bleeding time 45 - 180 seconds. As a result of the variables, some birds were dead on leaving the stunner and prior to exsanguination, while others were not dead before entering the scald tank (Griffiths and Purcell, 1984).

Gregory and Wotton (1990b) reported when using a constant current water bath stunner with current waveform of 50 Hz sinusoidal AC, for 4-5 seconds; that increasing the current between 60 and 90 milliamps per bird caused 90% of the birds to fibrillate. When 45 and 60 milliamps per bird were used, some birds did not lose neck tension, and if this was used as criterion to asses stunning, it meant they were not properly stunned. They concluded that "a stunning current of no less than 105 milliamps should be used to provide at least 52 seconds of apparent insensibility and that currents of less than 75 milliamps should never be used".

Gregory and Wilkins (1989d) recommend the use of currents of less than 130 milliamps or greater than 190 milliamps to stun chickens, since they found the incidence of carcass defects to be lower in these ranges of current.

They reported an increase and then a decrease in carcass defects such as red wingtips, shoulder joint and hemorrhages of the wing veins with increasing current. The incidence of deep breast muscle hemorrhages was reportedly higher for currents above 130 milliamps, and broken bones occurrence was increased between 75 and 170 milliamps.

C. FACTORS AFFECTING STUNNING

Schutt-Abraham et al. (1983) reported no age, weight or sex effect on the resistance of broilers 6 to 8 weeks old, noticing that the individual resistance varies between and within broilers. These findings were supported by those of Heath (1984b) who reported dependency between current and the impedance of the individual bird, but indicated that age, sex and body weight had little effect on the impedance of broilers. He also noted that even though wetting the legs of layers reduces their impedance by up to 90%, it has much less effect on the impedance of broilers.

Grandin (1989) indicated that an animal's sensitivity to electricity can be affected by factors such as weight, fat thickness, access to drinking water prior to stunning, wetness of the skin, mineral content or salt content in the water which is on the skin, skin thickness and age. She describes old laying hens with scaly legs as having a higher electrical resistance than young broilers, noticing that the electrical resistance of poultry increases greatly as the animal ages.

Woolley et al. (1986a,b), determined the resistivity of different tissues of birds and found little variation from bird to bird with the exception of the skull bone which indicates that birds with thick and dense skull bones are most likely to be inadequately stunned. The abdominal fat tissue had the greatest resistivity of all tissues measured.

D. EFFECTS OF STUNNING ON POULTRY

1. Physiological effects

Lopes da Silva (1983) describes how seizures are induced by affecting the spontaneous electrical activity of the higher brain centers upon application of a sufficient amount of current to the brain. As a result of this seizure, a state of unawareness and unresponsiveness is induced (Gregory and Wotton, 1989) such, that birds are unable to respond to an external sensory stimulus. This seizure indicates that electrical stunning disrupts primary pathways in the brain, making it unlikely for the stunned birds to be responsive to sensory stimuli. In a previous study, Gregory and Wotton (1987) determined that currents above 100 milliamps per bird caused inhibition of epileptiform activity in the brain and that currents below 100 milliamps caused low frequency epileptiform activity.

Stunning stimulates muscle contractions and simultaneously decreases the heart and respiratory rates with an increase in blood pressure (Kuenzel and Walther, 1978).

Signs of effective stunning are body tremors, rigid extension of the neck, lack of response when the comb is pinched and absence of the corneal reflex (Heath et al. 1981). Some of the physical changes that may be observed during stunning include arched necks, open-fixed eyes, tucked wings, extended-rigid legs, quivering (tonic spasms and tremors), turned up tail feathers, and lack of defecation which decreases as the stunning current increases (Wabeck, 1987; Papa and Dickens, 1989).

Richard and Sykes (1967) reported that recovery from stunning at 90 volts for 4 seconds occurred within approximately 45 seconds after the electric shock was applied, with bradycardia (slow heart rate) persisting for about 2 minutes. All physiological parameters altered by stunning, were reported to return to normal levels within 60-75 seconds from stunning by Kuenzel and Walther (1978) and when the stunned condition was assessed by absence of corneal reflex, Scott (1978) reported that stunned birds remained unconscious for 35 to 40 seconds after stunning.

Gregory and Wotton (1990b) reported an increase in time for recovery of tension in the neck muscles with an increase in the stunning current of broiler chickens when using a water bath stunner. They also expressed the inability at that point, to establish the required duration of the insensibility period from electrical stunning in order to provide a humane kill.

In the United Kingdom it is required by law that birds must bleed for not less than 90 seconds before entering the scalder (Heath et al., 1981) and continuous research is being done to establish minimum periods for bleeding after venesection of poultry with the purpose, as indicated by Gregory and Wotton (1988), of ensuring that birds are allowed to bleed to death before scalding.

Mountney et al. (1956) observed that electrically stunned turkeys bled slower than those killed by other means, but that after sufficient bleeding time, no significant difference existed in the total amount of blood loss.

The relationship between maximal bleed-out and type of electrical circuit was studied by Kuenzel and Walther (1978) and by Kuenzel et al. (1978). Upon evaluating a variable frequency circuit, alternating current (AC) and a direct current (DC) circuit in stunning male chickens, these authors reported that maximal bleed-out was obtained when using high frequency stunning and that DC stunning produced the least blood loss, with no significant difference observed in the bleeding efficiency between the AC or variable frequency circuit. No correlation was found between maximal bleed-out and the rate of change in the heart rate and blood pressure after stunning using either circuit, suggesting that the distribution of blood following stunning is an important response of broilers for maximizing bleed-out.

Veerkamp and de Vries (1983) reported a decrease in blood loss after neck cutting when stunning voltage was increased from 75 to 200 volts. This was similar to those results reported by Kuenzel and Ingling (1977). A later study done by Veerkamp (1988) indicated that as the current level increased, blood loss decreased and a more red appearance of the carcass, especially at the wing tips and tail, was observed.

2. <u>Quality effects</u>

The importance of bleeding in relation with carcass quality presents a controversial issue and has been extensively discussed.

A chicken carcass has been considered to be well bled (Kotula and Helbacka, 1966a) if it does not present redness on the skin surface, engorgement of the visceral blood vessels, or congestion of the heart, liver and spleen. Inadequate blood removal from poultry can result in either downgrading or condemnation of the carcass as not suitable for human consumption. Kuenzel and Ingling (1977) indicated the importance of optimizing the bleed-out stage in poultry process in order to enhance the quality of the carcass. The potential downgrading due to excess blood in tissues as well as a possible condemnation of carcasses as cadavers was reported to be related with an inadequately bled-out bird. Scott (1978) reported that thorough bleeding improves the "keeping quality" of the meat. This concept was shared by Chambers (1979) who stated that "bleeding should be as complete as possible". However, a study conducted by Heath et al. (1983) reported that the incidence of pink or red skins birds was not related to the amount of blood left in the carcass and that this characteristic does not develop until the birds are machine plucked.

The method of slaughter had no relation with the blood distribution within a carcass as reported by Kotula and Helbacka (1966a) who found no significant differences in the percentage of total blood in breast, wing, thighs, drumsticks, back, liver, gizzard, feet, lungs, feathers, and liquid lost during cutting up. They found that the birds that were stunned retained the least amount of blood when compared with birds that were kosher-slaughtered or killed by other means, but that given time, the total blood loss evens out and no advantage of one method over another is evident (Kotula and Helbacka, 1966b).

Murphy et al. (1988) found no visible differences between stunned and non-stunned turkeys in effects such as red wing tips, reporting however, significantly less blood loss in stunned birds. This is in agreement with the findings of Pollard et al. (1973) who reported an increase in blood retained in the viscera of stunned broilers, suggesting that stunning produces a shock state in birds which results in whitening of the skin and pooling of blood in the viscera. Thus, the net effect would be an improvement in the surface quality of the birds without increasing the total blood loss.

It is well established that development of rigor and muscle shortening in poultry leads to greater muscle toughness and that delay of rigor by various methods contributes to greater tenderness (de Fremery and Pool, 1963; de Fremery, 1965; Lyon and Wilson, 1986). A study done by Lee et al. (1979) designed to determine the effect of stunning on biochemical changes and its relationship to final meat tenderness in broilers, reported that electrically stunned birds were more tender that the no-stun controls after 4 hours aging. It was concluded that electrical stunning inhibited the rapid breakdown of adenosine triphosphate (ATP), creatine phosphate (CP) and glycogen, delaying the onset of rigor until after chilling of the carcasses by which time the muscle temperature has reached 4°C. Consequently, the rigor process occurred at low temperature where potential heat shortening was avoided, and resulted in improved meat tenderness. Thompson et al. (1986) reported a significant effect of electrical stunning by elevating the pH of broiler breast meat immediately after slaughter, but no effect was observed after 24 hours aging and the effect of stunning on breast meat tenderness was not clear.

Murphy et al. (1988), reporting similar findings in the electrical stunning of turkey, observed a delayed postmortem glycolysis and rigor onset in turkey muscle with differences in muscle characteristics during the first 4 hours postmortem but with no effect from stunning after 8 hours. Previous work done by Goodwin et al. (1961) showed an improvement in the tenderness of breast and thigh muscles of electrically stunned turkeys related to an increase in "aging" time, but reported no significant effect of the slaughter method on the tenderness of breast meat and thigh meat after electrical stunning.

It is of common belief among poultry processors that the voltage used for stunning birds has an effect on certain carcass defects; ineffective bleed-out being one important defect of consequence. Wabeck (1987) reported the effects of improper stunning of poultry as a higher incidence of poorly bled birds, broken keels, broken wish bones, cadavers, deep red areas in legs, wings and breast, hemorrhagic thighs, bloated blood vessels in wings and red tips, broken wings, and broken capillaries in the breast muscle. Findings reported by Heath (1984a) indicated that stunning voltages were of no effect in the amount of blood drained from the carcass of broilers or in its appearance.

Wilson and Brunson (1968) reported that hemorrhaging in thighs of broilers was caused primarily by handling of the birds during loading and processing and by the struggling of the birds after they were placed in the processing line, a condition that appeared to be aggravated by electrical stunning. Bilgili (1990) in a review of carcass defects associated with downgrading of broilers, indicated that approximately 12% of all defects can be attributed to bruises and/or hemorrhages on processed carcasses; within this class, discoloration accounted for 11% of the total, and bruises on the wing, thigh, drum and breast accounted for 36,4,30 and 19% of the total, respectively. Total bruises values are higher than those previously reported by Griffith and Nair (1984) who indicated that downgrading in broilers due to bruises was in the order of 3-8%, with a higher distribution in breast and drumsticks. This distribution of bruises is in agreement with the findings reported by Benoff (1981) indicating that breast bruises are the largest component (50%) of downgrading in broilers.

Fleming et al. (1991) reported that the method used for immobilization of turkeys during slaughter affects muscle color, and supported the association between electrical stunning and incidence of hemorrhages in the muscles. Gregory and Wilkins (1989d) investigating this aspect on turkeys, found, upon evaluating defects such as skin and muscle hemorrhaging, broken bones and engorgement of veins with blood, that only breast hemorrhaging was affected by the stunning current.

Gregory and Wilkins (1989a) studied the effect of the stunning current at slaughter on carcass quality of broiler chickens and found that currents between 111 and 190 milliamps were associated with an increased incidence of red wingtips and hemorrhaging in the breast muscle, wing vein and shoulder.

Gregory et al. (1990) examined the effect of electrical stunning in conjunction with the effect of breed of hen on the incidence of broken bone damage. They found that breed, age of bird, and stunning currents had no effect on the incidence of broken bones. The use of high frequencies in stunning however, resulted in reductions in bone damage. Further study done by Gregory and Wilkins (1990) indicated that increasing the voltage increased the incidence of broken bones in the collar region of stunned broilers, and that this damage was mostly caused by processing. This is in agreement with the previous findings of Gregory and Wilkins (1989d) and Gregory (1988) who reported an increase in bone fracture with increasing voltage (over 100-300 volts range) and have also indicated that only the bones in the collar region appeared to be broken during stunning.

E. OTHER FACTORS AFFECTING CARCASS QUALITY

In addition to stunning voltages and currents, there are other factors during the slaughter process that contribute to the incidence and extent of carcass defects on processed broilers.

1. <u>Pre- slaughter condition of the birds</u>

It is believed that the physiological state of the vascular system can be affected by the extent of pre-slaughter stress experienced by the bird. Warris (1984) explains that the action of two neuro-transmitters (epinephrine and nor-epinephrine) released upon stress is to shunt the blood from the peripheral vascular beds into large central blood vessels, enhancing the extent of bleed out.

Darre (1984) reported sight restriction prior to slaughter as having a marked soporific effect on the behavior of chickens. This was reflected by gradual reduction in heart and respiration rates at slaughter, resulting in a lower carcass pH.

Antemortem wing flapping has been correlated with increased reddening of wing tips in broilers and turkeys (Gregory et al., 1989).

Benoff (1981) reported a higher incidence of carcass defects in summer and autumn months, which he explained by a longer residence of the broilers in the growing houses during these periods to compensate for the reduced feed intake during hot weather. Later work developed by Goodwin (1986) reported a seasonal effect on carcass bruising. He explained the increased bruising during summer was due to the rupture of dilated blood vessels and capillaries during handling; heat causing peripheral vasodilation to increase heat dissipation from the skin would be responsible for this phenomena. Cold temperatures stimulate peripheral vasoconstriction and thereby cause redistribution of blood from extremities to central blood vessels.

2. Delay between stunning and bleeding

Chambers (1979) reported that delay between stunning and bleeding may be followed by rupture of the capillaries because stunning may increase the blood pressure. Bilgili (1992) includes this as a factor affecting carcass quality indicating that a long time elapsed between stunning and bleeding has been associated with rupture of capillaries due to increased blood pressure resulting from a compensating effect of blood flow mechanisms to the loss of blood.

3. Type of cut and bleeding efficiency

Cutting of both carotid arteries is proven so far to be the best neck-cutting method being used during slaughter of poultry. It results in a greater blood loss and is effective if rapid death is required (Davis and Coe, 1954; Gregory and Wotton, 1986; Gregory and Wotton, 1988; Gregory and Wilkins, 1989c).

The influence of stunning and type of cut (unilateral versus bilateral carotid and jugular veins) as well as bleed-out time on the extent of blood loss has been reported by Kuenzel et al. (1978), Gregory (1988) and Gregory and Wotton (1986). Death is usually caused by severing the blood vessel in the neck at the junction with the bird's head, the cutting operation is done either manually (with a knife) or automatically with a machine with one or two revolving blades (Gregory and Wotton, 1986).

Gregory (1978) remarked on the importance of severing all the soft tissues of the underside of the neck during venesection of turkeys to assure both jugular veins and carotid arteries are cut. The carotid arteries in turkeys lie within the muscles surrounding the neck bones, deeper than in chickens.

Blunt knife cuts have been associated with premature cessation of blood flow (Kuenzel et al., 1978). Redskin has been associated with short bleed-out times due to live birds entering the scalder and responding physiologically to heat (Heath et al., 1983, Griffiths, 1985) and with antemortem skin irritation due to wet litter and damp cages (Brown, 1981).

4. Picking efficiency

Red wing tips and tails can be increased by removal of flight and tail feathers during picking due to infringement of blood from the damaged veins (Heath, 1984).

Mohan Raj et al. (1990) report a higher incidence of defects when broilers are mechanically plucked than hand plucked. Occurrence of carcass defects such as red pygostyles and wing vein hemorrhages happened only in the mechanically plucked broilers.

G. OBJECTIVES OF THIS RESEARCH

The importance of rendering an animal insensible prior to bleeding during the slaughter process is well established (N.R.C., 1985; Grandin, 1989; Heath, 1984b). Among the different methods developed and available to stun animals

(A.V.M.A., 1978), the poultry industry uses electronarcosis to achieve a humane stunning (Stadelman et al., 1988; Heath et al., 1981).

There has been controversy regarding the effects of electrical stunning during poultry slaughter as well as its effectiveness. The belief, among many people, that electronarcosis is directly associated with a large number of defects is strong (Heath et al., 1983). Bilgili (1992) indicates that a significant number of bruises and / or hemorrhages detected in poultry carcasses occur during the slaughter process, even though, live production and bird handling also have been a cause of these defects. Broken bones, bloody wing joints, red wing tips and blood splattering in the breast muscle have been associated with the stunning process as reported by Gregory and Wilkins (1989a); Gregory and Wilkins (1989b); Veerkamp and de Vries (1983); Gregory et al. (1990); Bilgili (1990); and Bilgili (1992).

The conditions under which electrical stunning should be applied, to be effective, are not completely understood or known. A wide variation in resistance from bird to bird has been reported (Schutt-Abraham et al., 1983; Heath, 1984) supporting the importance of stunning by using a constant current and not constant voltage stunner (Grandin, 1989; Heath, 1984; Ingling and Kuenzel, 1978); however, the factors affecting the efficiency of stunning itself are not completely discerned.

In an effort to help achieve a better understanding of the electrical stunning process and the variables involved, this study was designed to look at several factors which may have an effect on the resistance to current flow and the ability to effectively stun poultry using a constant current stunner prototype.

The main objectives of this project were:

1. To determine the variation of impedance in market weight broilers and turkeys and to establish design parameters for voltage, frequency and current.

2. To determine the optimal electronarcosis parameters to increase carcass quality and value.

3. To develop regression equations for market chickens and turkeys to compensate for variability attributable to size, sex, ambient temperatures, and feed and water withdrawal.

III. MATERIALS AND METHODS

A. APPROACH

1. Phase one

The research was divided into two phases. The first phase was designed to determine the natural variation of resistance in market weight broilers and turkeys. Using non-invasive procedures, different parameters were evaluated with the objective of gathering information that later would be used by Dr. Krishnan Ramu (Electrical Engineering, Virginia Polytechnic Institute and State University) in the design of a constant current stunner prototype under a research project entitled "Design and Development of an Electronic Stunner". This prototype model was used in the remainder of this project to complete objectives 2 and 3 at the second experimental phase.

2. Second phase

Several factors thought to be associated with the resistance to current flow were considered during this phase. These factors are ambient temperature, body moisture as a function of the time elapsed between feed and water withdrawal and stunning, and weight as a function of sex and age of the bird.

B. EXPERIMENTAL DESIGN

1. Phase One

1.1. Broilers

Peterson-Arbor Acres male and female broilers were used for this experiment. Seven hundred thirty four broilers weighing between 1 and 5 Kgs were submitted to different treatments to obtain the information on impedance required by Dr. Ramu for the design of the prototype and also to establish which conditions should be used in phase two of the study to properly evaluate the stunning process. A waveform generator was used as the electrical source to deliver a constant current at two different frequencies. An independent voltmeter (Tektronic, model TM 515) was used to measure the different voltages required to obtain a constant current level at each frequency applied.

At the beginning of phase one, birds were suspended from a conventional shackle, 1 milliamp of current was applied at frequencies of 60 and 600 Hz, and the voltage necessary to obtain 1 milliamp of current was measured. This information was for a later determination of resistance characteristics of individual birds. Different head-to-feet contacts were tested, using different parts in the head of the bird to make one contact and different parts in the shackle to obtain the feet contact. Different conditions of skin treatment were tested, some birds were dry, others were wet only at the points of contact, in others the whole body was wet, some with plain water and others with brine solution (saturated). All this was done in an effort to establish the path and conditions through which best electrical contact was obtained.

At a second facet in phase one, stunning assays were performed using a constant voltage stunner (Simmons Engineering Co, Dallas, Georgia) to determine the current range required to achieve stunning of the birds. This unit is one commercially used by many poultry processors and its electrical features are high frequency (1000 Hz), pulse DC and variable voltage settings. Once again, different conditions of contact and skin treatment were used, incorporating measurements of the time required to obtain an apparent stunning condition. This condition was evaluated by a physical response with signs such as body tremors, extended rigid legs, arched neck, open-fixed eyes, tucked wings and turned up tail feathers (Lopes da Silva, 1983; Heath et al., 1981; Wabeck, 1987).

A comparison between the constant current device developed at Virginia Tech and a constant voltage stunner (Simmons Engineering) was done. The frequency of the Simmons unit was approximately 1000 Hz and the constant current device was programmed at 995 Hz. The testing was done at low levels of current to demonstrate the ability to consistently stun every bird and to minimize damage. The constant current device was tested between 8 and 20 milliamps and the constant voltage device was tested between 20 and 25 volts.

1.2. Turkeys

BUTA-6 (British United Turkeys of America, Lewisburg, WV) turkeys weighing between 3 and 10 Kgs were used for this experiment. One hundred thirty two toms and hens were used to determine ranges of resistance for design purposes of the prototype stunner being developed by Dr.Ramu and to establish adequate stunning conditions for the second phase of the study. At the beginning of the first phase, for resistance determinations, the birds were individually suspended from a shackle where they received 1 milliamp of current through head-to-feet contact. The voltage required to obtain that amperage at 60 and 600 Hz was recorded. The current was applied first to the bird dry and again after the bird was sprayed down with brine solution. Different electrical contacts were tested to determine which path and conditions would result in better conduction. Amperages and voltages were measured by independent meters.

At the second facet of phase one, the birds were individually suspended from a shackle and different voltages were applied while recording the amperage necessary to induce stunning. Time and best conditions of contact and skin treatment to obtain unconsciousness when evaluated by the physical characteristics described by Heath et al. (1981) and Wabeck (1987) of body tremors, arched neck, tucked wings, rigid extension of legs and open fixed eyes were determined.

2. <u>Second Phase</u>

The experimental design used was a Box-Behnken response surface design, which would result in logistic regression equations that could be used to optimize the current for the different experimental variables. To determine if ambient temperature is a factor affecting the stunning process, spring and fall combined, and summer were the seasons chosen to process birds. Temperature variables of 65 ± 5°F (18.3 ± 3°C) during spring, and 85 ± 5°F (29.5 ± 3°C) during summer were expected. The weight of the birds was established as a function of age by allowing birds within the same temperature range to grow for additional time. The water and feed withdrawal regimes were administered to groups of birds of the same age, sex and specie. The experimental unit used was a "pen" of birds comprised of 10 birds to account for bird-to-bird variability. The experimental design, illustrated in Figure 1, required three levels for each factor to be determined, therefore three levels of current, weight, and water and feed withdrawal were used.

AMBIENT TEMPERATURE
One level at a time
Two levels in total
↓

WEIGHT
A function of sex and age
Three levels for each specie and gender
↓

WATER AND FEED WITHDRAWAL
Three levels for each temperature and weight combination

2 hours
5 hours
8 hours

Figure 1. Experimental Design.

2.1. Broilers

Peterson Arbor-Acres male and female broilers were used for this experiment. The weight range desired for chickens was from 3 to 5.5 pounds (1.4 to 2.5 Kg) for both males and females. The weight ranges were related to age as follows:

- male broilers were grown for 36, 43 and 50 days,
- female broilers were grown for 37, 44 and 51 days.

The ambient temperature factor was distributed as follows:

- Summer was considered between June and September, therefore broilers were processed during August.
- Spring and fall were considered between March-June and September-December, therefore broilers were processed during May and some repetition was done in September-October.

The distribution of treatments used in the experimental design for chickens is shown in Table 1, for any level of ambient temperature.

TABLE 1. CURRENT LEVEL IN MILLIAMPS RECEIVED BY EACH EXPERIMENTAL UNIT[1] OF BROILERS ACCORDING TO THE STATISTICAL MODEL.

FEED/WATER WITHDRAWAL (HRS)	MALES AGE (DAYS)			FEMALES AGE (DAYS)		
	36	43	50	37	44	51
2	29	8;50	29	29	8;50	29
5	8;50	29	8;50	8;50	29	8;50
8	29	8;50	29	29	8;50	29

[1]Experimental unit is composed of 10 birds.

At each level of ambient temperature used (spring and summer), a total of 130 male and 130 female broiler within all weight ranges, were electrically stunned (10 birds/ feed and water withdrawal (f.w.w) level/ current level). A constant current device designed as a prototype unit by the Department of Electrical Engineering at VPI was used. Current levels of 8, 29 and 50 milliamps were applied using a frequency of 400 Hz and a sinusoidal alternating (AC) waveform. The highest and the lowest current levels were chosen on the basis of what was observed during phase one of the project and also to fulfill requirements of the statistical model. The live weight of each bird was determined just prior to stunning. By being individually suspended from a shackle, head-to-feet contact was obtained placing one electrode to the shackle and the other to the head of the bird. Stunning current levels where applied for 7 seconds to the bird dry. Eight out of the ten birds were immediately processed . Following exsanguination (90 seconds), scalding (30 seconds at 140°F / 60°C), mechanical picking (for 15 seconds) and hand evisceration, all carcasses where chilled in iced water for 2 hours and individually evaluated for visual carcass defects. Breast meat was removed for later measurement of color and pH.

2.2. Turkeys

BUTA-6 (British United Turkeys of America, Lewisburg, WV) toms and hens were used for this experiment. The weight ranges desired for turkeys were:

- from 24 to 35 pounds (10.9 to 15.9 Kgs) for males and
- between 12 and 18 pounds (5.4 to 8.2 Kgs) for females.

The weight ranges were related to age as follows:

- male turkeys were grown for 112, 126 and 140 days and,
- female turkeys were grown for 84, 98 and 112 days.

The ambient temperature factor was distributed as follows:
- Summer was considered between June and September, therefore turkeys were processed from June to August.
- Spring and fall were considered between March through June and from September to December, therefore turkeys were processed from April to June and some repetition was done during September through November.

A third group of turkeys was processed during October and November with the intention of simulating winter conditions, using an environmental chamber with temperature adjustment (0°C ± 0.5°), to determine if this factor had an impact on the variables being studied. These birds were processed following the same procedure described above but with cooping being done 3 hours prior to slaughter and feed/water withdrawal taken off from that time. After the first two experimental unit were processed no effectiveness of this treatment was observed, therefore, the rest of the group was processed as a repetition of the fall experiment with the only difference being cooping time.

The distribution of treatments used in the experimental design for turkeys is shown in Table 2 for any level of ambient temperature.

TABLE 2. CURRENT LEVEL IN MILLIAMPS RECEIVED BY EACH EXPERIMENTAL UNIT[1] OF TURKEYS ACCORDING TO THE STATISTICAL MODEL.

FEED/WATER WITHDRAWAL (HRS)	MALES AGE (DAYS)			FEMALES AGE (DAYS)		
	112	126	140	84	98	112
2	30	10;50	30	30	10;50	30
5	10;50	30	10;50	10;50	30	10;50
8	30	10;50	30	30	10;50	30

[1] Experimental unit composed of 10 birds.

At each level of ambient temperature used (spring and summer), a total of 130 toms and 130 hens within all weight ranges were electrically stunned (10 birds/ feed and water withdrawal (f.w.w.) level/ current level). A constant current device designed as a prototype unit by the Department of Electrical Engineering at VPI was used. Current levels of 10, 30 and 50 milliamps were applied, using a frequency of 400 Hz and a sinusoidal alternating (AC) waveform. The highest and the lowest current levels were chosen on the basis of what was observed during phase one of the project and also to fulfill requirements of the statistical model. The live weight of each bird was determined just prior to stunning. By being individually suspended from a shackle, head-to-feet contact was obtained placing one electrode to the shackle and the other to the head of the bird. Stunning current levels where applied for 7 seconds to the bird in dry. Eight out of the ten birds were immediately processed. Following exsanguination (approximately 120 to 180 seconds), scalding (40 to 45 seconds at 140°F / 60°C), mechanical picking (for 30 seconds), and hand evisceration, all carcasses where chilled in iced water for 2 hours and individually evaluated for visual carcass defects. Breast meat was removed for afterward measurement of color and pH.

C. VARIABLES MEASURED

The variables measured and recorded are given in Figure 2. According to economic considerations, special importance was given to the relationship between stunning and broken bones, blood splattering and breast meat color. Bone breakage and blood splattering were subjectively evaluated according to presence or absence of the defect. Breast meat color was evaluated using a Minolta colorimeter determining Hunter values for lightness (L), redness or greenness (a) and yellowness or blueness (b).

VARIABLES MONITORED AND RECORDED

SPECIE
SEX
WEIGHT
AGE
FEED / WATER WITHDRAWAL REGIME
BODY TEMPERATURE -SKIN AND CORE
STUNNING CONDITION
RECOVERY TIME
BLOOD SPLATTER
BONE BREAKAGE
COLOR OF BREAST MEAT
pH OF BREAST MEAT

Figure 2. Variables recorded.

Recovery time was determined in two birds from the ten comprising each experimental unit, and these same birds were used to obtain skin and core temperatures. These birds were not evaluated for defects as they were allowed to recover after stunning. The current optimization was to be evaluated in terms of bone breakage, blood splattering and breast meat color.

1. <u>Assessment of stunned condition</u>

The birds were considered to be effectively stunned after the 7 seconds, measured with a stopwatch, if behavioral signs such as body tremors, tucked wing, rigid extension of the legs, arched neck holding the head back and absence of corneal reflex were observed. These signs have been reported as associated with stunning by Heath et al.

(1981), Lopes da Silva (1983), Scott (1978) and Wabeck (1987).

2. Recovery time

After 7 seconds of stunning, recovery time was determined in 2 birds for each experimental unit. A stopwatch was used to measure time elapsed between end of stunning and achievement of recovery. The birds were considered as recovered from stunning when they could hold their heads up, corneal reflex was back, and muscular tone in general was restored which was determined by gently pushing the bird in order to test whether it could balance on its feet.

3. Skin and core temperature

Skin temperature was measured using a contact pad sensor at the bottom of the bird's foot. Core temperature was obtained by determining rectal temperature.

4. Bone breakage and blood splattering

The eviscerated chilled carcasses were dissected and examined for appearance defects, broken bones and muscle hemorrhage. The skin covering the thorax, abdomen and upper part of the legs was removed manually and the muscle of the legs and breast was evaluated for surface defects. Several incisions were made in each carcass part looking for the presence of deep hemorrhages (Wiggins and Wilson, 1976). Wing and leg joints were examined for presence of hemorrhages as well. When removing the breast meat, the pectoralis major was separated from the pectoralis minor to reveal any surface damage. Finally each carcass was evaluated as defective for each condition observed, including broken bones at the collar region (furcula), which has been reported as mostly affected during stunning by Gregory and Wilkins (1989c). It must be noted that in the evaluation the defective condition was assessed for any degree of occurrence of the defect.

5. Breast meat color

As a way of obtaining an objective measurement of the breast meat color, the breast meat was removed from each carcass comprising the experimental unit after the carcasses had been evaluated for defects. Color was measured by determining Hunter's L,a,b values for lightness, redness and yellowness respectively (Clydesdale, 1969). A Minolta Chroma Meter II reflectance system (Minolta Corporation, Ramsey, NJ) calibrated to a white standard (L=97.91; a=-0.7; b=+2.44) was used to accomplish color measurement. Each half breast was measured at three points at random and the average obtained was recorded.

6. Breast muscle pH

The pH value of the breast muscle, including both pectoralis major and minor, was recorded using a temperature compensated pH meter with a combination spear electrode (Orion pH). Every time pH was measured, the ph meter was calibrated with a two points calibration method using buffers pH=4.0 and pH=7.0. In the birds processed during summer the pH determination was done after 24 hours slaughter. In birds from spring/fall repetition, the pH determination was accomplished after 2 or 24 hours slaughter.

D. STATISTICAL ANALYSIS

All data was analyzed using analysis of variance (ANOVA). The Box-Behnken response surface design used in the experimental design should result in regression equations that would permit the optimization and determination of the proper current usage to achieve stunning.

E. PROCEDURE

The conditions used in the second phase of the project for all the experiments on broilers and turkeys were the following:

- individual head-to-feet contact was obtained by placing one electrode directly to the shackle and the other to the head of the bird;
- stunning was done with constant current for 7 seconds, using a sinusoidal AC waveform at 400 Hz; and
- the birds were stunned dry, without brine solution.

Since the ambient temperature levels expected during processing periods did not occur consistently, the data was treated as if repetition of each experiment was done without considering a seasonal effect. The data was averaged within experiment and between repetitions by sex.

Body temperature (skin and core) was measured but is not reported here because the values recorded were in a range outside of meaningful interpretation. This was possibly caused by human error in the reading of the temperature scale, which was an analog scale that required adjustment of the expected range.

The third group of turkeys with 3 hours cooping time prior to slaughter was treated separately, also using averages within the experiment.

IV. RESULTS AND DISCUSSION

PHASE ONE

A summary of the most relevant results obtained during phase one of the project is presented in this section.

A. <u>BROILERS</u>

The average resistances observed in broilers that received 1 milliamp of current at 60 Hz and the range of voltage required to produce this current flow through birds that were dry, wetted with plain water or wetted with brine solution are presented in Table 3.

TABLE 3. MEAN RESISTANCE VALUES AND VOLTAGE RANGE IN BROILERS RECEIVING 1 MILLIAMP AT 60 Hz UNDER DIFFERENT SKIN CONDITIONS.

	BIRD DRY	BIRD WETTED WITH PLAIN WATER	BIRD WETTED WITH BRINE SOLUTION
# BIRDS	51	51	21
AVG. RESISTANCE (KOHMS)	9 ± 0.02	7 ± 0.03	7.3 ± 0.08
MIN. VOLTAGE (VOLTS)	4.1	2.5	1.4
MAX. VOLTAGE (VOLTS)	11.0	10.9	11.0

The different average resistance and voltage range observed in broilers wetted with brine solution at 60 Hz and 600 Hz when receiving 1 milliamp of current are presented in Table 4.

TABLE 4. OBSERVED VOLTAGE RANGE REQUIRED TO CONDUCT 1 MILLIAMP AT 60 Hz AND 600 Hz IN BROILERS WETTED WITH BRINE SOLUTION.

FREQUENCY	60 Hz	600 Hz
# BIRDS	21	21
AVG. RESISTANCE (KOHMS)	7.3 ± 0.08	5.8 ± 0.07
MIN. VOLTAGE (VOLTS)	1.42	1.26
MAX. VOLTAGE (VOLTS)	11	11

Table 5 shows the range of amperage observed during stunning of broilers for 7 seconds using a constant voltage stunner (Simmons Engineering). The voltage levels applied were 20, 23, 25 and 60 volts. The stunner delivered current at approximately 1000 Hz with pulse DC.

TABLE 5. VARIATION IN AMPERAGE OBTAINED IN THE CONSTANT VOLTAGE STUNNING[1] OF BROILERS AT 20,23,25 AND 60 VOLTS.

	VOLTAGE (VOLTS)			
	20	23	25	60
# BIRDS	52	27	14	37
AVG. AMPERAGE (MILLIAMPS)	18.6 ± 0.5	21 ± 0.75	17.8 ± 0.98	51.9 ± 2.34
MIN. AMPERAGE (MILLIAMPS)	11.5	11	10	27
MAX AMPERAGE (MILLIAMPS)	27	30	21.9	104

[1] Constant voltage stunning for 7 seconds, 1000 Hz pulse DC.

The results obtained from the comparison between the Virginia Tech constant current device and a constant voltage stunner (Simmons Engineering) are presented in Table 6. With the constant current device, all birds were stunned with currents above 10 milliamps. Some of the birds under 10 milliamps were also stunned, but several were not. The constant voltage device was not able to deliver a consistent stun in the range tested, 20 to 25 volts, due to the bird-to-bird variation. It required a current over 20 milliamps to stun all birds tested.

TABLE 6. COMPARISON IN CONSISTENCY OF STUN IN BROILERS USING A CONSTANT CURRENT AND A CONSTANT VOLTAGE STUNNER.

	CONSTANT CURRENT (≤20 mAMPS)		CONSTANT VOLTAGE (≤25 VOLTS)	
	FEMALES	MALES	FEMALES	MALES
# BIRDS	31	34	62	50
# BIRDS STUNNED	27[1]	28[1]	39	45
# WITH BROKEN BONES[2]	1	2	0	3
# WITH HEMORRHAGE	0	0	3	4
# WITH BLOOD SPLATTER	1	2	3	1

[1] All birds not stunned by the constant current device were ≤ 10 mA during testing to determine the baseline for constant current stunning.
[2] Number of birds with broken bones does not include picker damage.

The maximum voltage for a bird not stunned by the constant current device was 12.5 volts for a female and 10.34 volts for a male. All birds were stunned at amperages greater than 20 mA with the constant current device and voltages greater than 25 volts with the constant voltage device. The advantage of using constant current is the ability to set the device to a low setting and still be assured of a stunning charge.

B. <u>TURKEYS</u>

The differences observed in resistance and the voltage range required to conduct 1 milliamp of current in turkeys that had only the legs or the whole body wetted with brine solution are presented in Table 7. Electrical contact was made at the bar supporting the shackle and to the shackle itself. The average resistance and voltage range required to obtain 1 milliamp in each case are reported in Table 8.

TABLE 7. OBSERVED MEAN RESISTANCE AND VOLTAGE RANGE NECESSARY TO CONDUCT 1 MILLIAMP OF CURRENT IN TURKEYS UNDER DIFFERENT CONDITIONS.

	ONLY LEGS WETTED WITH BRINE[1]		WHOLE BODY WETTED WITH BRINE[2]	
FREQUENCY	60 Hz	600 Hz	60 Hz	600 Hz
AVG. RESISTANCE (KOHMS)	6.2 ± 0.14	4.6 ± 0.09	5.1 ± 0.02	3.3 ± 0.01
MIN. VOLTAGE (VOLTS)	1.83	1.83	1.17	1.12
MAX. VOLTAGE (VOLTS)	10.5	10.6	9.96	5.82

[1] Data from 10 turkeys
[2] Data from 84 turkeys

TABLE 8. VOLTAGE RANGE REQUIRED TO OBTAIN 1 MILLIAMP AT 60 Hz AND 600 Hz IN TURKEYS USING DIFFERENT ELECTRICAL CONTACTS.

	CONTACT AT BAR[1]		CONTACT AT SHACKLE[2]	
FREQUENCY	60 HZ	600 HZ	60 HZ	600 HZ
AVG. RESISTANCE (KOHMS)	1.5 ± 0.08	1.3 ± 0.07	1.1 ± 0.01	1 ± 0.01
MIN. VOLTAGE (VOLTS)	4.01	0.66	3.87	0.62
MAX. VOLTAGE (VOLTS)	4.8	3.12	4.78	1.21

[1] Data from 6 turkeys
[2] Data from 14 turkeys

The voltage ranges required to produce the flow of 1 milliamp of current in turkeys that were dry or wetted with brine solution are presented in Table 9. These measurements were made at 60 Hz.

TABLE 9. VOLTAGE RANGES IN TURKEYS[1] DRY OR WETTED WITH BRINE SOLUTION NECESSARY TO OBTAIN 1 MILLIAMP OF CURRENT FLOW AT 60 Hz.

	DRY BIRDS	BIRDS WETTED WITH BRINE SOLUTION
AVG. RESISTANCE (KOHMS)	6.2 ± 0.2	3.33 ± 0.11
MIN. VOLTAGE (VOLTS)	1.88	1.43
MAX. VOLTAGE (VOLTS)	11.0	7.84

[1] Data from 9 birds

The amperage obtained when stunning turkeys with constant voltage, using a Simmons stunner, at 20 volts for 7 seconds are presented in Table 10.

TABLE 10. AMPERAGE RANGE OBSERVED DURING CONSTANT VOLTAGE STUNNING OF TURKEYS[1] AT 20 VOLTS.

	20 VOLTS
AVG. AMPERAGE (MILLIAMPS)	9.64 ± 0.8
MIN. AMPERAGE (MILLIAMPS)	3.3
MAX. AMPERAGE (MILLIAMPS)	12

[1] Data from 10 turkeys, stunned for 7 seconds, 1000 Hz pulse DC.

SECOND PHASE

A. <u>BROILERS</u>

Resistance to electrical flow in response to constant current stunning showed a significant ($p \leq 0.0001$) gender difference. Resistance was calculated according to Ohm's Law and the plot of resistance versus amperage by gender is shown in Figure 3. For each amperage level used, females had a consistently higher resistance than males, manifested as a reading of a higher voltage required to obtain a determined amperage. As amperage increased, resistance decreased. The average resistance values by gender for each amperage level applied are presented in Table 11.

Mass or weight was not an influential factor in determining current flow in broilers as observed in Figure 4. Regression coefficients between calculated resistance and weight were determined by gender, with females having a R^2 of 0.002 and males an R^2 of 0.34.

Abdominal fat tissue has been reported as having high resistance to the pass of current (Woolley et al.,1986a,b). Therefore, a physiological difference between sex might help explain the observed differences in resistance. Twining et al. (1978) reported that males are lower in fat and have more moisture in the meat than do females.

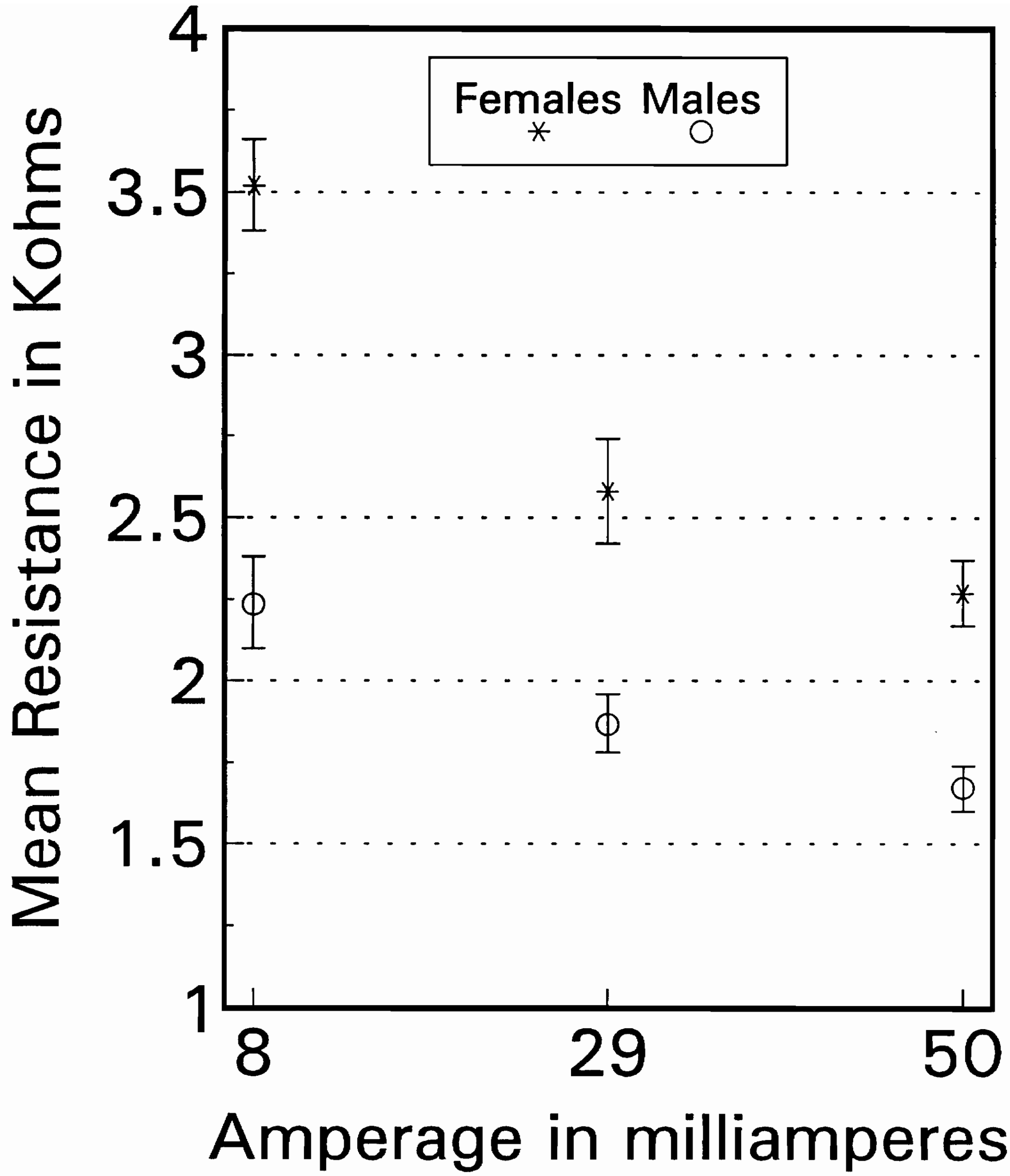


Figure 3. Gender differences in resistance of broilers between 1 and 3 Kg during constant current stunning for 7 seconds. Significant differences ($p<0.0001$) at each amperage level.

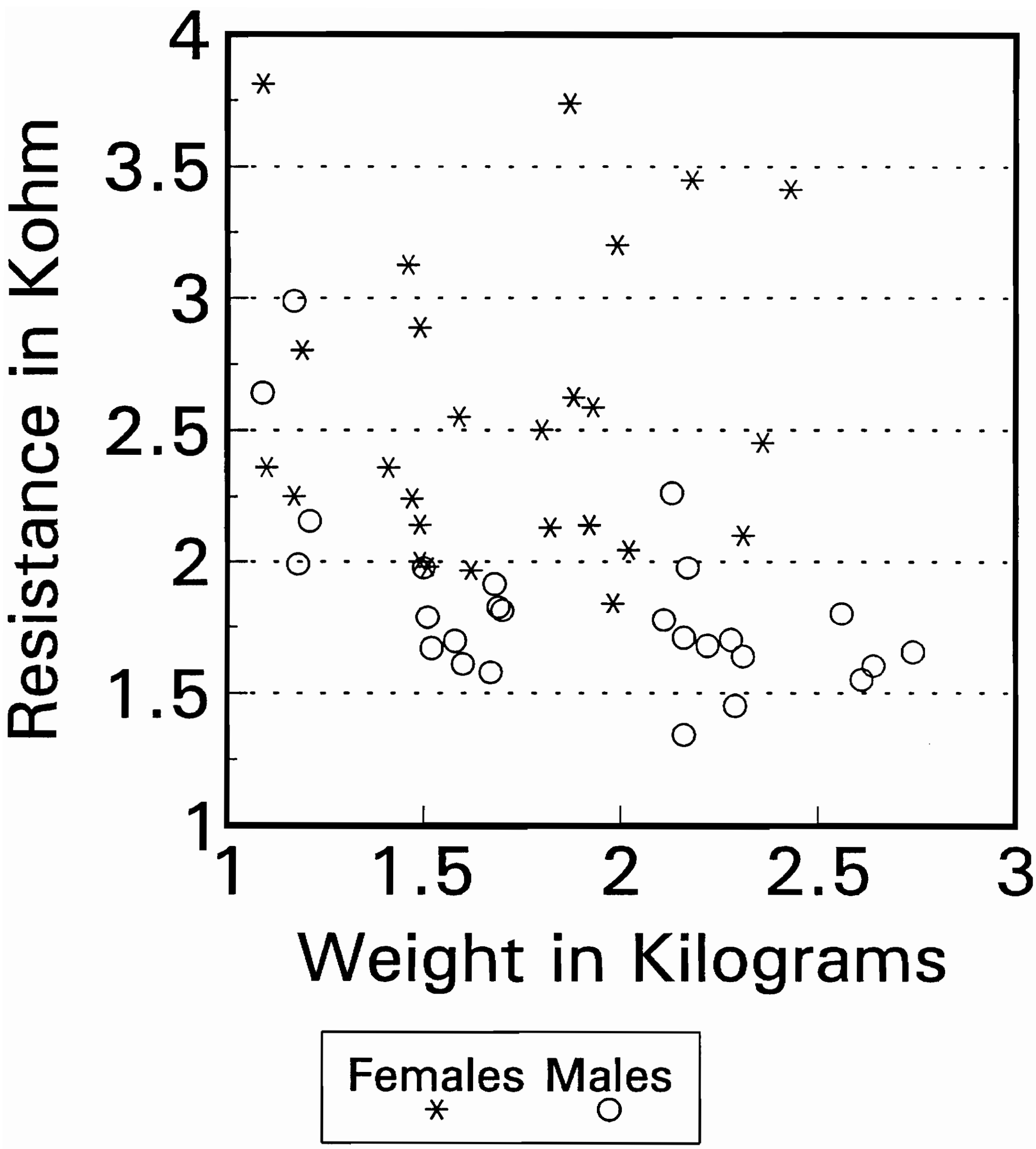


Figure 4. Resistance variation in broilers 1 to 3 Kg as a function of weight during constant current stunning for 7 seconds; female R-square=0.002 and male R-square=0.34.

To date, no effect of age, weight or sex has been reported on the resistance of broilers. Woolley et al. (1986a,b) reported variation in resistance between 1 and 2.6 Kohms for broilers, while Gregory and Wotton (1987) reported a range of 1.2 to 1.97 Kohms in broilers stunned in the range of 31 to 117 mA per bird for 2.5 to 6.5 seconds.

TABLE 11. RESISTANCE VALUES OF BROILERS DURING CONSTANT CURRENT STUNNING FOR 7 SECONDS WITH 60 Hz AC.

AMPERAGE (milliamps)	FEMALES[1]	MALES[1]
8	3.5 ± 0.14	2.2 ± 0.14
29	2.6 ± 0.16	1.9 ± 0.26
50	2.3 ± 0.10	1.7 ± 0.07

[1] Significant differences by gender ($p<0.0001$)

1. Stunning efficiency

Understunned birds were observed only after stunning with 8 milliamps, with a higher percentage of understunned males than females, as shown in Figure 5. One possible explanation may be found in the assessment of the stunning condition. Evaluation at low amperage was complicated because the physical activity of the bird (such as wing flapping) continued during current application. Physical signs of complete stun were often not clearly present or

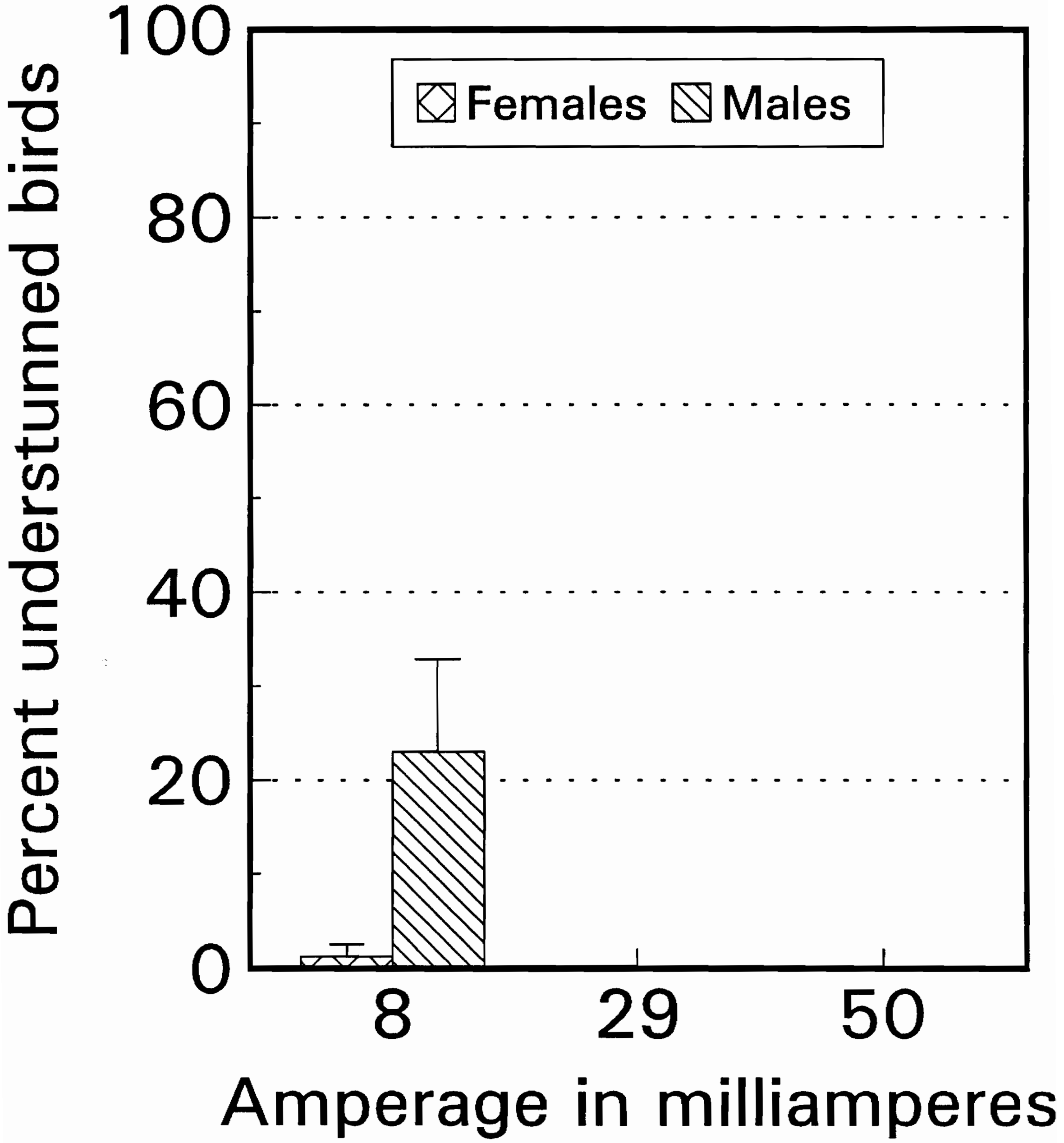


Figure 5. Percentage of understunned broilers after constant current stunning for 7 seconds.

occurred at the end of the stunning period. Stunning condition was determined while taking the bird off the shackle and placement in the cone to be venesected. Another explanation might be found in the physiological differences between gender (Twining et al., 1978) which could determine different current pathways during stunning, resulting in high resistor females. Hens have more body fat, thus more resistance to the flow of current. The current path may be more to the brain causing stun at lower amperage, while in males the current path may go via the heart and blood without affecting the brain to the same extent. Woolley et al., (1986a,b) have also reported differences in resistivity between broiler hens due to differences in thickness of the skull bone. Therefore, it is possible that males have a thicker skull bone which would result in some birds being inadequately stunned. No significant effect ($p > 0.05$) was observed between feed withdrawal or weight class in the percentage of understunned birds.

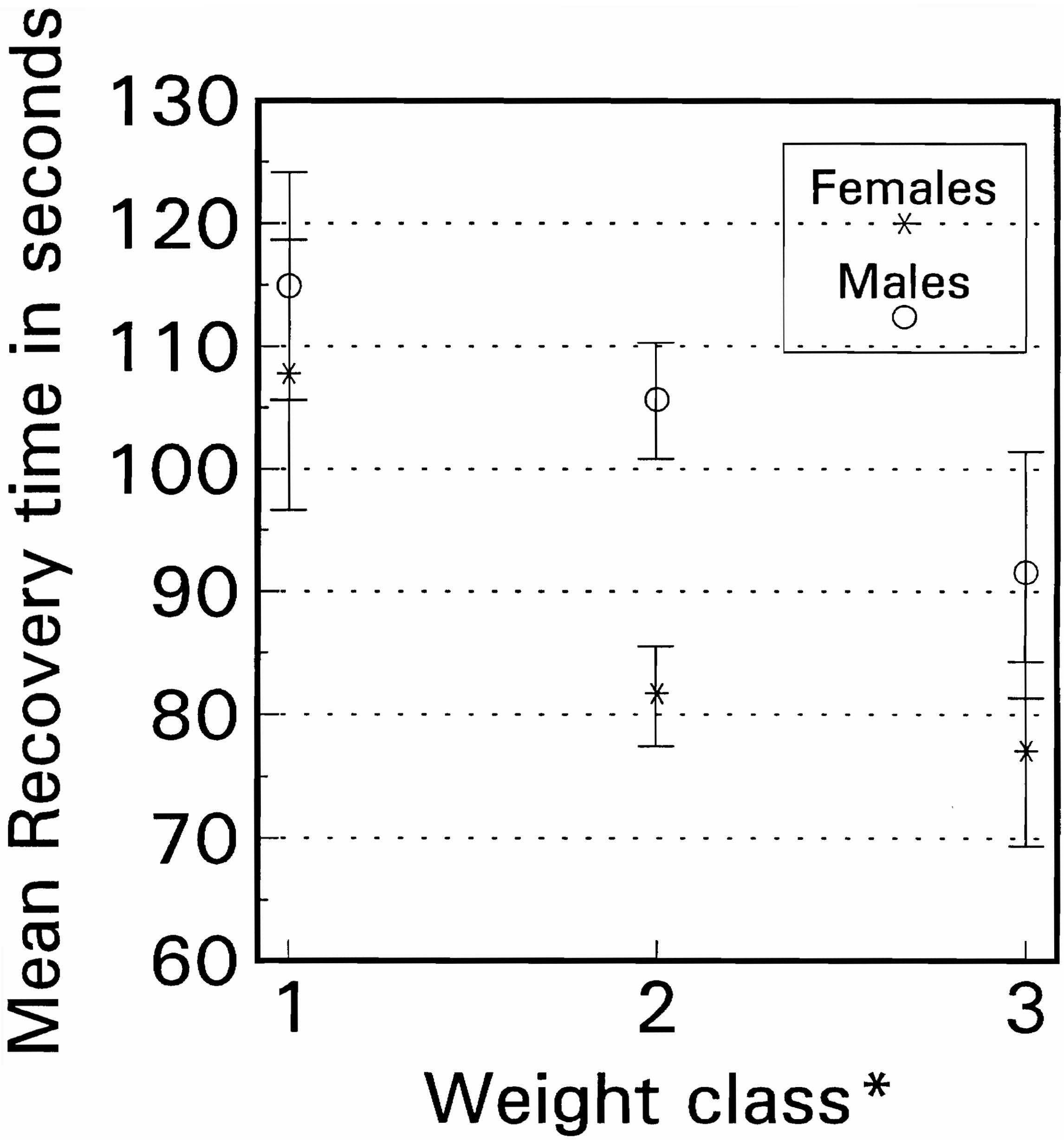
2. <u>Recovery time</u>

A significant gender difference ($p=0.009$) in recovery time after constant current stunning was observed. Males had longer recovery times than females, indicating that females undergo a lighter stun than males. It is possible that recovery was misjudged in occasions being influenced by factors such as females being lighter than males, therefore more able to move during the assessment of recovery. There might also be an interaction between body weight and recovery. The main indication of recovery was the ability of the bird to stand on their feet showing muscle control. The average value for recovery time in females was 89 seconds and in males 105 seconds.

Amperage, feed and water withdrawal had no significant effect on the recovery time of broilers at the levels used in this experiment. Weight class showed a significant effect ($p=0.004$) with a decrease in length of the recovery time period as weight class increased, older birds recovered faster that younger ones (Figure 6).

3. Defects

Birds were considered as defective if one or more of the defects being looked for was observed during carcass evaluation. Significant differences ($p=0.004$) were observed between sex for the incidence of carcass defects. The percentage of defective birds was significantly affected by amperage ($p=0.009$) and weight class ($p=0.0001$) at the levels used in this research. This confirms previous findings by Mayes (1980) and Griffith and Nairn (1984) who found a relationship between bruising and the mean body weight of broilers.



* Weight class refers to growth periods.
Females for 37, 44 and 51 days; males for
36, 43 and 50 days.

Figure 6. Recovery time variation as a function of weight class after constant current stunning for 7 seconds in broilers.

Feed and water withdrawal showed no significant effect on total defective birds. Figure 7a shows the relationship between the percentage of defective birds, by gender, and weight class, while Figure 7b shows the relationship between the percentage of defective birds and amperage level by gender.

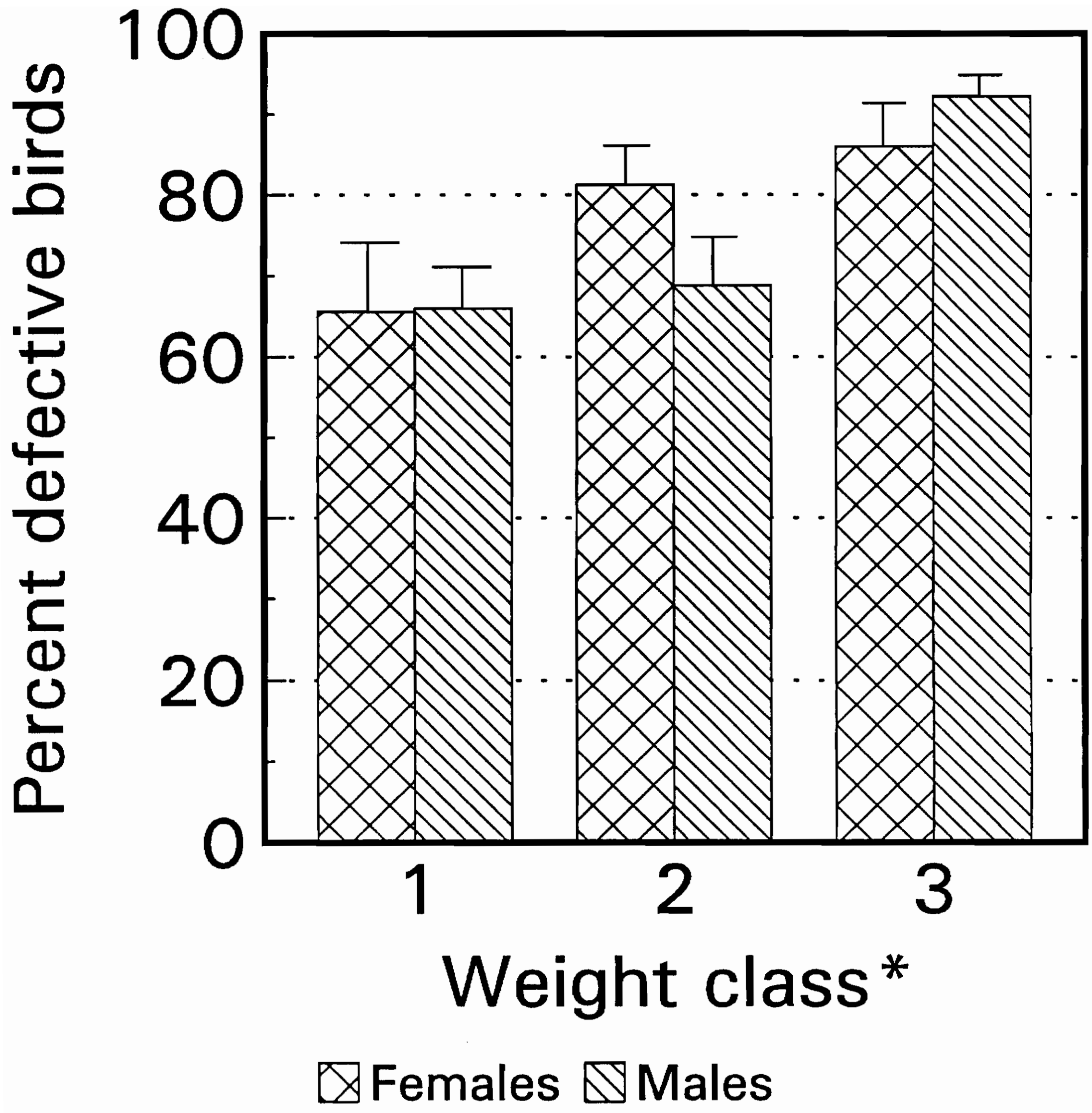
3.1. Bone breakage

Gender showed no significant differences for the occurrence of broken bones. Feed and water withdrawal, weight or their interaction had no significant effect ($p<0.05$) in the amount of broken bones observed in broiler chickens after constant current stunning.

Amperage had a significant effect ($p=0.033$) in the occurrence of broken bones in the collar region of broilers. This effect has been previously reported by Gregory and Wilkins (1989d). Figure 8 shows the relationship between the percentage of broken bones and amperage level.

3.2. Breast and thigh blood splatter

Most of the breast splatter was seen as streaks of blood in the surface of the pectoralis minor muscle without deep penetration. No significant effect ($p < 0.05$) of feed and water withdrawal, amperage, weight class or their interaction was found on the occurrence of breast or thigh blood splatter observed in broiler chickens.



* Weight class refers to growth periods. For females 37,44 and 51 days; for males 36,43 and 50 days.

Figure 7a. Percentage of defective birds as a function of weight class after constant current stunning of broilers during 7 seconds.

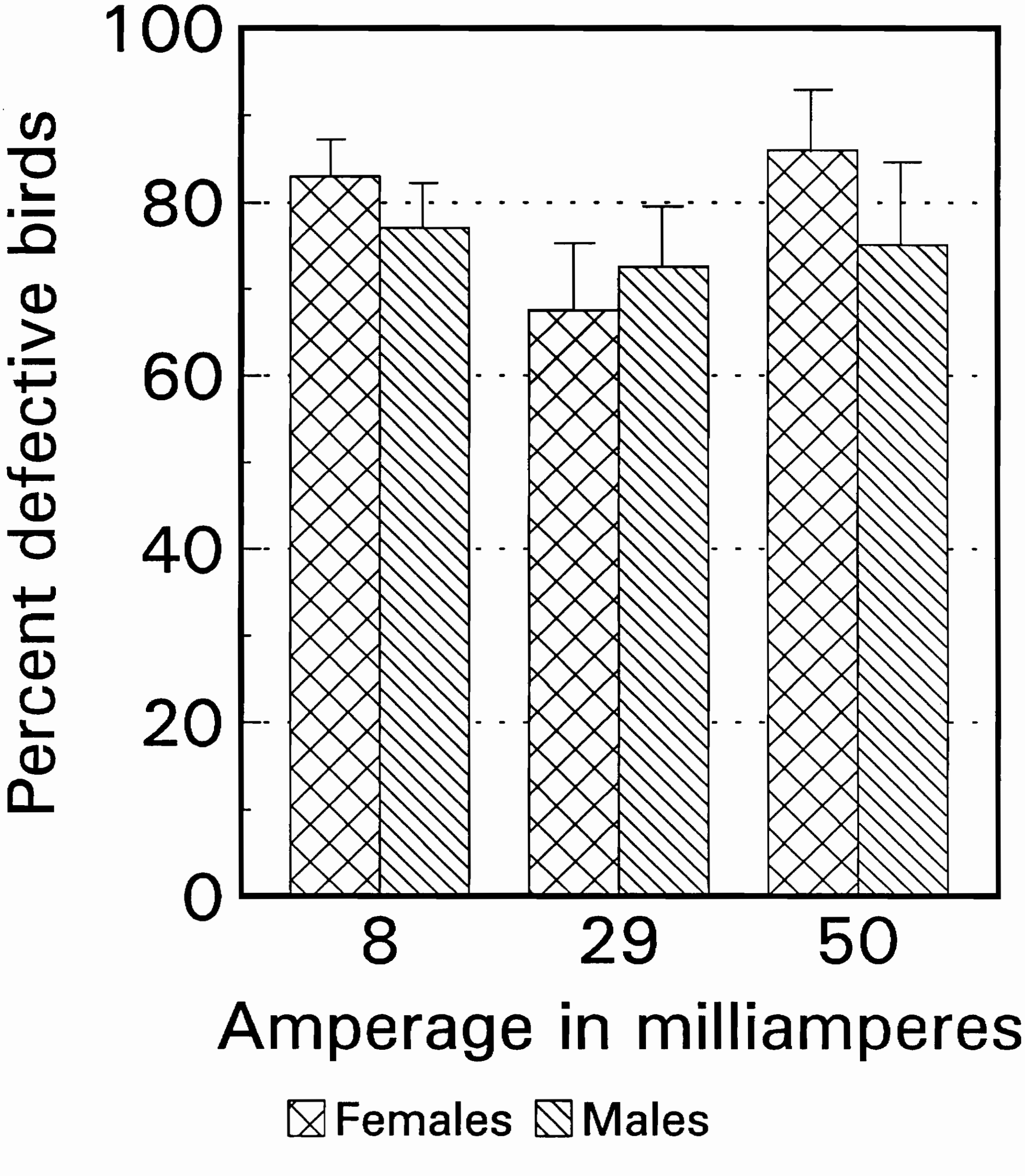


Figure 7b. Percentage of defective birds as a function of amperage level after constant current stunning of broilers for 7 seconds.

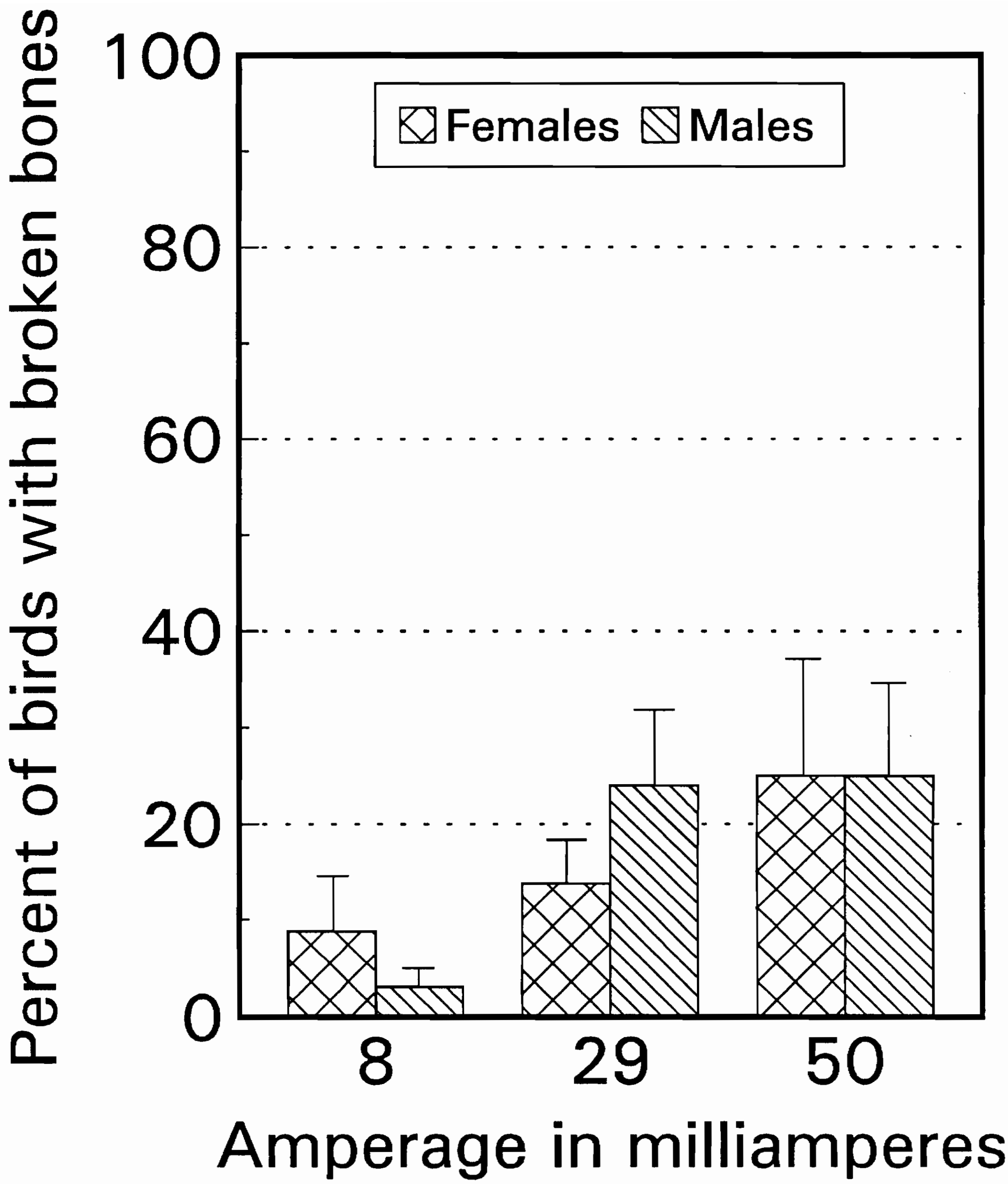


Figure 8. Percentage of broilers with broken bones after 7 seconds constant current stunning.

4. Breast meat pH

Significant differences (p=0.0001) between repetitions were observed for the pH values of breast meat. In the group of birds in which pH determination was done 24 hours after slaughter; no significant effect of sex, weight class, amperage level or feed and water withdrawal was observed.

Females had a pH of 5.84 ± 0.03 and males of 5.86 ± 0.05 Figure 9a). These values are slightly higher than the ultimate pH range reported in literature of 5.6-5.8 (Jones and Grey,1989). For the group of determinations accomplished 2 hours after slaughter, only a significant effect (p=0.004) of sex was found (Figure 9b). The average pH value for breast meat of females was 6.04 ± 0.02 where for males was 6.14 ± 0.02. These values indicate a pre-rigor state of the meat in which glycolysis has not been completed.

5. Breast meat color

No significant difference between sex in Hunter values for the color of breast meat in broilers was observed. Amperage, feed withdrawal or weight at the levels studied showed no significant effect. The average Hunter values observed by gender are presented in Table 12.

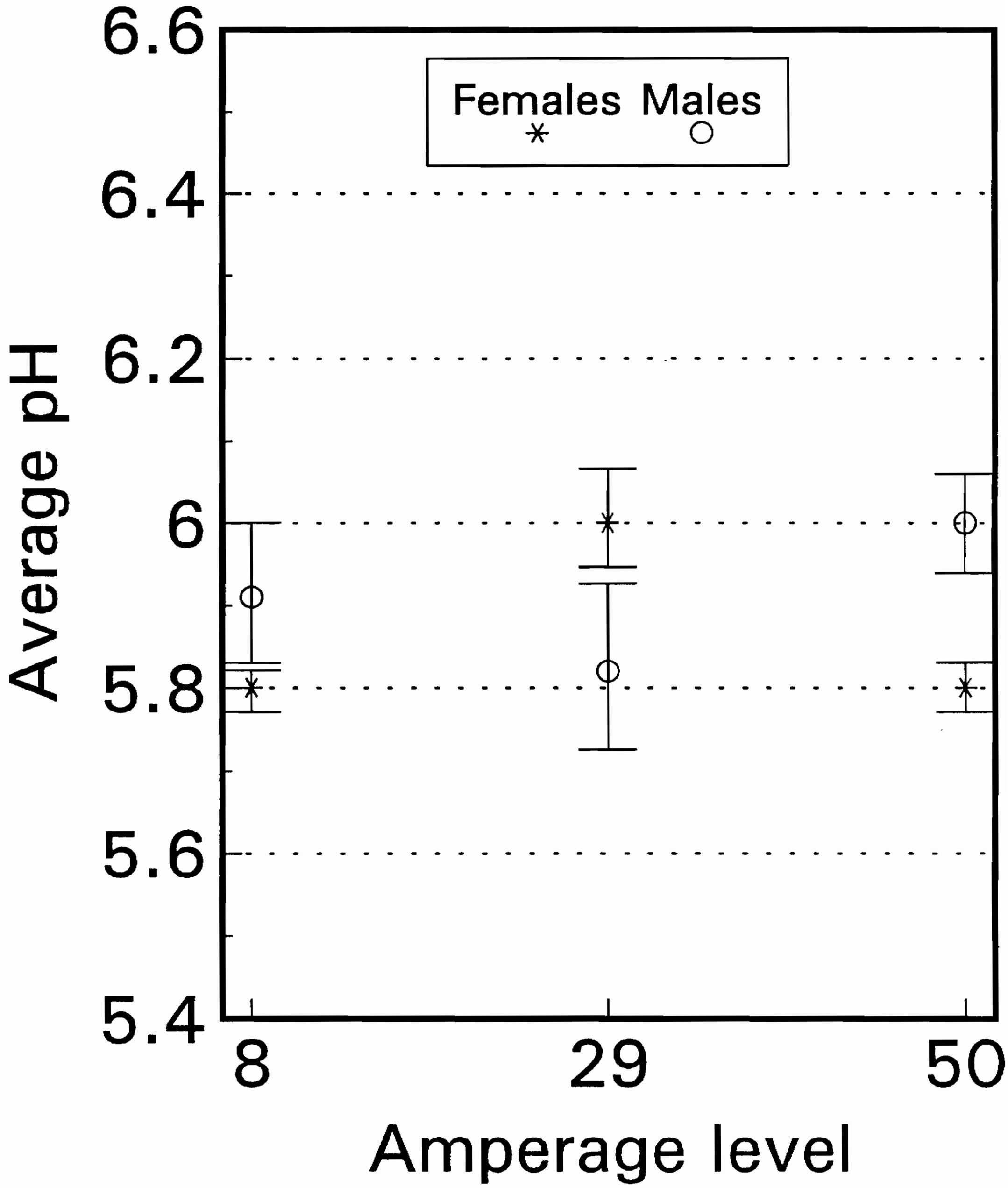


Figure 9a. Variations in pH of the breast meat in broilers after 24 hrs slaughter.

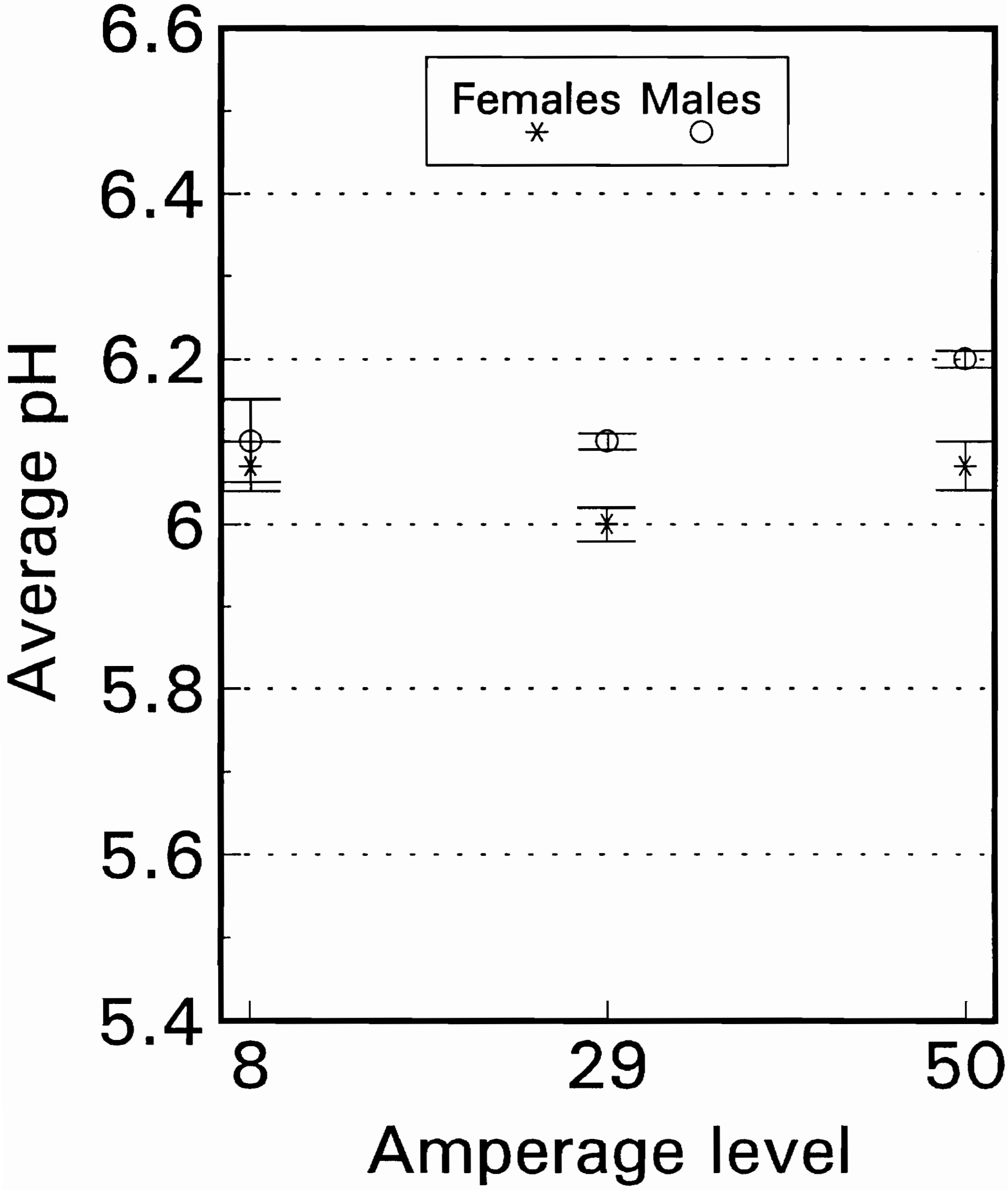


Figure 9b. Variations in pH of the breast meat in broilers after 2 hrs slaughter.

TABLE 12. HUNTER COLOR VALUES FOR BROILER BREAST MEAT.

HUNTER VALUES	FEMALE[1]	MALE[1]
L	52.8 ± 0.15	52.9 ± 0.08
a	4.49 ± 0.03	4.29 ± 0.03
b	5.33 ± 0.06	4.87 ± 0.04

[1] Differences in Hunter values between sex are no significant ($p > 0.05$).

B. STATISTICAL ANALYSIS

The statistical model used (Carter et al., 1977) was accurate in predicting occurrence of events in most cases which was verified by a χ^2 goodness of fit test that ranged from $p = 0.02$ to $p = 1$. However, for the model to work, it requires occurrence of the effect and even better, a significant difference between the effects, which was not the case in the present study. In many cases, no defect occurred at all or the differences observed were not significant. Thus, the contour plots obtained for all the interactions studied of defect versus amperage, feed withdrawal or weight class, were not indicative of any significant trend among variables. The logistic function with quadratic argument expected to best represent the interactions between the variables studied, was not able to optimize for the constant current stunning of broilers based on the occurrence of defects at the levels used in this experiment for the factors considered.

C. TURKEYS

Groups with similar conditions

A significant gender difference in resistance ($p \leq 0.0001$) to electrical flow in response to constant current stunning was observed. Resistance was calculated according to Ohm's Law and the plot of resistance versus amperage by gender is shown in Figure 10. For each amperage level used, hens had a consistently higher resistance than toms, manifested as a reading of a higher voltage required to obtain a determined amperage. Females had an average resistance of 3.1 Kohm while in males the average resistance was 2.3 Kohm. The average resistance values by gender, for each amperage level applied are presented in Table 13.

Mass or weight was not an influential factor in determining current flow in turkeys as observed in Figures 11a and 11b, which show the relationship between resistance and weight by gender, for all the amperage levels applied. Regression coefficients between calculated resistance and weight were determined by gender, with females having a R^2 of 0.22 and males an R^2 of 0.006.

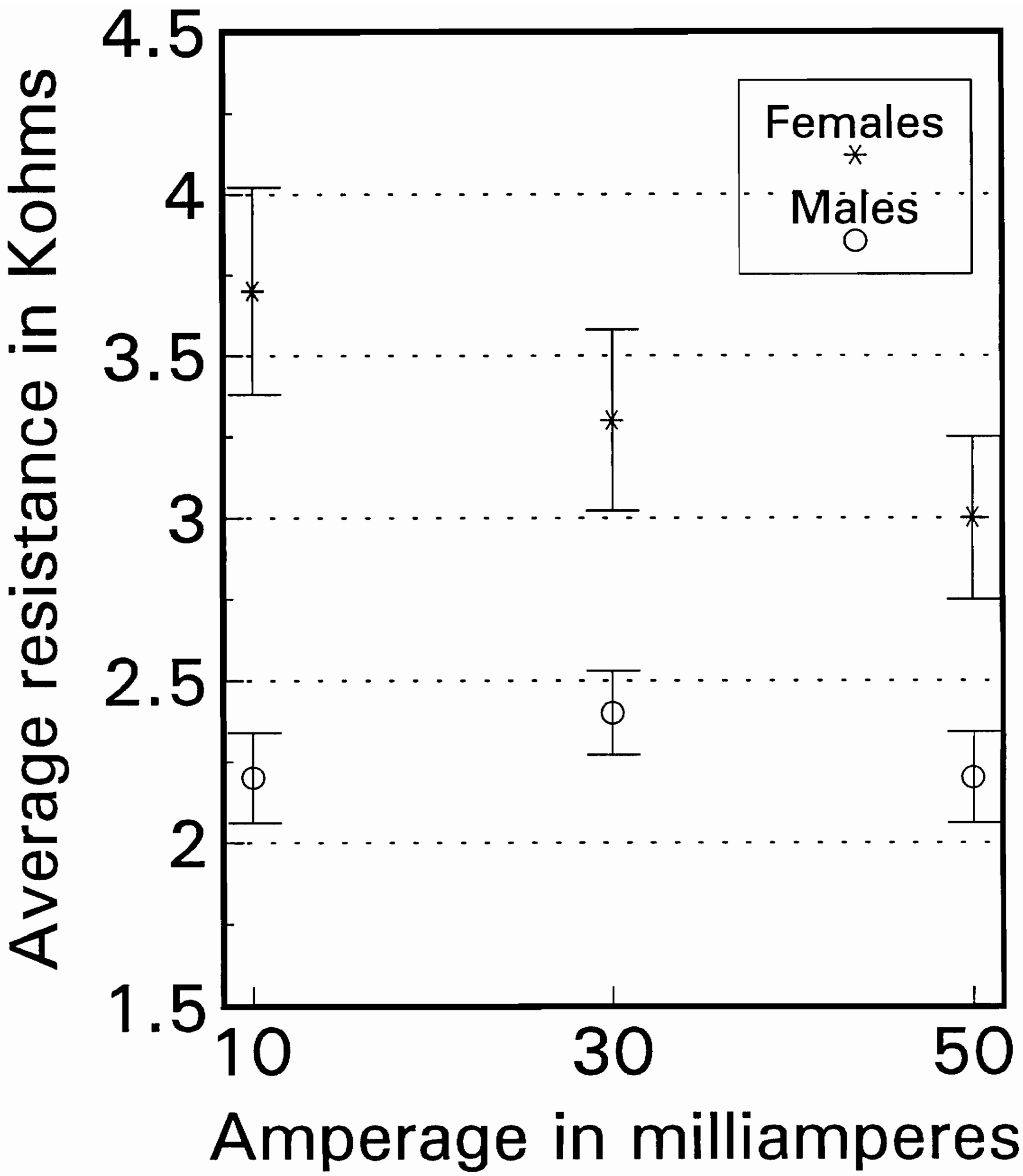


Figure 10. Gender differences in resistance of turkeys 4.5 to 14 Kg during constant current stunning. Gender differences are significant ($p<0.0001$).

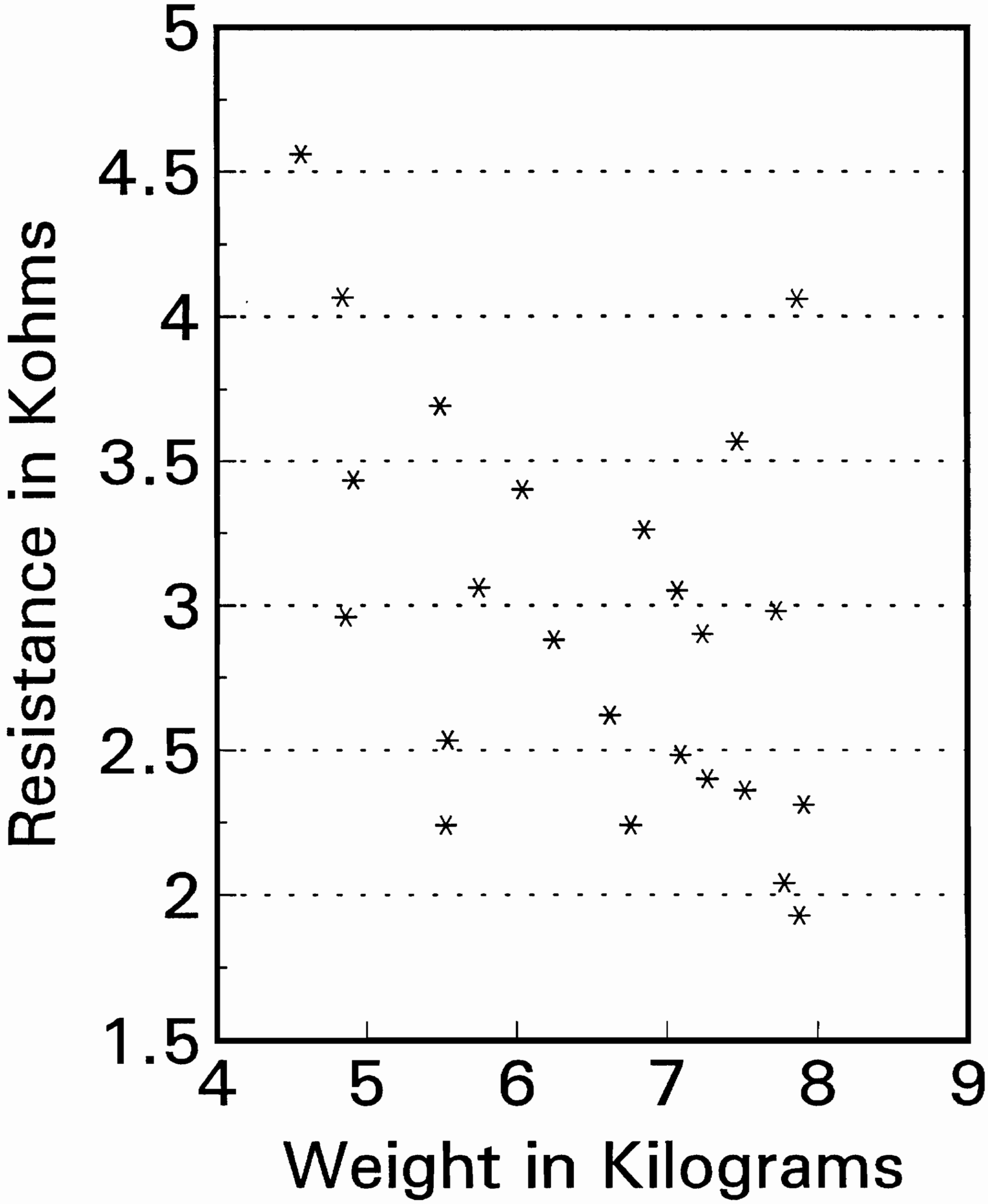


Figure 11a. Resistance variation in turkey female 4.5 to 8 Kg during constant current stunning. R-square=0.22.

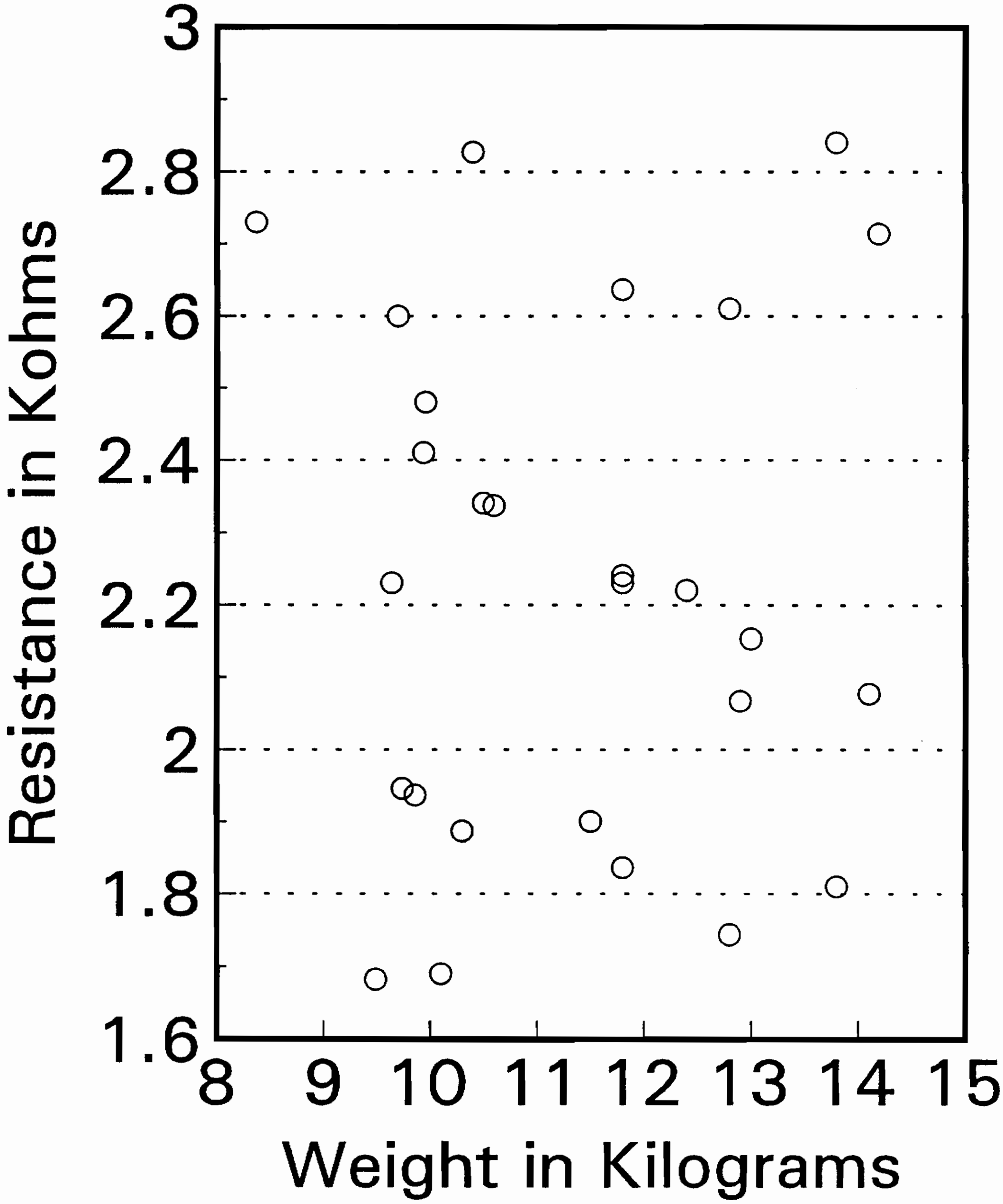


Figure 11b. Resistance variation in turkey male 8 to 15 Kilograms during constant current stunning. R-square = 0.006.

The higher resistance of females can be attributed to physiological differences between toms and hens which may result in different current pathways and also present differences in tissue resistivity. According to Posati (1979) males are lower in fat and have more moisture in the meat than do females.

TABLE 13. RESISTANCE VALUES[1] OF TURKEYS (KOHMS) STUNNED WITH CONSTANT CURRENT FOR 7 SECONDS.

AMPERAGE (milliamps)	FEMALES	MALES
10	3.7 ± 0.32	2.2 ± 0.14
30	3.3 ± 0.28	2.4 ± 0.13
50	3.0 ± 0.25	2.2 ± 0.14

[1] Values significantly different ($p \leq 0.0001$) between sex

1. Stunning efficiency

Understunned birds were observed only after stunning with 10 mA as shown in Figure 12, with a higher percentage of males than females being understunned. This gender difference ($p=0.002$) is consistent with the difference observed in broilers. A possible explanation may be found in physiological differences between gender which could result in different pathways for current flow. Posati (1979) has reported differences in the composition in meat

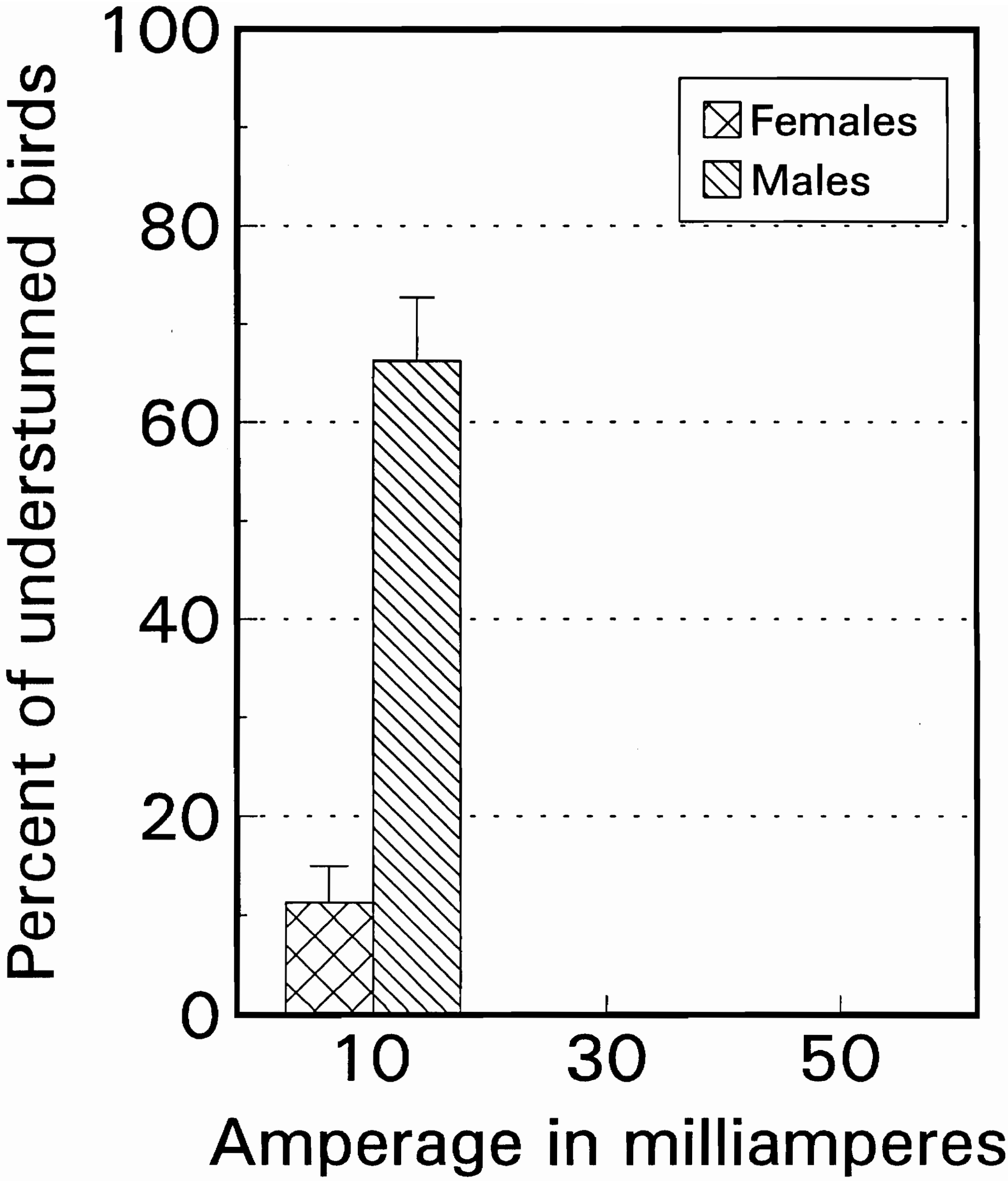


Figure 12. Percentage of turkeys understunned after constant current stunning for 7 seconds.

of males and females turkeys which may determine the stunning efficiency. Woolley et al.(1986b) reported differences in resistivity of the skull bone in broiler hens due to different thickness. The same difference may apply to turkeys, which would explain that some birds did not reach sufficient current density in the brain, therefore were inadequately stunned. Feed withdrawal showed no significant effect in the percentage of understunned birds.

2. Recovery time

A significant difference between gender (p=0.0001) in recovery time after constant current stunning for 7 seconds was observed with males having longer recovery times than females. This effect may be explained in function of females weighing less which would allow them to move easier than males. This factor might have been misleading for the assessment of recovery from stunning as evaluated by physical response, since the determinant behavior for recovery was the ability of the bird to stand on their feet showing recuperation of muscle tension. An average hen had a recovery time interval of 83 seconds and a male of 115 seconds. These values are within the acceptable range reported by Wabeck (1987) who indicated that total recovery time should be from 1 to 2 minutes.

The effect of amperage on the recovery time period of turkeys is significant (p=0.03), with an increase in the length of this period with increasing amperages (Figure 13). Feed and water withdrawal and weight class had no significant effect on the recovery time of turkeys and no clear trend was found between these factors.

3. Defects

A bird was considered defective when one or more defects being evaluated was found during carcass inspection. Differences by gender were significant for the occurrence of defective birds (p=0.0003). Table 14 shows the percentage of defective birds by gender. Amperage level had significant effect (p=0.0089) in the percentage of defective birds as observed in Figure 14a.

TABLE 14. PERCENTAGE OF DEFECTIVE TURKEYS (%) AFTER CONSTANT CURRENT STUNNING FOR 7 SECONDS WITH 60 Hz AC.

AMPERAGE (milliamps)	FEMALES	MALES
10	59	64
30	51	56
50	47	46

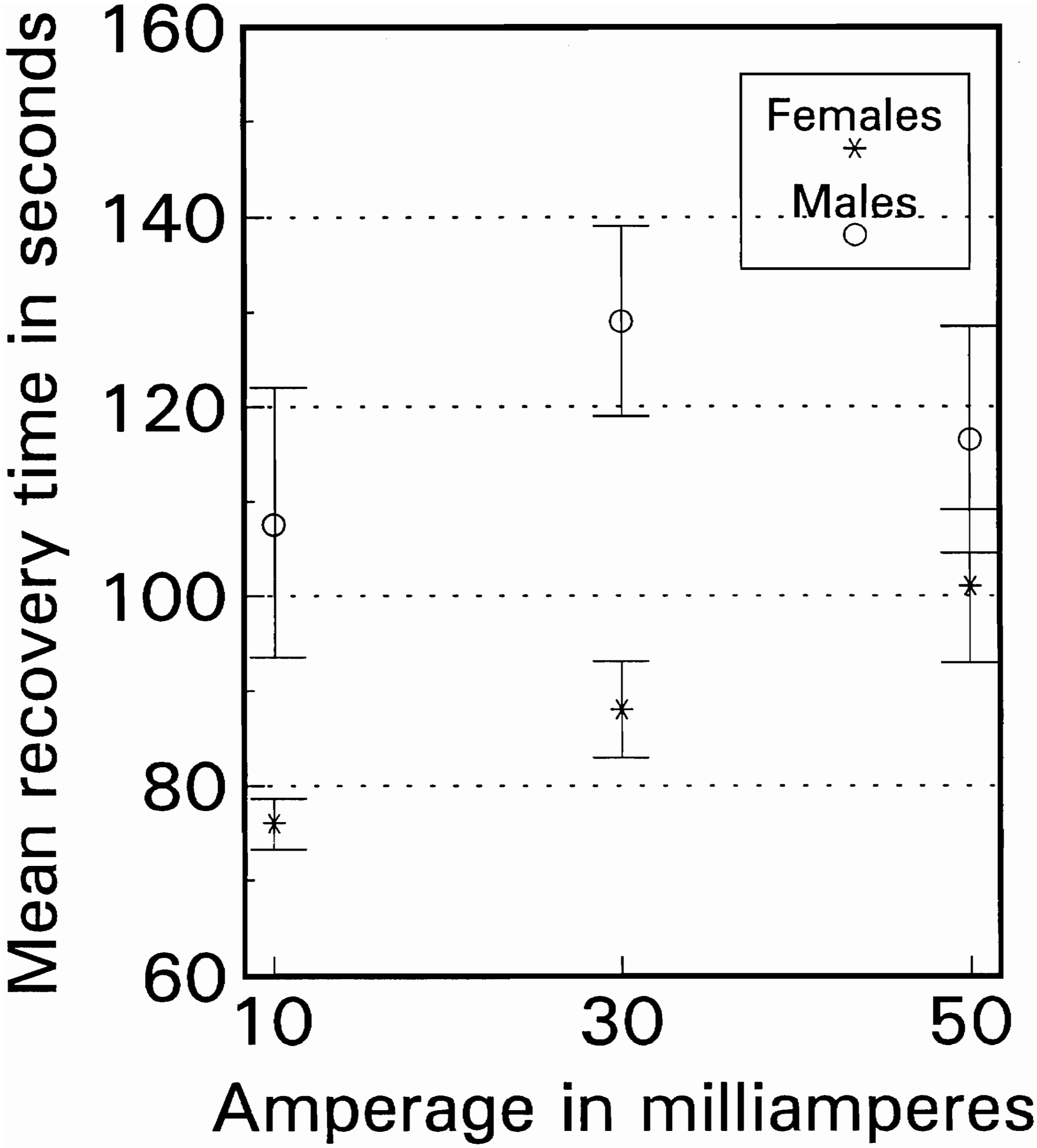


Figure 13. Differences in the mean recovery time of toms and hens after constant current stunning for 7 seconds.

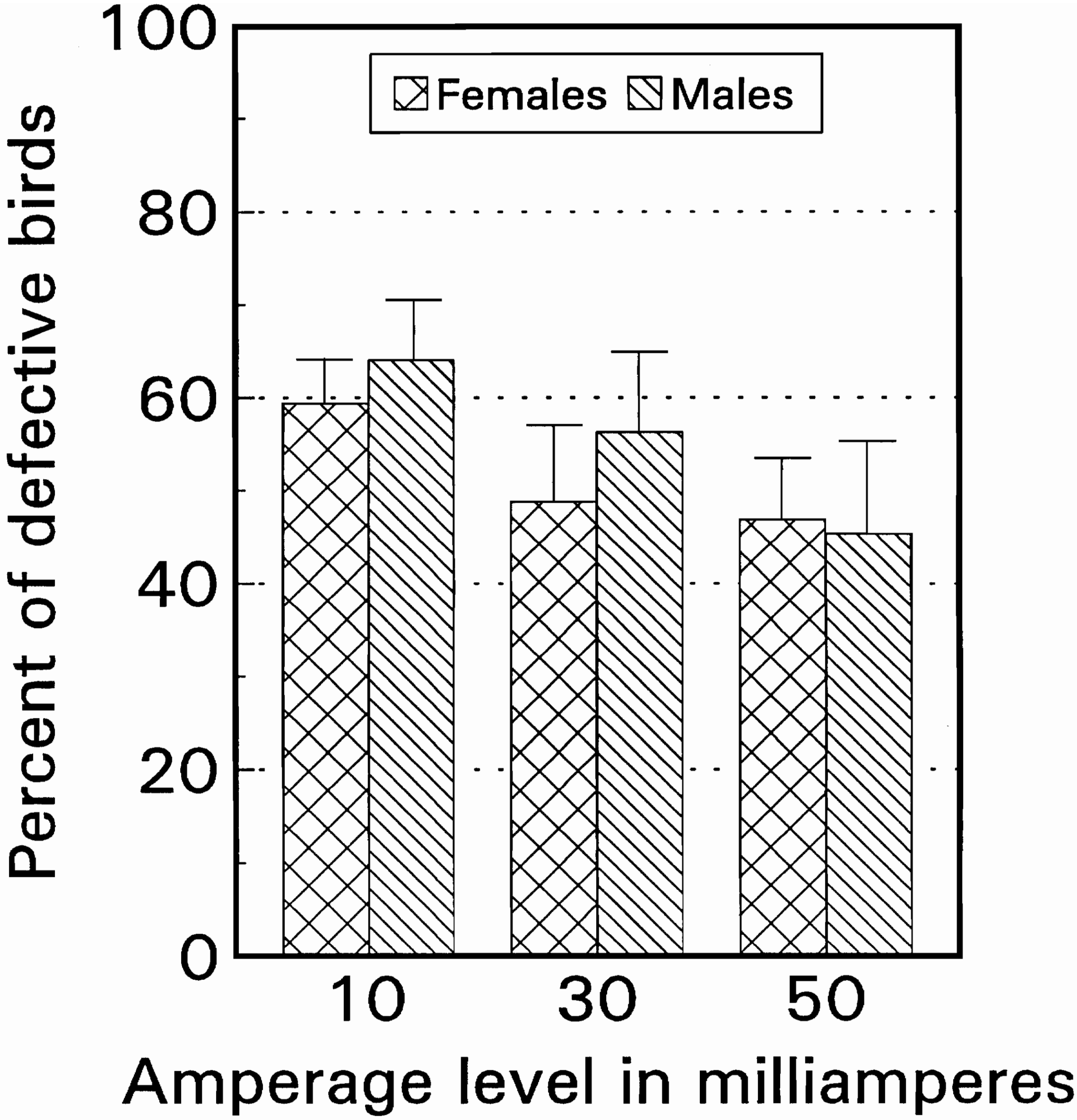


Figure 14a. Percentage of defective turkeys as a function of amperage level in constant current stunning for 7 seconds.

Feed withdrawal had no significant effect in the percentage of defective birds. Weight class had a significant effect ($p=0.0011$) in the incidence of defects in turkeys (Figure 14b).

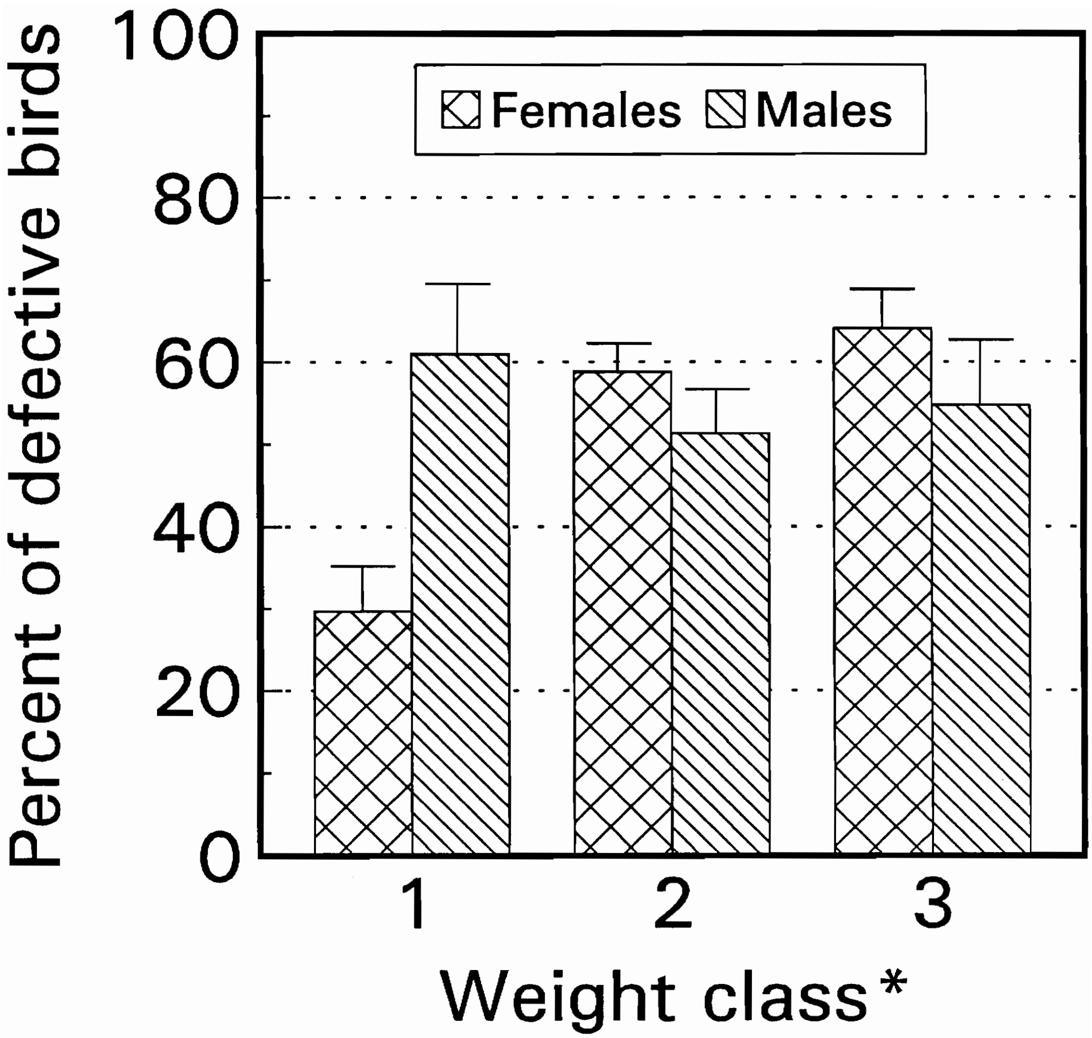
3.1. Bone breakage

No significant effect ($p < 0.05$) of water and feed withdrawal, amperage, weight or their interaction was found on the amount of broken bones observed in turkeys after constant current stunning. There was no clear trend in the interaction between these factors and incidence of broken bones.

3.2. Breast and thigh splatter

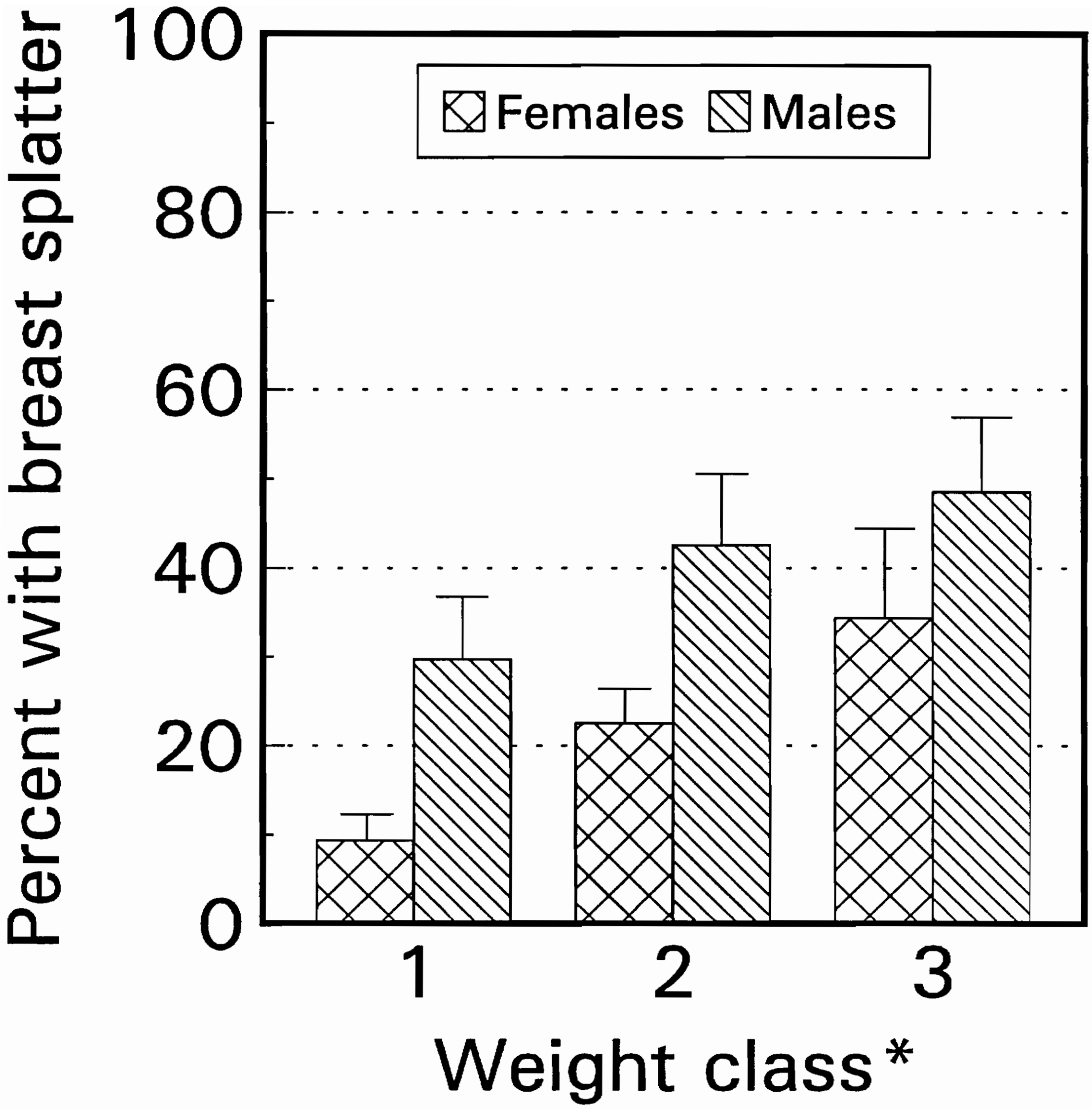
No significant effect ($p < 0.05$) of water and feed withdrawal, amperage or their interaction was found on the incidence of breast splatter observed in turkeys.

A significant gender difference ($p=0.026$) was observed between males and females for the incidence of breast splatter, with males having a higher percentage of birds with breast splatter than females for any treatment group. Weight class had a significant effect ($p=0.006$) on the incidence of breast blood splatter in this group of turkeys (Figure 15). No significant effect ($p < 0.05$) was observed due to amperage, weight class or feed withdrawal for the incidence of thigh blood splatter.



* Weight class refers to growth periods. For females 84,98 and 112 days; males for 112, 126 and 140 days.

Figure 14b. Percentage of defective turkeys as a function of weight class after constant current stunning for 7 seconds.



* Weight class refers to growth periods. For hens 84,98 and 112 days; toms for 112, 126 and 140 days.

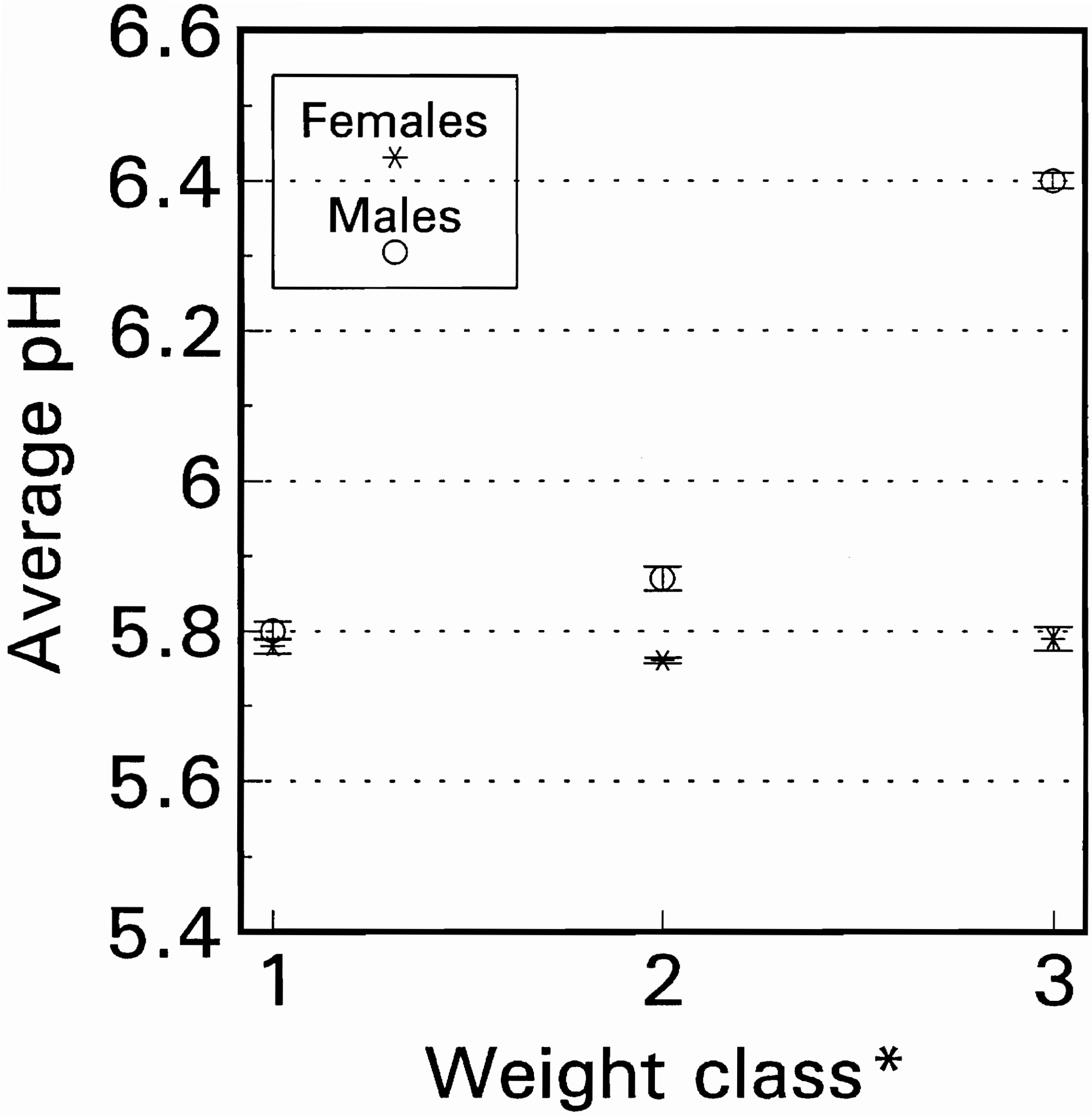
Figure 15. Percentage of turkeys with breast blood splatter after constant current stunning for 7 seconds.

4. Breast meat pH

A significant difference ($p=0.0097$) in the pH value of breast meat was observed between repetitions. In the group of determinations done 24 hours after slaughter, hens breast meat had an average pH of 5.77 ± 0.007 where toms's was 6.01 ± 0.07. For the group of determinations done 2 hours after slaughter, the pH values were, for hens of 5.87 ± 0.02 and for toms of 6 ± 0.04. Gender ($p=0.0001$), weight class ($p=0.0001$) and their interaction ($p=0.0001$) had a significant effect on pH of breast meat. Figures 16a and 16b show the plot of the average pH versus weight class by gender. The differences due to gender can be attributed to physiological differences between toms and hens, which result in different composition of the muscle tissue. This difference has been reported to increase with age (Posati, 1979) which might help explain the differences observed by gender and the weight class effect. Amperage or feed and water withdrawal had no significant effect on the breast meat pH.

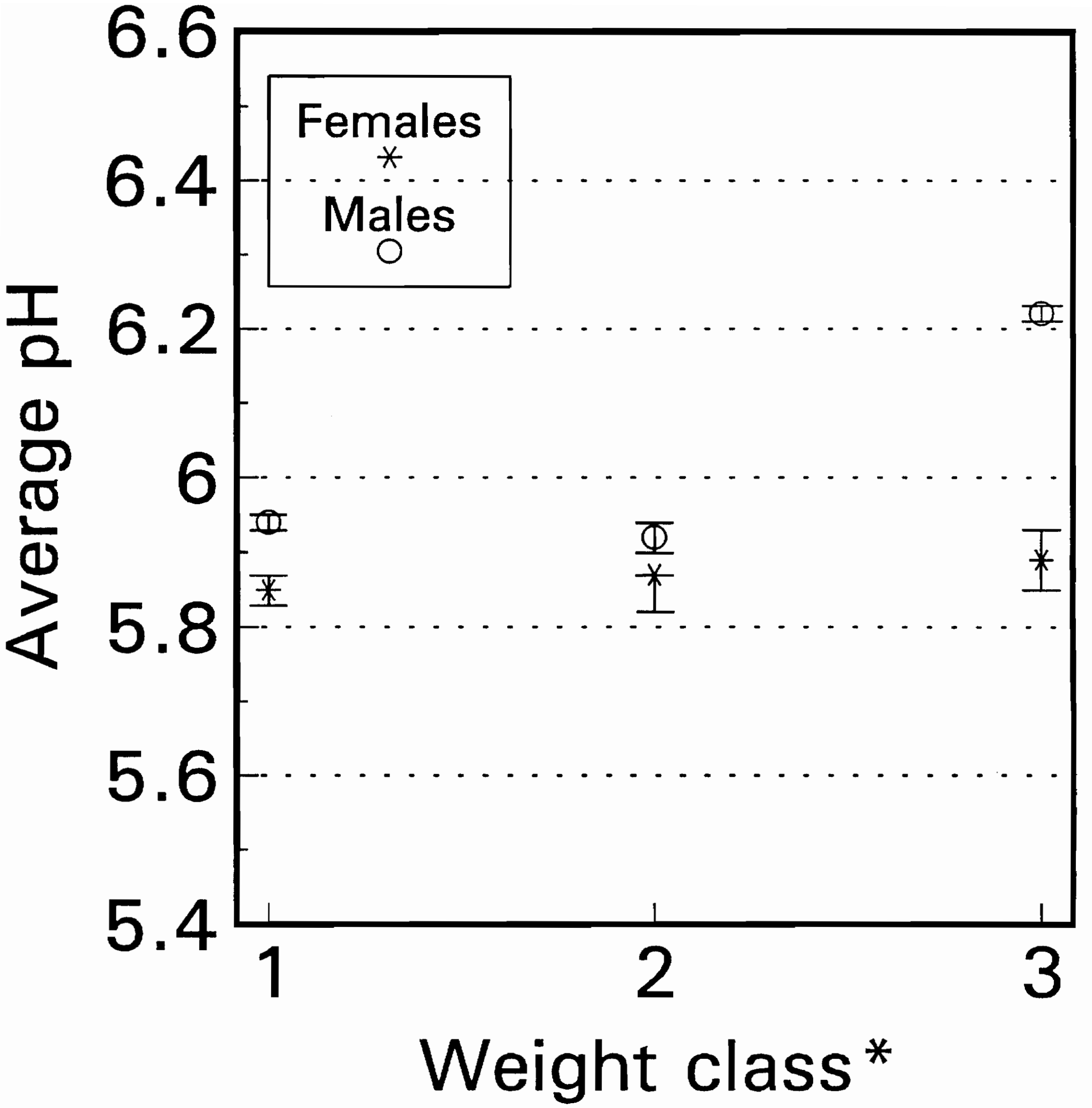
5. Breast meat color

No significant difference or effect in Hunter values for the color of breast meat of turkeys, between gender, was observed due to amperage, feed withdrawal or



* Weight class refers to growth periods. For hens 84,98 and 112 days; for toms 112, 126 and 140 days.

Figure 16a. Average pH of turkey breast meat as a function of weight class after 24 hours from slaughter.



* Weight class refers to growth periods. For hens 84,98 and 112 days; for toms 112, 126 and 140 days.

Figure 16b. Average pH of turkey breast meat as a function of weight class after 2 hours from slaughter.

weight class. Table 15 shows the average Hunter values obtained by gender when measuring color of the breast meat.

TABLE 15. HUNTER COLOR VALUES FOR TURKEY BREAST MEAT.

MINOLTA VALUES	FEMALE[1]	MALE[1]
L	50.6 ± 0.2	50.1 ± 0.42
a	4.74 ± 0.17	5.90 ± 0.22
b	0.96 ± 0.0.16	1.54 ± 0.24

[1] Differences between sex are no significant ($p>0.05$).

Turkeys cooped three hours prior stunning

This group of birds had only one repetition thus results were averaged within the experimental unit and analyzed. The results obtained for the majority of the parameters evaluated were similar to those previously informed for the group of turkeys without the cooping time variable. However, it must be noted that the previous analysis done on the turkeys without cooping time did not include the averages of this group but they are within same ranges.

1. Recovery time

No significant difference between gender was found in recovery time after constant current stunning for 7 seconds. As average this group of turkeys had a recovery time interval of 85 seconds. Amperage did not have a significant effect upon recovery time.

2. Defects

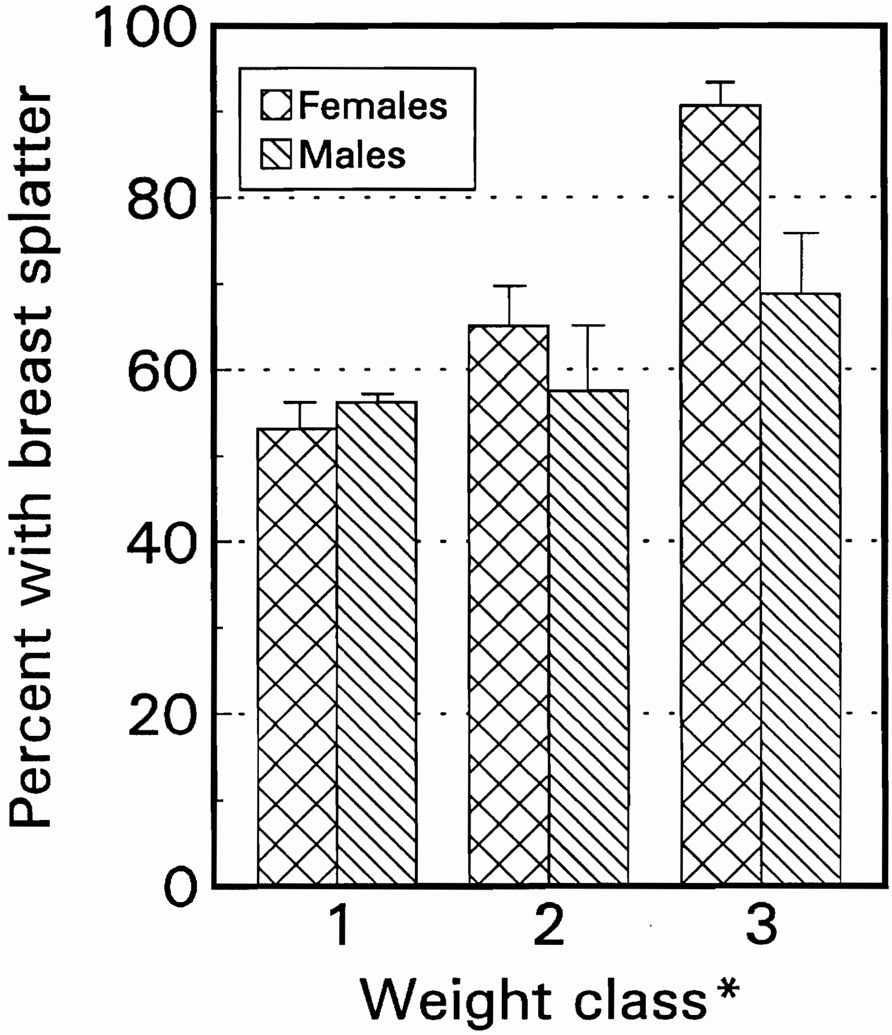
Differences by gender were not significant for this group. Amperage or weight class had no significant effect ($p > 0.05$) for the percentage of defective birds.

2.1. Breast and thigh splatter

Prevalence of breast blood splatter showed no significant difference ($p < 0.05$) between sex. Weight class had a significant effect ($p=0.04$) in the incidence of breast splatter for this group of turkeys (Figure 17). Blood splatter in the thighs was significantly higher ($p=0.0034$) in females (Figure 18).

3. Breast meat pH

A significant effect ($p=0.014$) in the pH value of breast muscle was observed due to feed and water withdrawal (Figure 19). This might be attributed to larger depletion of nutrients to the muscle fiber at the time of slaughter, resulting in less formation of lactic acid during glycolysis, reaching a higher pH.



* Weight class refers to growth periods. Hens for 84,98 and 112 days; toms for 112, 126 and 140 days.

Figure 17. Percentage of turkeys with breast blood splatter after constant current stunning for 7 seconds and 3 hours cooping prior slaughter.

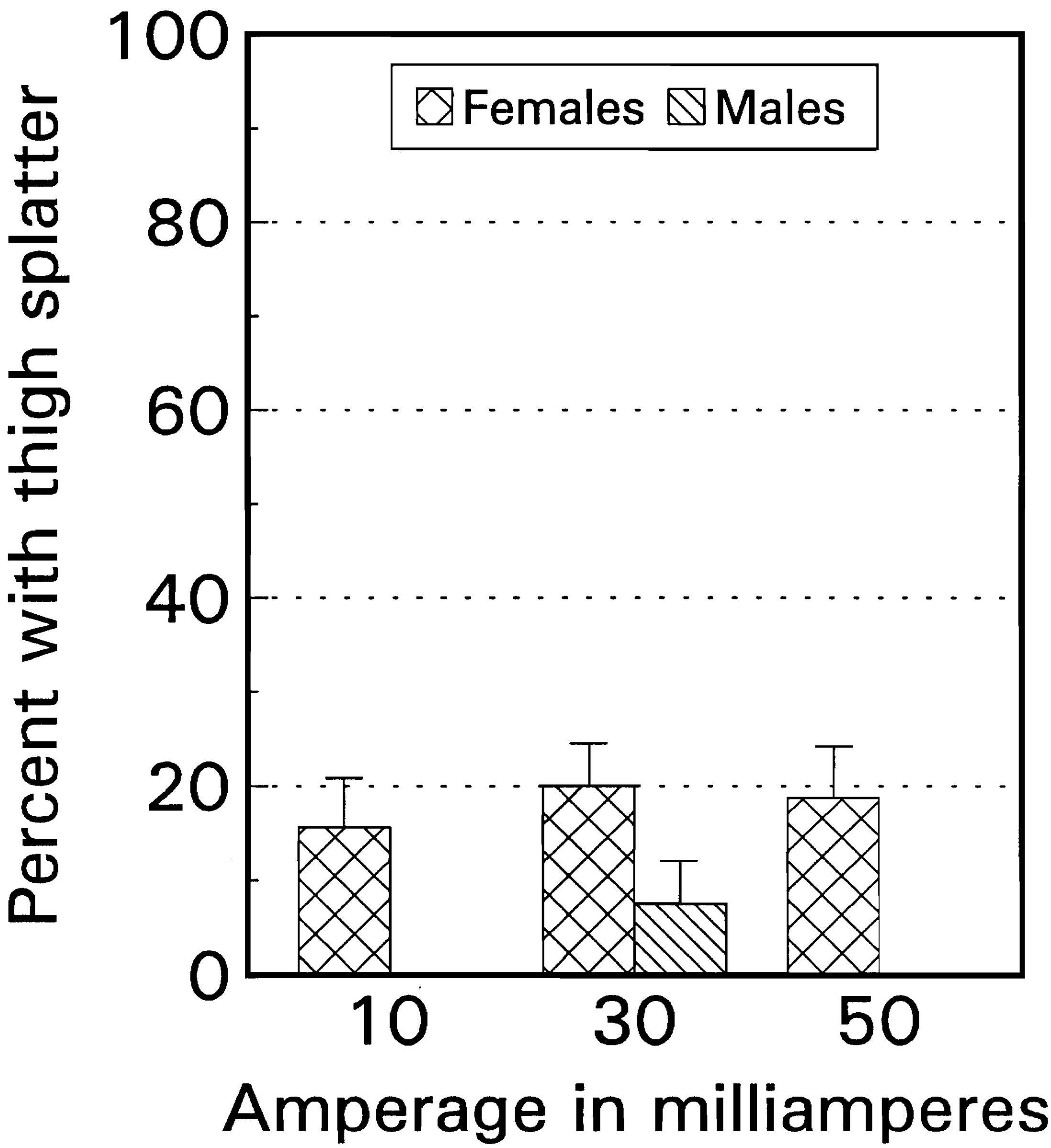


Figure 18. Percentage of turkeys with thigh splatter after 7 seconds constant current stunning and three hours cooping prior slaughter.

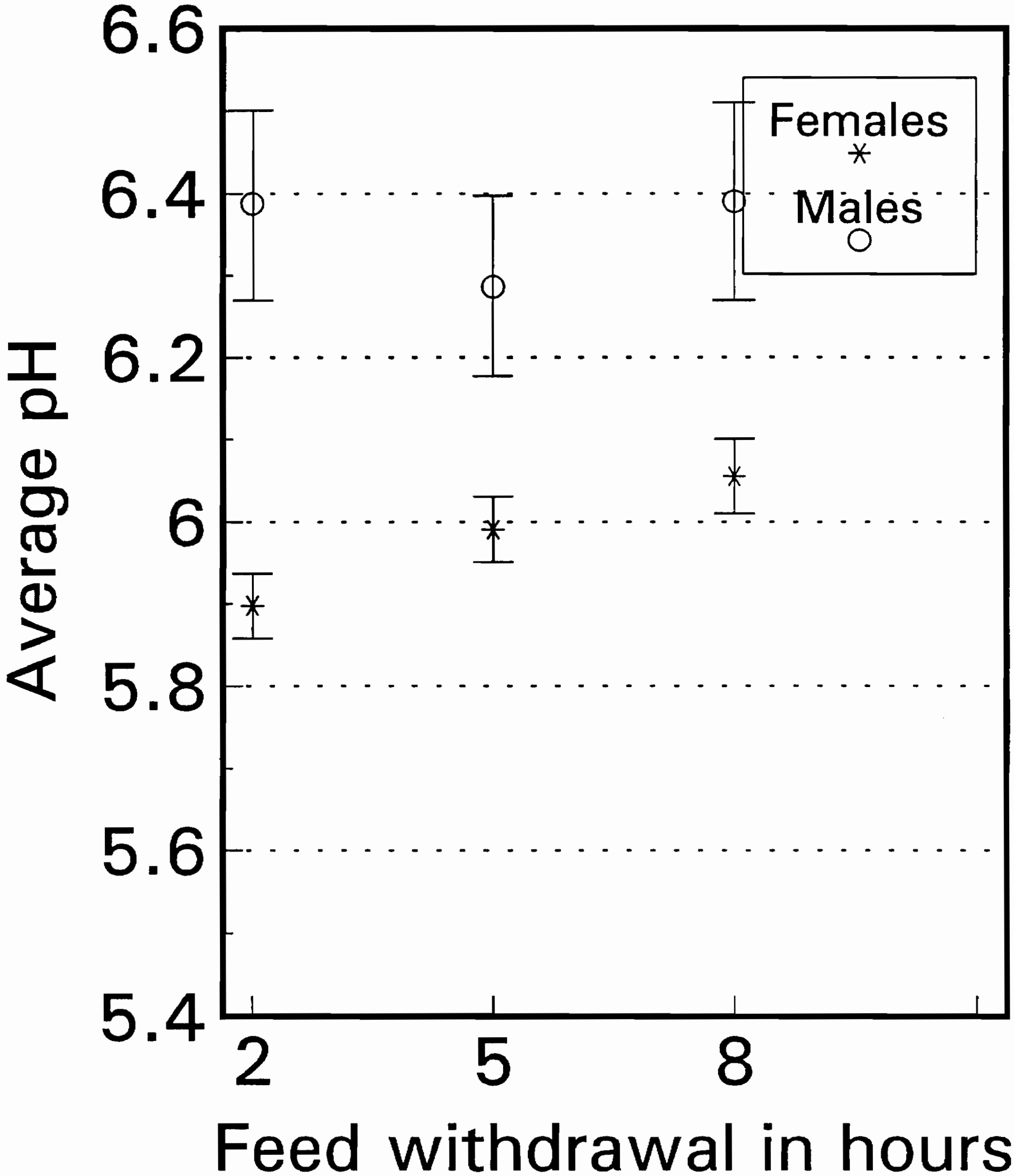


Figure 19. Average pH of breast meat of turkeys after constant current stunning for 7 seconds and three hours cooping before slaughter.

4. Breast meat color

Besides a gender difference affecting the color of breast meat, Hunter values indicated a significant effect ($p \leq 0.01$) of weight class as well. However, the results obtained do not lead to any defined pattern and can not be explained. No correlation was found between these values and the incidence of breast blood splatter.

Cooping time did not result in significant differences from the group of turkeys processed without this parameter, except for the color of breast muscle. The effect on pH of the breast muscle resulted in higher readings of ultimate pH. This effect can be attributed to the larger depletion of nutrients to the fibre, due to feed and water withdrawal, on death of the bird. Therefore, glycolysis would be affected resulting in less lactic acid formation.

D. STATISTICAL ANALYSIS

The statistical model used (Carter et al., 1977) was accurate in predicting occurrence of events in most cases which was verified by a χ^2 goodness of fit test that ranged from $p = 0.01$ to $p = 1$. Since the model requires occurrence of the defect and significant differences between the effects, which was not the case in the present study, in most cases the contour plots obtained for all the interactions studied, defect versus amperage, feed withdrawal or weight class, were not indicative of any significant trend among variables. The logistic function with quadratic argument expected to best represent the interactions between the variables studied, was not able to optimize for the constant current stunning of turkeys based on the occurrence of defects at the levels used in this experiment for the factors considered.

V. SUMMARY AND CONCLUSIONS

Birds were stunned using a prototype constant current device designed by Electrical Engineering at Virginia Polytechnic Institute and State University.

A gender difference in resistance ($p \leq 0.0001$) to electrical flow in response to constant current stunning was observed in broilers and turkeys. These results are opposite to those reported by Schutt-Abraham et al. (1983) and Heath (1984b) who have indicated that there is little or no effect of sex on the resistance of poultry. No effect of weight or age was observed in the resistance of broilers or turkeys which is in agreement with results reported by Schutt-Abraham et al.(1983), Heath (1984b) and Grandin (1989).

Constant current application for 7 seconds at 400 Hz of 30 mA per bird in broilers and 50 mA per bird in turkeys was found sufficient to achieve stunning in this species. Lower amperages resulted in understunned birds, presenting a source of misleading judgement of the stun condition and excess stress due to excessive struggle of the bird. However, the results indicate possible differences between gender for current pathways which need to be further studied in order to determine stunning effectiveness. These current levels are similar to those reported by Veerkamp (1988) as the minimum necessary to induce effective immobilization in birds. He reported that a minimum of 20 mA per bird is required to stun a bird.

Recovery from stunning showed significant differences ($p \leq 0.009$) between gender in broilers and turkeys, with males requiring a longer time to regain consciousness than females. There might had been a misjudgement of this condition due to weight of females whom maybe were able to move easier than males. The length of this period was similar for broilers and turkeys and greater than the values reported by Richard and Sykes (1967), Kuenzel and Walther (1978), Scott (1978) and Gregory and Wotton (1990b). In broilers, weight class had a significant effect ($p=0.004$) in the length of this period with a decrease in recovery time as birds got bigger. In turkeys, amperage had a significant effect ($p = 0.03$) in the recovery time, with an increase in this interval as the amperage level increased. This effect has been previously reported in chickens by Gregory and Wotton (1990b).

The occurrence of carcass defects, expressed as total defects, showed significant differences by gender in both species. No report of this difference by other authors was found. Amperage and weight class had a significant effect on the incidence of defects when defects were grouped together and expressed as defective birds. The incidence of carcass defects in all and every category measured, i.e broken bones and breast and thigh blood splatter was much more pronounced in broilers than turkeys.

Incidence of broken bones occurred mainly in the collar region of the birds (furcula), with higher incidence of this defect in broilers than turkeys. This is in agreement with previous findings by Gregory and Wilkins (1990). Amperage level had a significant effect (p=0.033) in the occurrence of broken bones in broilers. These results confirm those reported by Gregory (1988) and Gregory and Wilkins (1989d).

Breast blood splatter was mostly seen as streaks of blood in the outerface of the pectoralis minor muscle. Turkey males had a significantly higher incidence of breast blood splatter than females.

Weight class had significant effect in the pH of broilers and turkeys with positive correlation. Turkeys showed gender differences in ultimate pH readings. These effects can be attributed to the composition of poultry meat which is dependent upon species, diet, age, sex and growth environment (Stadelman, 1988).

Turkeys cooped three hours prior to slaughter differed from the other group only in some aspects. They presented no gender difference in recovery time. The percentage of defective birds was not significantly affected by gender, amperage or weight class. Feed and water withdrawal had a significant effect on breast muscle pH. Breast meat color was significantly affected by gender and weight class.

The conclusions reached are:

- The variations in resistance between and within species demonstrate the need for a stunner to deliver a preset constant current to each bird;

- There are significant differences between gender in resistance, recovery time, and carcass defects;

- Optimization of electronarcosis parameters for poultry was not achieved due to the inability of the statistical model to represent the interactions between the variables studied at the levels used in this study.

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