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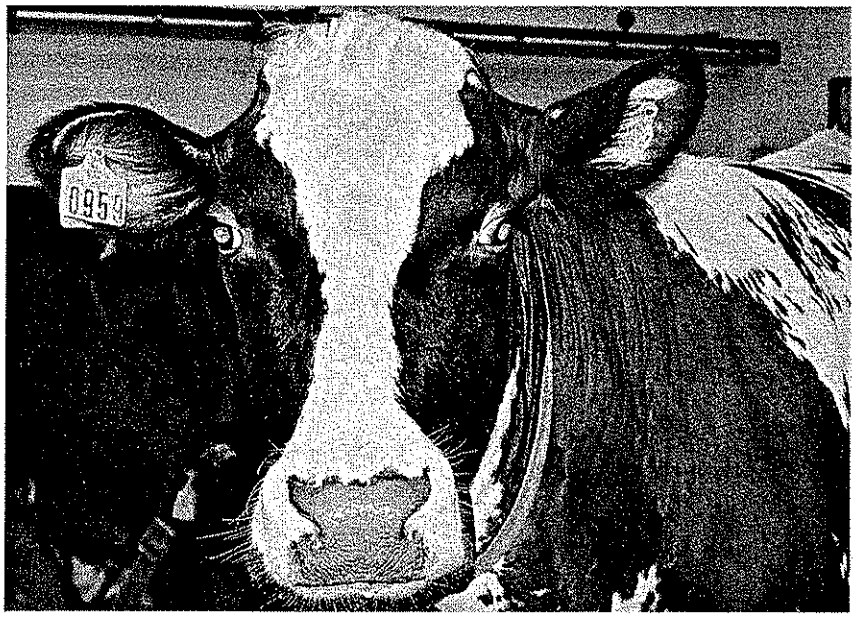


Content pages

Sammanfattning

Denna rapport handlar om effekterna av transporttid och därtill hörande transportförhållanden på djurens välfärd och köttkvalité. Arbetet utgör en del av CATRA-projektet (QLK5-199-01507: *Minimising stress including factors on cattle during handling and transport to improve animal welfare and meat quality*: www.bt.slu.se/catra catra/) som finansierades av EU och Djurskyddsmyndigheten/ Jordbruksverket.

Projektet bestod av åtta delområden: Förstudie, Effekt av transporttid (under 14 timmar och över 14 timmar vid längre distanser), Effekt av vibration och rörelse (under laboratorie- och fältförhållanden), Lämpligaste hantering före och efter transporten, Luftkvalité i fordonen, Djurtransporternas logistik inklusive optimering av rutten och utveckling av ett IT-styrd och kontrollsystem.

Syftet med projektet var att samla tillräckligt med data för att utveckla metoder att begränsa och minimera stressfaktorer under hantering och transport av nötkreatur; utveckla riktlinjer och rekommendationer för personal i slakteri- och transportbranscherna och som underlag för handlingsprogram för att förbättra djurvälfärd och köttkvalité på EU-nivå. Detta kan uppnås genom optimal utformning av hanteringsytor, transportfordon och övriga transportförhållanden och att föreslå ett effektivt, IT-stött logistiksystem. Genom åtgärderna kan nötkreaturens välfärd och köttkvalitén förbättras så att producenternas och slakteriernas ekonomiska konkurrenskraft stärks. I den svenska delen av CATRA-projektet studerades effekterna av transporttiden för att bestämma inverkan av transporttid upp till 11 timmar på djurens välfärd och köttkvalitén efter slakt då djuren transporterades från gårdar till slakteri med djurtransportlastbil. Det slutliga målet är att optimera transporttiden med avseende på välfärd, köttkvalité och andra stressrelaterade faktorer.

Kor, kvigor, tjurar och kalvar ingick i studierna och följande resultatparametrar observerades: blodparametrar (kortison, glykos, lactate, CK), kliniska parametrar (hjärtfrekvens, balansen), köttparametrar (blåmärken, PH-24, mörhet) och etologiska parametrar.

De parametrar som varierades i studierna var lastningen (ramp/lyft), inredningssystem (beläggning, gruppering, djurens uppställning i och utformningen av lastutrymmet), luftkvalitén (lufthastighet, luftens fuktighet och temperaturfördelningen i lastutrymmet samt ammoniak- och koldioxidhalterna), vibrationer, transporttid, viloperioder och utfodring. Samtidig och kontinuerlig mätning av hjärtfrekvens, kroppstemperatur och luftkvalité samt videoupptagning gjordes under färden från gård till slakteri. Blodprov togs före och efter transport samt under viloperioder.

Mätresultaten visar att transport och hantering orsakar stress hos djuren och att lastning och lossning är de händelser i hanteringskedjan som orsakar högst stressnivå. Med avseende på transporttid visar resultaten att transporttid som överstiger 6 timmar är särskilt stressande för djuren då de transporteras med vanlig djurtransportlastbil utan särskild utrustning. I detta fall fanns signifikant korrelation mellan transporttid och stressnivå bestämd med fysiologiska parametrar. Den observerade påverkan på köttkvalitén var emellertid mindre säker. Slutsatsen blir därför att transporttiden har större inflytande på djurets välfärd än på köttkvalitén då djuren transporteras i vanliga transportfordon.

Förhållanden och hantering före transporten såsom inhysningssystem, förberedelser, lastning, planering och handhavande liksom lossning och slakt vid slutet av transportkedjan utgör viktiga utmaningar med olika möjligheter att förbättra välfärd och köttkvalité.

Lastnings- och lossningsfaciliteter (t.ex. ramp, drivningsväg och sidolämmar) samt golvets kvalité har avgörande inflytande på både välfärd och köttkvalité. Nötkreatur från uppbundna stallsystem stressas mer av transport än lösgående nötkreatur och löper större risk att resultera i dåliga slaktkroppar och sämre köttkvalité.

Mätningarna med avseende på luftkvalité visar att ammoniak och koldioxidhalterna ökar med ökande transporttid och i några fall blev koncentrationerna oacceptabelt höga då enbart fanns naturlig ventilation. Under fältmättningarna observerades inga mätbara koncentrationer av metan. För att motverka termisk stress rekommenderas att installera mekanisk ventilation (både för att kyla och värma upp).

Följande slutsatser kan dras av de nuvarande studierna:

- Transporten i sin helhet är stressande för djur och kan äventyra deras välfärd.
- Lastning och lossning är mest stressande enligt bedömning baserat på mätning av hjärtfrekvens och observation av djurens beteende.
- Resultaten av blodprovsanalyserna visar att stressnivån är korrelerad till transporttiden. Kalvar är mest känsliga för transporttid och följs av tjurar medan kor är relativt sett mindre känsliga för transportsträckan.
- Transporttid över 6 timmar är stressande för djur som transporteras med vanlig djurtransportlastbil utan särskild utrustning medan transporttidens negativa påverkan på köttkvalitén inte kan bestämmas med samma säkerhet.
- Temperaturens jämnhet i lastutrymmet beror av årstiden och antalet stopp.
- Koncentrationerna av ammoniak och koldioxid ökar med transporttiden och tillfälligtvis kan acceptabel nivå överskridas.

Summary

The current report deals with the effect of transport time and associated transport conditions on animal welfare and meat quality. The work is part of the EU EU and Animal Welfare Agency /Swedish Board of Agriculture, funded project **CATRA** (QLK5-1999-01507: *Minimising stress inducing factors on cattle during handling and transport to improve animal welfare and meat quality:* ***www.bt.slu.se/catra/***).

The project was composed of eight work packages: Baseline survey, Effect of transport time (below 14 hours and long distance more than 14 hours), Effect of vibration and motion (to be conducted both in laboratory and field conditions), Optimising pre-and post-transport handling, Air quality in the vehicles, cattle transport logistics including route optimisation, and development of control system.

The purpose of the project was to gather sufficient data and to develop methods for controlling and minimizing stress inducing factors during handling and transport of cattle; develop guide-lines and recommendation for end-users, such as meat and vehicle industries and the policy makers, to improve animal welfare and meat quality on the European level. This could be fulfilled through optimization of design of handling areas, transport vehicles, and transport-associated conditions, and by promoting an IT-supported effective logistic system. Hence cattle welfare and meat quality will be improved, thereby enhancing the economic competitiveness of producers and abattoirs.

As part of CATRA, this part of the project is the work done in Sweden regarding the effect of transport time, with the objective of determining the effect of transport time (up to 11 hours) on animal welfare and post mortem meat quality, when cattle are transported from farms to abattoirs by commercial vehicles. The ultimate objective is to optimise transport time in relation to welfare and meat quality taking into consideration other stress inducing factors.

Animals on which the experiments performed were cows, heifers, bulls and calves. Response parameters that were considered were: blood parameters (cortisol, glucose, lactate, CK,), clinical parameters (heart rate, postural stability), meat parameters (bruising score, PH-24 , tenderness), and ethological parameters.

Input parameters considered were parameters for loading facilities (ramps, lifts), penning systems (stocking density, social group, standing orientation, design of loading compartment), air quality (air speed, relative humidity, evenness of temperature in the compartment, level of NH_3, CO_2), vibration, transport time, resting time, and feeding regimes. Simultaneous and continuous measurement of heart rate, body temperature, air quality parameters, and video recording was conducted from farm to the abattoirs. Blood samples were taken before and after transport, and also during resting.

The results obtained indicated that the transport and handling events are stressful for the animals as a whole, and loading and un-loading are among the most stressful events in the studied conditions. Regarding transport time, the results showed that transport time after six hours is particularly stressful for the animals when transported with usual vehicles without special equipments. In this case, it was reported a significant correlation between transport time and animal stress evaluated by physiological parameters. However, less detrimental

effect of transport time on meat quality has been observed. It may therefore be concluded that transport time has influences more on animal welfare than meat quality when transported in conventional vehicles.

Transport preceding and initiating conditions and processes such as keeping system, preparation, loading, planning and management, as well as unloading and lairage at the end of the transport chain are important challenges bearing various possibilities to improve welfare and meat quality.
Loading and unloading facilities (such as ramp, driveways, and side-block) and quality of floor have significant influence on both welfare and meat quality. Cattle from tied housing systems are more stressed by transport than untied cattle and there is a greater risk to develop bad carcass- and meat quality.

As regard to air quality, the concentration level of ammonia and carbon dioxide increase with transport time and it occasionally passes the acceptable level when only natural ventilation is used. During the field experiment no detectable methane has been found.
To prevent thermal stress, the installation of mechanical ventilation system (both for cooling and heating purposes) is recommended.

The conclusions deduced from the current studies are as follows:

- Transport conditions, as a whole is stressful for animals and compromise their welfare.
- Loading and unloading activities are the most stress inducing factors identified using the heart rate measurements and behaviour observations
- Result of the analysis of blood parameters showed that level of stress correlates with transport time. Calves are most sensitive to transport time followed by bulls, and cows are relatively less sensitive to transport length.
- Transport time after six hours is stressful for the animals when transported with usual vehicles without special equipments. However, less detrimental effect of transport time on meat quality has been observed,
- The evenness of temperature in the loading pens depends on season and number of stops
- Concentration level of ammonia and carbon dioxide increase with transport time and it occasionally passes the acceptable level.

Definitions of terms

The following definitions were made as related to transport activities.

Stop time:

Stop time is a still standing of the transport vehicle between 5 and 60 minutes. It was noted that after five minutes of stop time the climate in the vehicle starts to change which leads to the behavioural alteration of animals. During the test stops duration less than 5 minutes should be documented for a reference.

Break time:

Stops duration more than 60 minutes is considered as break.

Loading stop:

Stop duration to load animals from other farms.

Loading time:

Definition was given for two conditions: for individual animal and for group of animals. If the loading performs one animal at a time, loading time is the time when the first animal separates from its group to the time when the last animal enters the vehicle and the ramp closes.

Loading time for a single animal is the time interval between the time when the animal separates from its group until closing of the loading ramp of the vehicle
Loading time for a group of animals is the time interval between opening of the pen at the farm until closing of the loading ramp of the vehicle.

Transport time:

Transport time includes loading, driving and unloading, i.e., the time interval from the beginning of loading until the end of unloading (adopting the EU rules).

Unloading time:

Unloading time is the time from opening of the vehicle's ramp until the last animal entered the lairage pen or driving path. However, when considering the case of individual animal, the unloading time will be the time interval when the vehicle's ramp opens until that particular animal enters the lairage pen or driving path.

Collecting time:

It is the time between the beginning of the loading time on the first farm until the end of the loading time of the last animal on the last farm

Lairage time:

Lairage time is the time from the last animal enters the lairage pen (closing the door) until the last animal leaves the pen.

DTS time:

DTS (driving time to stunning) is the time when the animal leaves the lairage pen until the door of the stunning box is closed.

Stunning time

It is the time interval between stunning and sticking.

Fasting time:

It is the time interval from the last feeding until stunning.

1. Introduction

Transport and the associated activities could subject uncomfortable and stressful conditions to animals leading to poor welfare, reduced meat quality (Honkavaara, M. and P. Kortesniemi, 1994; Warriss, P.D., 1990; Warriss, P.D., et al. 1995) thereby compromising the economic competitiveness of abattoirs and farms.

Transport time is becoming important (Gebresenbet, G., Eriksson, B. 1998) as it could affect both welfare and meat quality. Study made by Fernandez et al (Fernandez X., et al., 996) on calves reported that a transport of 11 hours decreased live weight by 3.6%, which could be attributed to dehydration (Tarrant, P.V., et al, 1992). Very limited studies have been made to determine the effect of short haul and long distance (Warriss, P.D., et al., 1995), and there is no adequate data on the relationship between transport time length and welfare and meat quality. Therefore the existing legislations regarding the limitation of transport time do not have scientific bases. Especially EU transport and resting time regulations have to be verified in this regard (European Union, 1991).

Loading and unloading
Some recommendations and regulations already exist for the handling of cattle during driving, loading and unloading (Grandin, T, 1990). However there is an open discussion whether stress of loading and unloading in well designed facilities will destroy the positive effect of a resting period outside the vehicle, so that it would be alternatively preferable to provide resting conditions on the vehicle (Marahrens, M., J. Hartung and N. Parvizi, 1999). After long road transports, being continued by road or ship transport, a resting period is prescribed after 29 h (European Union, 1991; European Union, 1997) but little is known about the necessary time and resting conditions for the animals to recover in relation to the previous transport conditions.

Air quality
Effective ventilation system in the pen of the cattle transport vehicles is required to control gas concentration, temperature, humidity and air flow patterns in order to safeguard the welfare of animals during transport. Excess heat in summer and deep temperature in winter are critical situations in the pen (Berckmans, D., et al., 1993). Different areas of temperature and air velocity may be described on a moving vehicle depending on the ventilation system used and the space allowance (Randall, J.M., 1993). Hitherto limited research has been made regarding air quality in transport vehicles. Some principles and recommendations exist, mainly based on practical experiences.

Space allowance
Space allowance for cattle during road transport can have a significant effect on the level of bruising, carcass weight and risk of injury of the animals. Lower space allowance gives lower heart rate and less restlessness than the higher space allowance. In a study by Eldridge and Winfield (1988) three space allowances were used (0.87, 1.16 and 1.39 m^2) during six hours of transport. There was no difference in aggressive behaviour between space allowances but animals in the higher space allowances moved around more. A total of six animals went down, all in the lower space allowances. High and low space allowances had more bruising than the medium.

Tarrant et al (1988) investigated the effect of three stocking densities on steers. The densities were 200, 300 and 600 kg/ m^2. The conclusions were that high stocking densities had a negative effect on animal welfare compared to low and medium stocking densities. Mounting and pushing increased at a high stocking density, which can explain the increased bruising. It has been suggested by Eldridge et al (1988) that a space allowance of 10% less than 1 m^2/animal results in less stress than +10% of the same space allowance

As mentioned earlier, little is known on the effect of transport time (including short, long and international transport) on the welfare and meat quality and no optimization has been made on resting conditions after transport. More over, no detailed work has been made to determine which of the loading or un-loading activities are the most significant factors. Moreover, adequate research input is required to determine the air quality in the pen of the vehicles.

2. Objective

The objective of the present work is to determine the effect of transport time up to 11 hours on animal welfare and post mortem meat quality, when cattle are transported from farms to abattoirs by commercial vehicles. The ultimate objective is to optimise transport time in relation to welfare and meat quality taking into consideration other stress inducing factors.

3. Method and materials

3.1. Animals

Totally 196 cattle of three animal classes (calves, young bulls and cows) were transported from various farms to the Swedish Meats abattoir under normal commercial conditions. The animals used are calves (7-8 month old), young bulls (18-24 month old) and cows (cows that had at least one calf). Each experiment included five animals from the same animal class and from the same farm. Different breeds were used, but there were mostly Swedish red (51 %) and Swedish lowland, Holstein (22 %) cattle but also cross breeds between these and Hereford (4 %), Charolais (3 %), Limousine (5 %), Simmental (3 %) and Aberdeen Angus (1 %). Pure beef cattle were rare, only Charolais (6 %) and Hereford (5 %) were used. Calves were held at loose systems in 92 % of the farms included. Bulls were tied up in 92 % of the farms included and cows were held at tied systems in 75 % of the farms included.

Number of animals on the vehicle varied between 5 calves to 16 adult cattle. During the long transports other animals than the experimental ones were loaded only shortly before the unloading. During short and medium transports other animals often already were on the vehicle before the experimental animals were loaded and more animals were loaded afterwards.

3.2. Vehicle

The vehicle used was a VOLVO FM12 (see Figure 1a). It has air and leaf suspension system, natural ventilation system, a rear ramp and rubber floor. The vehicle has four pens with a size of 6.0-m^2 space in each pen where normally 4 adult animals are transported. The pens were divided with walls made of bars.

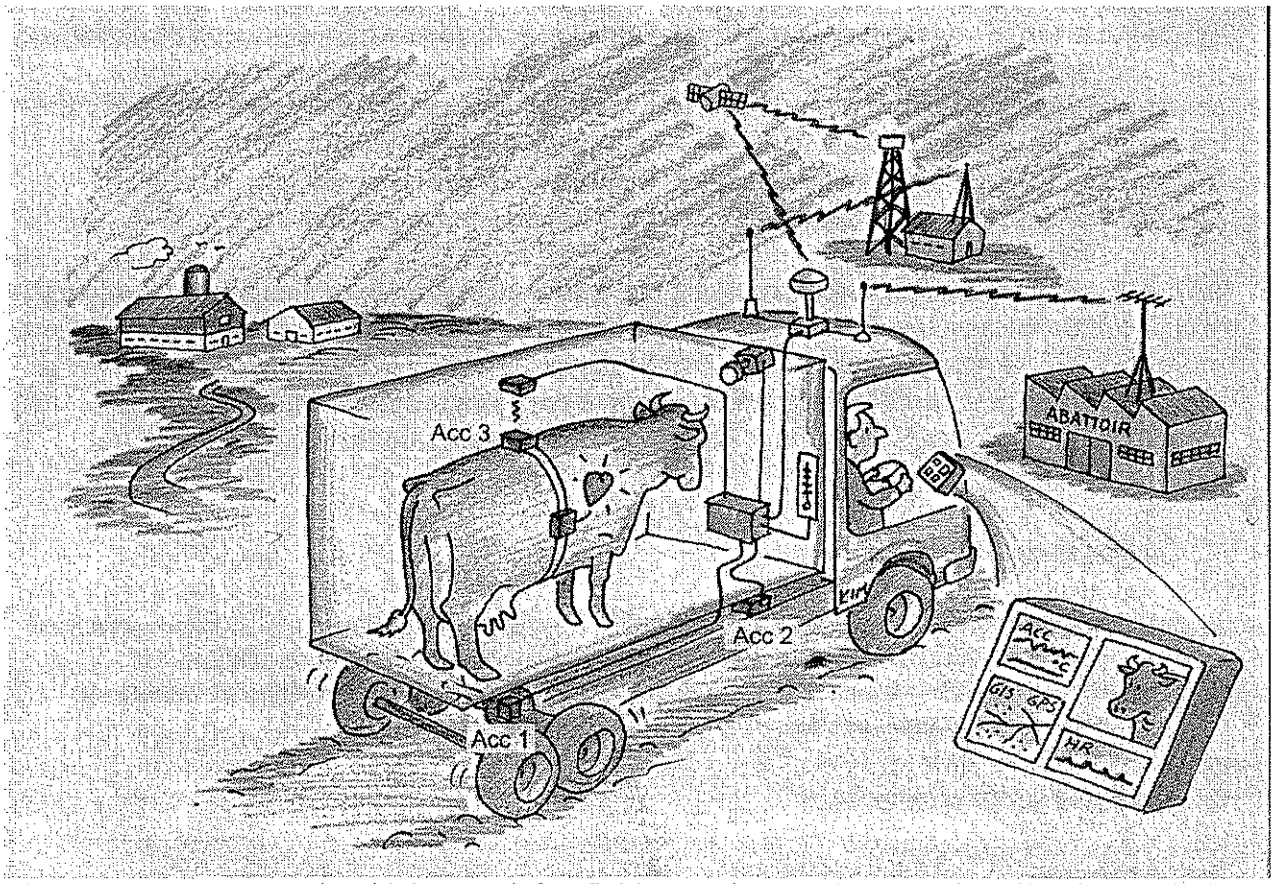


Figure 1a. Instrumented vehicles used for field experiments (sensors for vibration and air quality, video camera, and GPS systems installed)

3.3. Parameters

The parameters considered in this part of the project are:

(a) meat quality parameters (bruising score, rate of pH fall, tenderness, drip loss, glycogen and coloration);
(b) air quality parameters (air speed, relative humidity, temperature in the loading compartment, NH3, CH4 , O2);
(c) blood parameters (glucose, cortisol, lactate, and CK);
(d) clinical and ethological parameters (heart rate, body temperature, postural stability and behaviour);
(e) vehicle performances and penning method (vibration, transport time, stock density),

Other parameters are season and three classes of transport times (less than one hours, between four and six hours, and between eight and eleven hours). Each transport included five animals in the experiment but to get the right stocking density other animals from the same farm were loaded if necessary. For example calves were loaded six or eight per pen. With the higher stocking density three more animals from the same farm were loaded but not included in the experiment. To fill the slaughter vehicle new animals were loaded from other farms. The number of stops varied between one and four.

The short and medium transports took place in the morning and the animals arrived to the abattoir to be slaughtered at 11 am at the latest. The long transports started in the evening so that the animals arrived at about 7 am at the abattoir. Transportation over night occurs in Sweden but is not common practise. The animals from tied systems were tied during transport and the animals from loose systems were transported loose, according to the Swedish legislation. An overview of the experimental design is presented in Table 1.

Table 1. An overview of the experiments with the parameters used.

Animal class	Season	Density, m²/animal	Transport times
cows	summer	2.0	<2 h.
			3- 4 h.
	winter	1.5	10 – 11 h.
young bulls	summer	2.0	<1 h.
			4 – 6 h.
	winter	1.5	8 – 11 h.
calves	summer	1.2	<1 h.
			4 – 6 h.
	winter	0.8	8 – 11 h.

3.4. Measurement methods and materials

3.4.1. Blood samples

Blood samples were taken from five animals for every trip, prior to transport (at least one and half-hours before loading so that the animals may recover from stress induced by blood sampling process before loading) and after transport to determine the effect of handling and transport. Blood samples were collected in Lithium-heparin tubes and taken from the tail vein at the farm and from the jugular vein at the abattoir after stunning. When the animals arrived to the abattoir, they were immediately walked to the stunning box. The animals transported short and medium times were stunned before 11 am and the animals transported long were stunned around 7 am. The samples were centrifuged within 15 minutes after collection and the supernatant was filtered. Cortisol was analysed using RIA (ELISA), creatine kinase, glucose and lactate using photometer and multianalyser (kinetic UV-test, NAC-method).

3.4.2. Heart rate

The heart rate equipment, POLAR® Vantage (Polar, 1996), consists of a sensor and a receiver (see Figure 1b). The sensor was sewed to a girth belt that was attached to the animal so the sensor came just behind the left foreleg (Gebresenbet and Ericsson, 1998). If the animals had long hair they were shaved with an electric clipper. Electrode gel was always spread on the skin and the belts to ensure contact. The receiver was placed in a plastic box that was attached to the girth belt. The receiver stored values every 5-seconds on short and medium transports and every 15 seconds during the long transports because of the memory limit of the receiver. Each value is based on an error-detection algorithm during the interval used (Seaward et al., 1990).

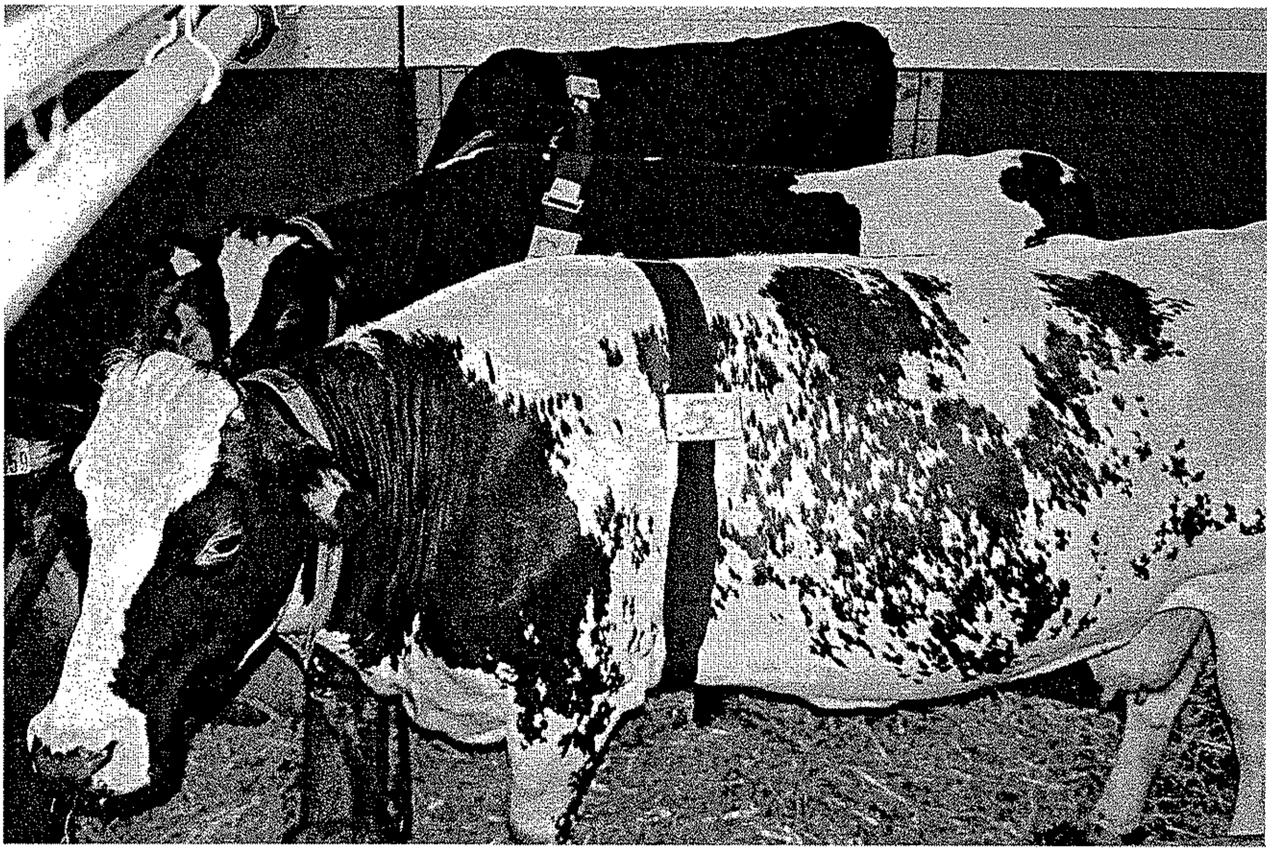


Figure 1b. Heart rate measuring sensor and receiver mounted on animals to record and save data continuously

3.4.3. Behaviour

Behaviour was observed during loading and unloading and a protocol was used as aid. During transport the animals were filmed with a video camera mounted in the loading compartment of the vehicle. The film was later viewed and the different behaviours noted and analysed. Loading and unloading was timed and the behaviour of the animals was observed (See Table 2). A special scoring system was developed (Maria et al, 2001) to evaluate loading and unloading behaviour. Each behaviour was multiplied with a score and all scores were summarized. Loading and unloading time was also given a score (See Table 3) that was then multiplied with the behaviour score. For example five animals were loaded and one animal fell and another turned twice. The total score for this group of animals is 1x1 + 2x0.5= 2. Loading time per animal was less then 1 minute which gives 0.5 points. Total score for this group is therefore 2x0.5=1

Table 2. Ethogram and scores given to animals during loading and unloading

Behaviour	**Definition**	**Points**
Slips	Looses balance but knees does not touch the ground	0.5
Falls	One or two knees touches the ground	1
Stops	Stands still for three seconds	0.5
Goes backwards	Takes two or more steps backwards	1
Turns	Turns and goes in another direction	0.5
Fights	Aggressive behaviour, such as butting, another animal	1
Mounting active	The animal mounts another animal	1
Mounting passive	The animal is mounted by another animal	0.5
Urinates		0.5
Faeces		0.5
Vocalisation		1
Total		**8**

Table3. Points given to animals depending on loading and unloading time separately

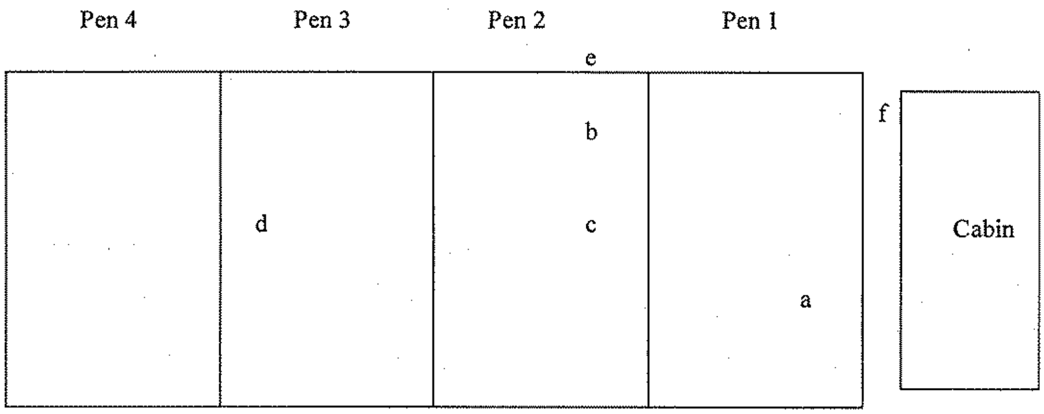
Time (minutes)	*Points*
<1	1
1-2	2
2-3	3
3-4	4
>4	5

3.4.4. Body temperature

In the first part of the project, body temperature was not considered. For the second part continuous measurement of body temperature was made by inserting a thermometer inserted intravaginal that stores data to a microchip and five cows were used for each trip. However, due to technical constraints, the measurement was limited to few animals.

3.4.5. Air quality

The vehicle that was used in the experiments was a VOLVO FM12 with natural ventilation system. The vehicle had four pens (see Figures 1c and 1d) and the loading box dimension of: lenght = 9.6 m; width = 2.55 m and height = 2.4 m. The vehicle accommodates 16 adult cattle at the most. Air conditions in the pen were measured by placing temperature sensors in five positions and the letters (a) to (f) in Figure 1 denote the placement of sensors. The sensors were placed in the front pen (a), in the second pen both at one side (b) and in the middle (c), in the third pen (d) and outside a window (e) in the summer and (f) in the winter. Sensors for relative humidity, carbon dioxide, methane and oxygen were placed at the position (b) and air speed at position (d). The measurements were made with a logger (TESTO 454, Nordtec Instrument, Sweden) and with different sensors (Ni-Cr-Ni, capacitive and thermal) see Table 4. Ammonia was measured with a single gas detector (Toxi Ultra, biosystems, Scantec lab AB, Sweden) placed in the middle of the cargo area. Methane, carbon dioxide and oxygen levels were measured with an instrument (GA 2000, Landfill gas analyser, Geotechnical Instruments, UK) placed in the middle that measures methane and carbon dioxide with infrared technology and oxygen with internal electrochemical cells.



a	Temperature
b	Temperature, relative humidity, gases
c	Temperature
d	Temperature
e	Outside temperature during summer experiments
f	Outside temperature during winter experiments

Figure 1c. Place of sensors during summer and winter experiments.

Table 4. Measuring parameters during the experiments with the instrument the parameters been measured with, sensor and measuring range and accuracy for every parameter.

	Instrument	Sensor	Measuring range and accuracy
Temperature	TESTO	Thermistors (NiCr-Ni)	Accuracy: 0-50 °C, ±0.4 °C; -20-0 °C, ±0.5 °C
Relative humidity	TESTO	(Capacitiv NTC) 1 measuring unit (RH + temp.)	Humidity measurements: 0 -100 %, -20 - +70 °C. Accuracy: ±1 % in the range of 10-90 % at 15 - 30°C, otherwise ±2 % Temperature accuracy: 0-50 °C, ±0.4 °C; -20-0 °C, ±0.5 °C
Air velocity	TESTO	(Thermal sensor) 1 measuring unit (velocity + temp.)	Measuring range velocity: 0-10 m/s; accuracy: ± 0.03m/s+5% of m.v. Measuring range temperature: -20 - +70 °C; accuracy: ±0.5 °C
Ammonia	TOXI ULTRA	Single gas detector	Measuring range: 0-50 ppm
Carbondioxide	GA2000	Infra-red cell	Measuring range/accuracy: 0-25 % (≥0.1%) / ±1 %
Oxygen	GA2000	Electrochemical cell	Measuring range/accuracy: 0-40 % (≥0.1%) / ±0.5 %
Methane	GA2000	Infra-red cell	Measuring range/accuracy: 0-70 % (≥0.1%) / ±0.5 %

For temperature and relative humidity measurements 35 successful experimental journeys have been made but of these only 13 have measured outside temperature successfully. Methane, carbon dioxide and oxygen measurements have 15 successful journeys been made during the summer part of the experiment.

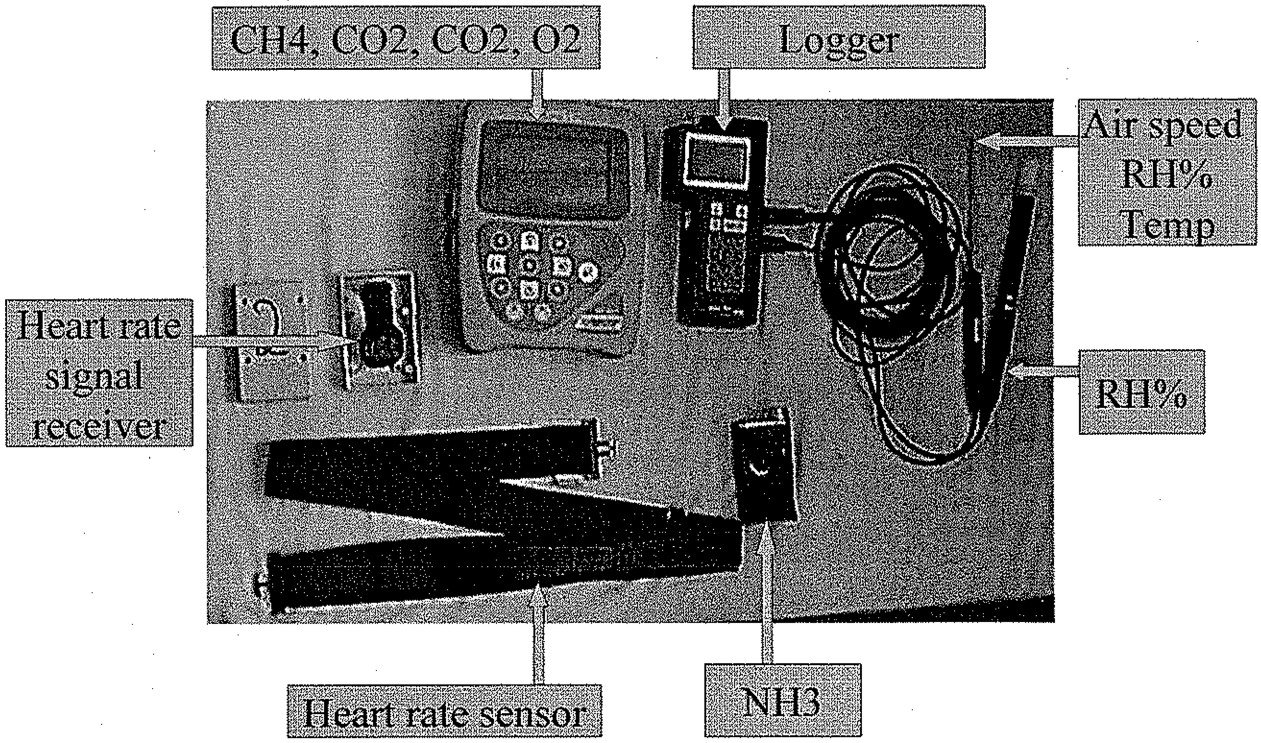


Figure 1d. Air quality measuring sensors

3.4.6. Meat sample

Meat samples of 3-5 g were taken for analyses of glycogen contents from longissimus dorsi muscle (LD) at 11th rib, through the space in between the spinal processes, about 45 minutes pm. The purpose was to evaluate the energy level in the body at slaughter. The sample was immediately frozen in dry ice (CO_2) and put into a sample can with ID numbers signed to each can. They were stored in –20°C at the abattoir during the week, before being transported to the chemical lab, where it was put in a freezer (–80°C).

The carcasses were chilled for 24 h in +4°C. During that time, temperature- and pH-fall was measured in LD between the 12th and 13th rib. For pH measurements, a Knicks 651-2 with a zerolytelektrode was used. The measurements were performed about 1, 3, 5, 18 and 24 hours pm. A 10 cm piece of meat was cut from the caudal part of LD, 24 hours post mortem for determination of drip loss, shear force and colour. After vacuum packaging the samples were stored in +4°C up to 9 days after slaughter. Glycogen content (50 min, pm) and tenderness of LD muscle (8 days, 4°C pm then heated in water until core temperature is 70 °C then chilled in 24 h, 4°C, pm) were measured.

3.4.7. Data and sample analysis

All statistical analyses were performed using SAS 8.01 statistical package. The GLM procedure was used to determine the effects of transport time and stocking density on heart rate. Least square means were calculated and used to test differences between pair of treatments. Heart rate data was divided into 5 events (see Table 5) and an average was calculated for each event.

Table 5. Heart rate was divided for analyses into events during handling and transport.

Event	Range of heart rate considered
Before loading	15 minutes before the vehicle arrived to the farm
Loading	An average were calculated during the time it took to load all animals
Peak during loading	Highest value during loading
Transport	An average from the time the vehicle leaved the farm until it arrived to the abattoir
Unloading	An average were calculated during the time it took to unload all animals

Meat parameters that were determined in the study are shown in table 6. Drip losses were determined as amount of exudated water (%) in the vacuum packages, after 8 days storage at +4°C. Drip losses were calculated by weighing the samples in the vacuum packages, then they were dried again without the packages. Finally the dried vacuum packages were weighed. [100x(1-2-3)/(1-3)] After measuring drip loss, two slices of meat were cut perpendicular to the fibre direction from the samples collected at the abattoir. A 3.5 cm slice was used for shear force determination and a 2.0 cm slice was used for colour determination.

The 3.5 cm slices were vacuum packed in cooking bags and heated to 74°C core temperature for 80 minutes in a 74°C water bath. After chilling in ice water for 15 minutes, 10 rectangular samples of 7x15 mm2 from each slice, were cut out parallel to the muscle fibres. The samples were covered with aluminium foil and were stored in room temperature until the shear measurements were started. This was done by using a modified Warner-Bratzler shearing blade of 1.0 mm thickness (Bouton & Harris, 1978) attached to an Instron 4301 apparatus. The technique implies that the force that is consumed to cut through the piece of meat is measured. The samples should not contain any connective tissues and should be as reproducible as possible. This method has earlier been correlated well with sensorical analyses.

The 2.0 cm meat slices for colour determination were placed in petri dishes, wrapped with a thin oxygen permeable film (Flexfilm 3, Teno AB, Sweden) and allowed to bloom for 1.5 to 2 hours at +4°C. The colour was measured using a Hunterlab Color Quest Instrument (Hunter Associates Laboratory, Inc., Reston, VA 22090 U.S.A.) with specular reflectance excluded, 25 mm aperture, illuminant D65, 10° Standard Observer and CIE (1976) colour scale. The average of 4 measurements across the surface was used. The relative contents of deoxymyoglobin (Mb), oxymyoglobin (MbO) and metmyoglobin (MetMb) were calculated from the reflectance curve according to Krzywicki (1979) using 710 nm (the highest wavelength of the instrument) instead of 730 nm. The instrument measures the reflectance between 400 nm and 710 nm at 10 nm intervals. Reflectance values at wavelengths not given by the instrument (473, 525 and 572 nm) were calculated using linear interpolation.

The analyses of glycogen were done by homogenising of 1 g meat samples in 5 ml percloric acid. Glycogen, glucose and glucos-6-phosphate were analysed in the homogenate by an enzymatic method according to Dalrymple & Hamm (1973).

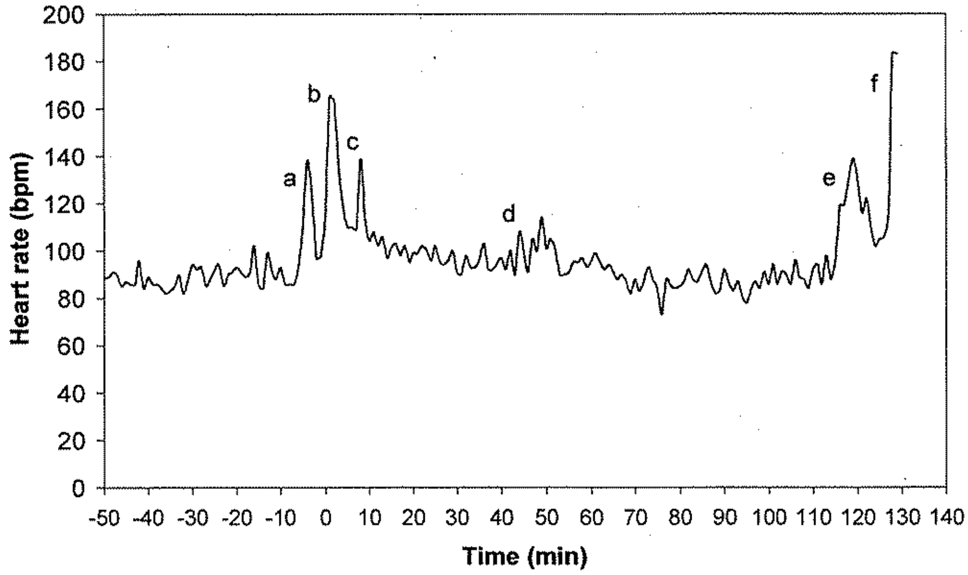
Table 6. Analyses for meat quality parameters

Parameter	Method	Time	Position	Amount	Storage
bruisings	observation	50 min pm	acc. to picture	3-scale	-
pH	pH-meter	1, 3, 5, 18 & 24h	10 – 11 rib	-	-
glycogen	enzymatic analysis	50 min pm	10 – 11 rib	2 - 3 g	dry ice
tenderness	Warner-Bratzler	8 days pm	fr. 2nd lumb. vertebra	10 cm	vacuumpack, + 4°C
colour	CIE $L^*a^*b^*$	"	"	"	"
drip	weighing	"	"	"	"

4. Results

4.1. Heart rate

As mentioned earlier heart rate was measured continually through out the field experiment. A typical heart rate curve is shown in Figure 2. Heart rate values are from a young bull from summer experiment, where the journey lasted for 1 hour and 35 minutes and the loading density was low. The first peak occurred when an animal near the experimental animal was loaded (time=-5), the second peak at loading (time=0), the third peak when the vehicle started to drive, the fourth small peak occurs when new animal was loaded to the vehicle, and the fifth and sixth peaks when the bull was unloaded (time=115) and then forced to go in to the stunning box. (time=128).



a) Animal near experimental animal is loaded
b) Loading
c) The vehicle starts to drive
d) Loading of new animals
e) Unloading at abattoir
f) In to the stunning box
Figure 2. Curve of measured heart rate from a young bull during summer experiment. One sample was saved every five second. X-axis represents time in minutes where 0 represent loading, negative time is before loading and positive after loading.

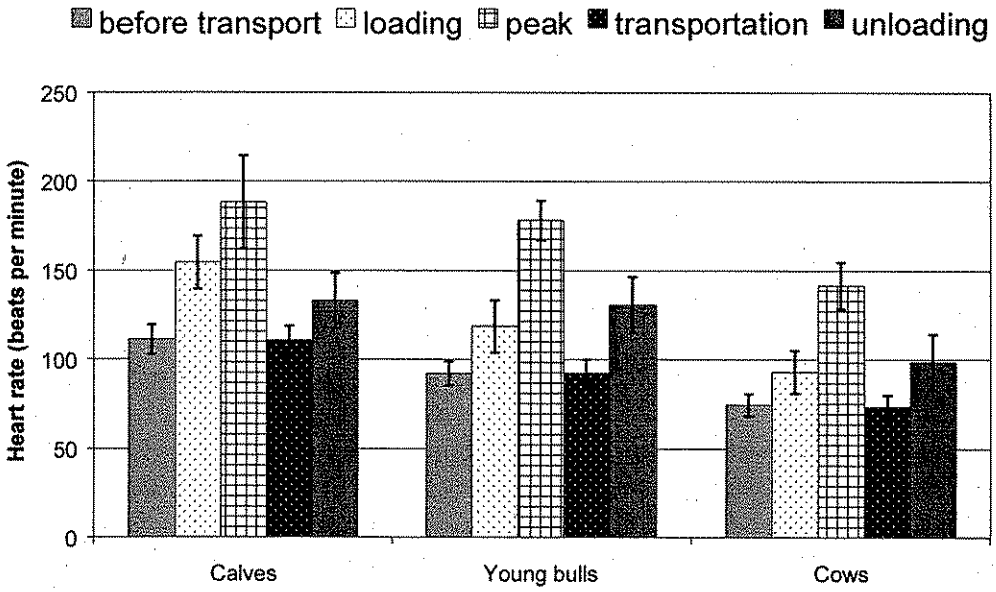


Figure 3. Heart rates of all animals transported from farm to abattoir. Values are means and standard deviations

Average heart rate with standard deviation before loading, during loading, peak value during loading, transport and unloading for all animal classes was calculated and is reported in Figure 3 and heart rate values for all experimental journeys are seen in Table 7-9.

Table 7. Heart rate data for calves before transport, during loading, peak value during loading, during transport and during unloading. The data is divided in transport time, density and season

transport time (h)	density m^2/animal	season	n	before transport	loading	peak value	transport	unloading
			51	111±16	154±30	188±52	111±16	133±31
<2	0.8	Summer	4	100±11	152±25	181±24	104±21	139±34
<2	0.8	Winter	4	113±22	153±25	181±16	108±10	133±133
<2	1.2	Summer	4	107±8	142±20	191±10	110±9	137±19
<2	1.2	Winter	4	104±12	159±138	202±20	131±16	147±29
4	0.8	Summer	5	105±12	140±35	188±27	107±12	150±34
4	0.8	Winter	5	94±10	140±28	175±26	93±14	107±17
4	1.2	Summer	4	111±7	140±24	193±36	104±11	126±20
4	1.2	Winter	3	110±14	150±16	169±15	105±14	
10 – 11	0.8	Summer	4	131±16	158±14	180±9	138±10	
10 – 11	0.8	Winter	5	99±5	183±39	215±9	108±17	
10 – 11	1.2	Summer	5	112±11	169±19	191±6	100±11	125±21
10 – 11	1.2	Winter	4	148±17	165±17	193±7	120±16	

n=number of animals

Table 8. Heart rate data for young bulls before transport, during loading, peak value during loading, during transport and during unloading. The data is divided in transport time, density and season

transport time (h)	density m²/animal	season	n	before transport	loading	peak value	transport	unloading
			44	92±13	118±29	178±22	92±15	131±31
<2	1.5	Summer	3	106±13	165±34	219±4	111±22	140±32
<2	1.5	Winter	3	80±8	92±21	160±8	83±12	140±18
<2	2.0	Summer	4	80±14	122±26	160±13	93±20	112±23
<2	2.0	Winter	4	91±8	113±26	182±19	98±13	136±39
4	1.5	Summer	4	90±10	104±27	187±14	93±10	129±37
4	1.5	Winter	5	84±10	117±22	178±11	91±13	129±33
4	2.0	Summer	4	101±12	126±24	177±4	94±12	141±31
4	2.0	Winter	4	90±9	119±30	187±27	84±9	118±28
10 – 11	1.5	Summer	4	90±8	113±23	172±19	82±15	
10 – 11	1.5	Winter	5	100±6	118±21	178±25	100±10	
10 – 11	2.0	Summer	2	100±12	115±28	161±38	103±11	
10 – 11	2.0	Winter	2				77±12	

n=number of animals

Table 9. Heart rate data for cows before transport, during loading, peak value during loading, during transport and during unloading. The data is divided in transport time, density and season

transport time (h)	density m²/animal	season	n	before transport	loading	peak value	transport	unloading
			45	74±12	93±24	142±26	73±13	98±31
<2	1.5	Summer	4	85±6	100±24	158±19	80±3	107±15
<2	1.5	Winter	5	67±4	98±21	138±40	76±14	
<2	2.0	Summer	4	76±13	87±20	135±35	73±12	73±15
<2	2.0	Winter	2	67±11	94±25	139±17	76±16	140±39
4	1.5	Summer	5	66±9	80±18	111±24	68±7	86±17
4	1.5	Winter	4	67±8	86±23	134±20	70±8	95±13
4	2.0	Summer	4	71±13	71±17	128±24	62±13	80±17
4	2.0	Winter	2	62±10	90±25	144±23	62±7	109±19
10 – 11	1.5	Summer	5	76±9	97±14	128±6	70±9	
10 – 11	1.5	Winter	3	94±12	109±24	168±17	87±11	
10 – 11	2.0	Summer	5	76±10	81±19	135±13	71±11	
10 – 11	2.0	Winter	2	85±6	122±33	180±26	84±17	

n=number of animals

Transport time

Heart rate analysis showed that calves transported for 4 h had lower heart rate during transportation than calves transported less than 2 h or for 11 h. Heart rate were significantly lower ($p=0.045$) for 4 h than for 11 h. The same could be seen for cows, those that had been transported for 4 h had significant lower heart rate ($p=0.02$) than those transported for less than 2 or 11 h. Young bulls had no significant differences depending on transport time, but had higher heart rate during the short transports that lasted less than 2 h. In Table 10 heart rates for the animal classes dependent of transport time is presented.

Table 10. Average heart rates for calves, cows and young bulls during transports of different long times.

Transport time	Calves	Young bulls	Cows
<2 h	113±8.4	96±6.5	76±4.4
4 h	102±4.9	90±4.1	66±4.4
10 – 11 h	116±7.2	90±6.8	78±11.9

Season

For calves there were no significant difference between summer and winter seasons but for cows the summer trials resulted in slightly lower heart rate (p=0.0501) than trials during winter. Young bulls had slightly (not significant) lower heart rate during winter than during summer trial.

Stocking density

Different stocking density didn't create any significant differences in heart rate. High stocking density resulted in slightly higher HR on calves but for cows and young bulls loaded at high density resulted in lower heart rate (see Table 11).

Table 11. Average heart rates on cattle during transport divided on loading density and animal class

Density	Average heart rate when transported		
	Calves	Young bulls	Cows
High	112±7.2	91±5.3	71±5.5
Low	110±6.9	93±6.3	75±4.7

Heart rate and time of the day

Average heart rates before transport was for calves 111±8 bpm, young bulls 92±7 and for cows 74±6 bpm. Heart rate values before transport varied depending on time of the day. The animals had lower heart rates before transport in the mornings (before short and medium transports) than in the night (before long transports) (see Figure 4). For calves the difference was significant and 16 bpm (p=0.0013), for young bulls it was not significant and 7 bpm (p=0.14) and for cows the difference was significant and 8 bpm (p= 0.0405).

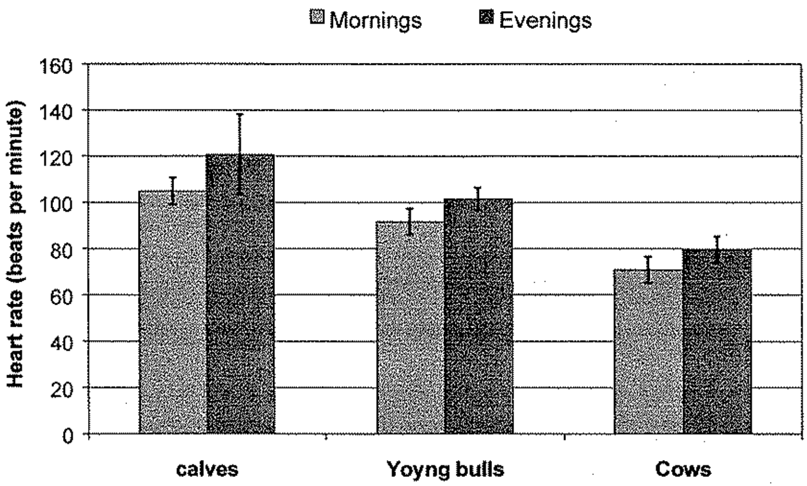


Figure 4. Heart rates for calves, young bulls and cows before transport that occurred in the mornings and in the evenings.

The differences in heart rate before transport didn't depend on season for calves. For cows season had significant effect. During winter heart rate in evenings were higher than heart rate in mornings (p=0.0003), during summer it was higher both in mornings (p=0.016) and evenings (p=0.021). For young bulls the biggest difference between mornings and evenings were seen during winter with a difference of 7 bpm (p=0.035).

Loading and unloading
Loading and unloading caused highest heart rates. During loading the heart rate was raised compared with the average heart rate before loading by 42 bpm in average for calves, 19 for cows and 26 for young bulls. The average peak value for calves during loading was 77 bpm higher than the average heart rate before loading. For cows and young bulls the peak values were 67 and 86 bpm higher respectively. Unloading raised heart rate compared with average heart rate before loading by 27 bpm for calves, 24 for cows and 39 bpm for young bulls.

Stock density, transport time and season
Calves
At low density, average heart rate during transport was significantly lower (p=0.016) at 2-4 hours transports than at long transports. Heart rate at 2-4 hours transport at low density was also significantly lower (p=0.0021) than heart rate at short transport and high stocking density. Short transport at high density resulted also in significantly higher heart rates (p=0.047) than transports made at medium transport time with high density. During winter the short transport resulted in significantly higher heart rate than winter-medium (p=0.0003), summer-medium (p=0.033) and summer–short (p=0.016) transport. The winter-medium transports heart rate was significantly lower than the long transports heart rate during summer (p=0.014). Transport during winter at high density gave higher heart rate than low density (p=0.0045).

Young bulls
No significant interactions for transport time and density for young bulls were seen. Heart rate for short transport during summer was significantly higher than long summer transport (p=0.04) and winter transport that were medium long (p= 0.033). Winter transport with high density gave higher heart rate than winter transport low density (p=0.045).

Cows
At high density and medium transport time heart rates were lower than both short (p=0.019) and long transports (P=0.038) at low density. Heart rate during the long winter transport was significant higher than heart rates during summer short (p=0.047), summer medium (p= 0.0004), summer long (p=0.0016) and winter medium (p=0.0009) transports. No significant differences were found for season and density for cows.

4.2. Blood parameters

The results of blood test for both summer and winter seasons are reported in Table 11.
As mentioned earlier the main blood parameters considered were cortisol, glucose, and CK and lactate for all animal, transport time and density classes.

4.2.1. Cortisol

Calves
In general concentration of cortisol increased up to more than 10 folds in some (se Figure 5a) with an average increase of about 290%. For low density and winter experiment, highest increase of cortisol was observed for short transport. As the transport time increased from medium to long, an increase of cortisol was more than doubled (see Figure 5). For the summer season, the tendency is the same as for winter, except that the cortisol from calves transported for the short time distance increased very high (by about 185 to 1400%, this is because the animals were very much excited during loading and refused to mount the ramp.

For high density, winter and summer seasons, cortisol increased for calves transported at medium transport time than short and long ones. This was particularly significant for winter season. There is a significant increase of cortisol from short time to both medium and long distance during summer. However, no significant increase was observed from medium to long distance.

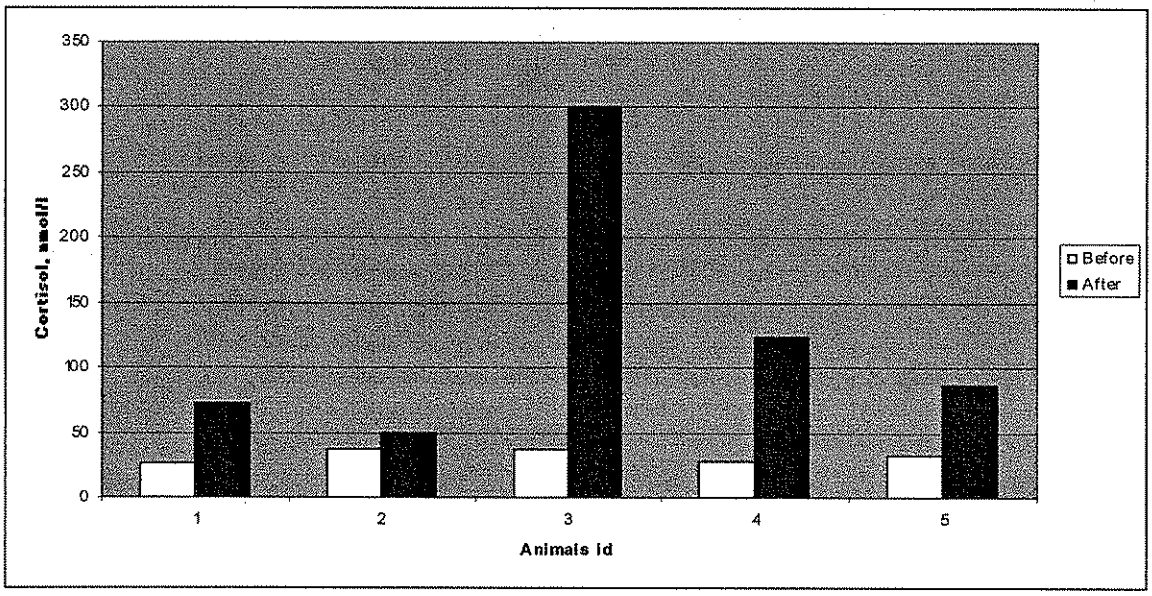


Figure 5a. Effect transport activities on concentration of cortisol in Calves

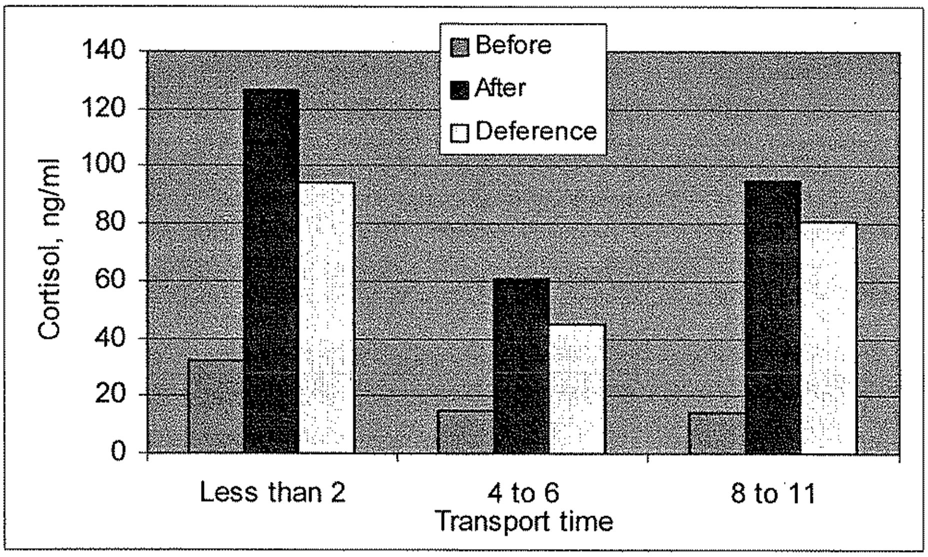


Figure 5. Effect of transport time on cortisol concentration in calves transported during winter, loaded at low density

Bulls

For winter experiment loading at both high and low densities, cortisol decreased with an increase of transport time. It increased slightly from short to medium and decreased thereafter with an increased of transport time (Figure 6). For summer season and low density, significant increase of cortisol was observed from short to medium transport time. An increase of cortisol was tripled from short to medium while it was doubled from short to long time transport. For summer with high-density loading, the result is similar with other results.

The highest increase of cortisol level was noted for short transport time, however, the rate of increase of level concentration for medium long transport..

There is a clear indication that short transport time is stressful for bulls under winter season transport. This may indicate that bulls may be sensitive for climate change and transport handling and adapt themselves as the transport time increases.

However, for the summer season transport, the effect of loading density on cortisol is more significant than transport time. Highest increase of cortisol was observed for short and medium transport time at high and low density respectively.

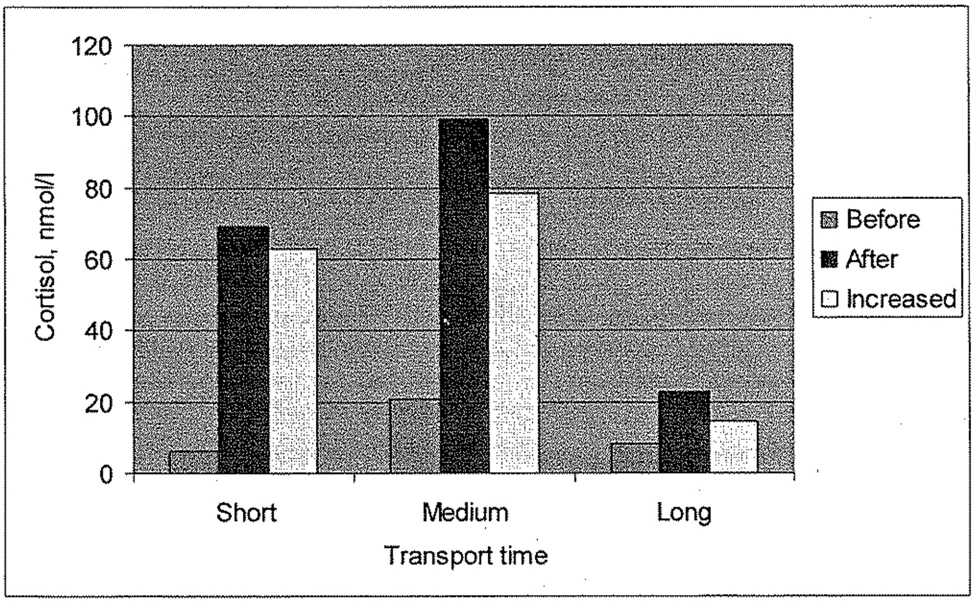


Figure 6. Effect of transport time on cortisol concentration variation for young bulls transported during winter and loaded at high and low density

Cows and heifers

The results from analysis for cortisol showed that the level of cortisol concentration increased considerably after transport by almost up to 15 times in some cases (Figure 7). However, variation between animal categories is significant in relation to stock density and transport time. There is an effect of transport on cows as related to cortisol concentration but is not as on other animal categories.

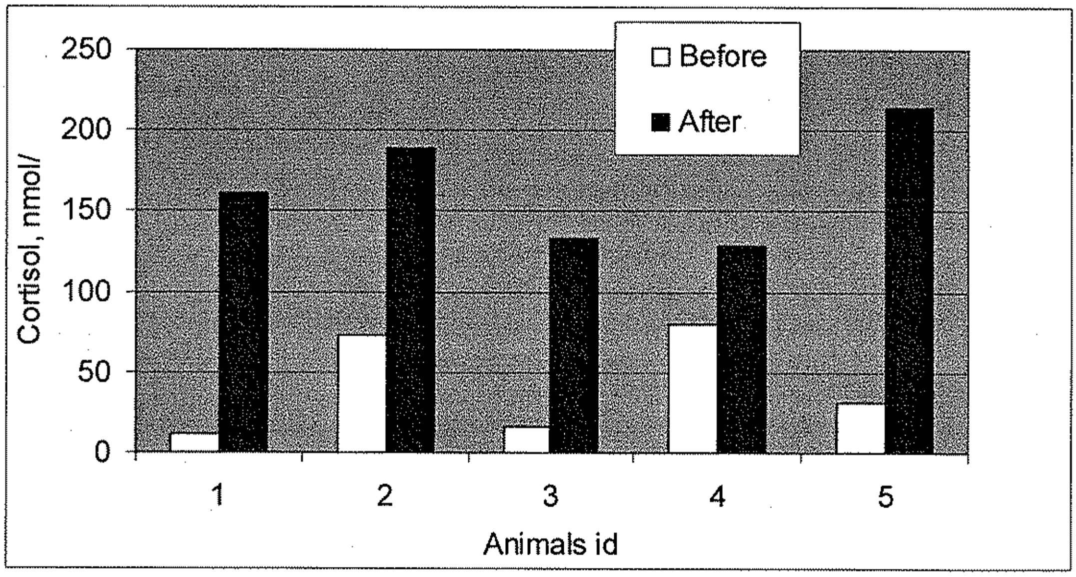


Figure 7. Effect transport activities on concentration of cortisol in heifers

4.2.2. Glucose

Calves

For winter season and low-density loading, glucose concentration increased with an increase of transport time for all calves used for the experiment. However, for high-density loading, glucose increased with an increase of transport time from short to medium, but decreased with an increase of transport time from medium to long transport time. For summer and low density the same behaviour was observed for glucose as for the cortisol. Calves, transported for shorter time were stressed than those transported for medium transport time. But glucose increased with transport time from medium to long distance. The result for summer and high density showed the same tendency as for the winter and low density loading.

Bulls

For both winter and summer seasons and low loading density, glucose increased with an increase of transport time (particularly, this is significant for low density (Figure 8 and 9). The rate of increase from short to medium transport time is faster than from medium to long transport time. For high-density loading, significant increase of glucose was observed for short time transport than the other two transport times. For this loading glucose decreased for an increase of transport time from short to medium, and thereafter increases with an increase of transport time.

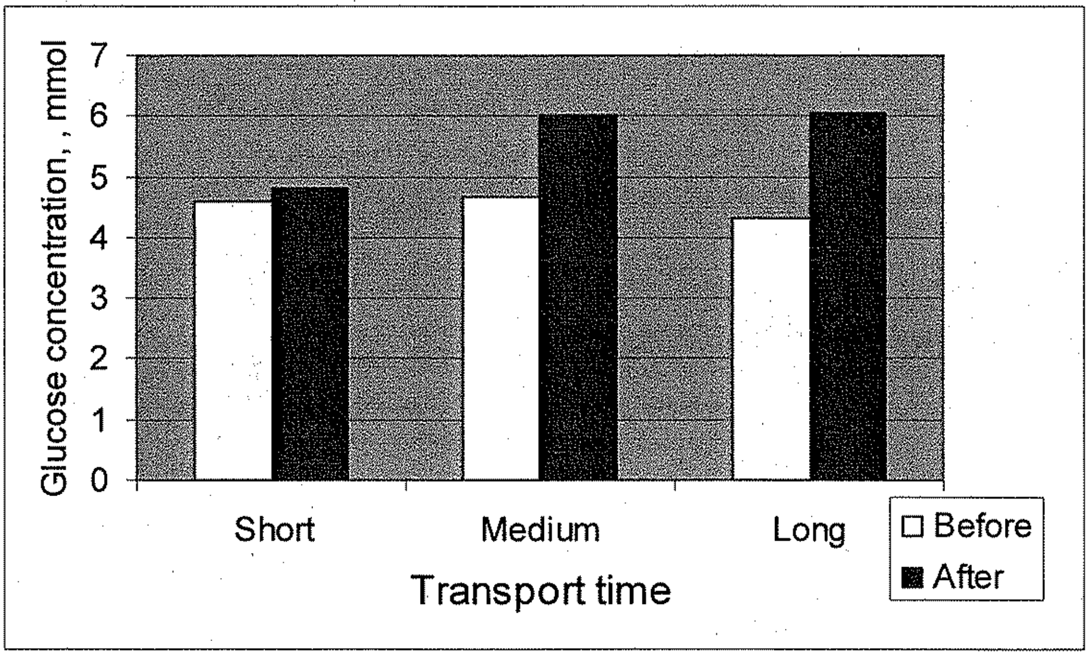


Figure 8. Effect of transport time on glucose concentration (when bulls were loaded at low density)

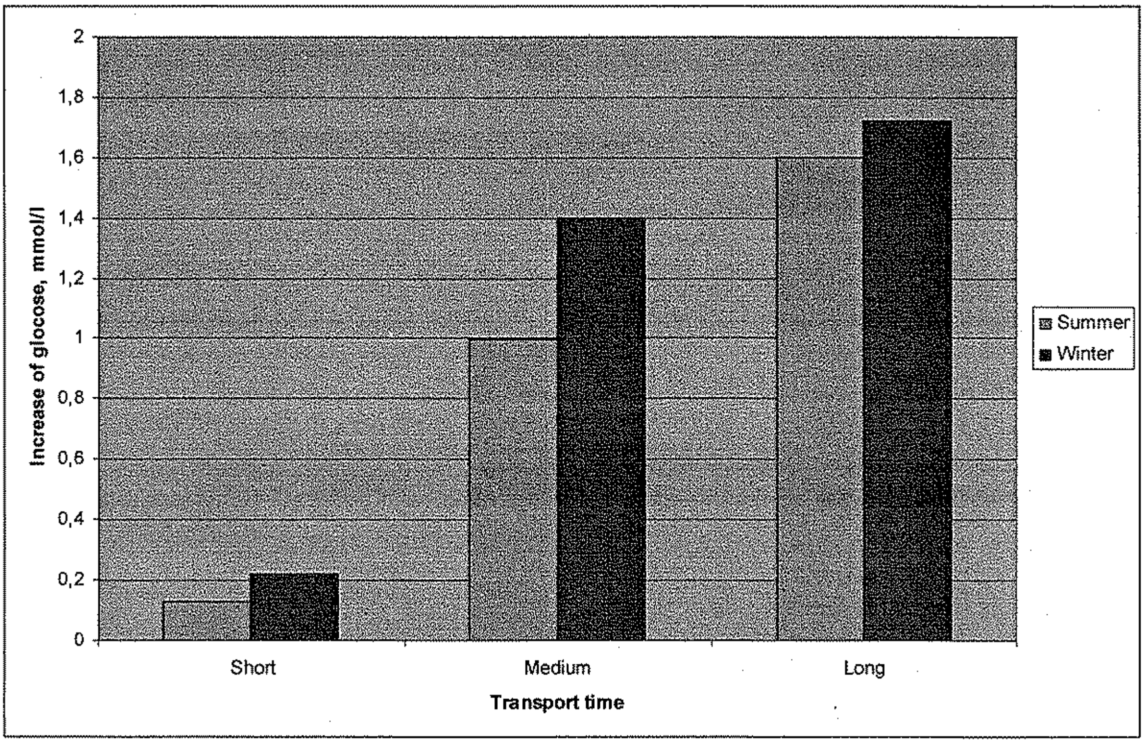


Figure 9. Effect of transport time on glucose concentration in bulls

Cows

For winter season and low density, glucose increased with transport time from short to medium transport time and decrease thereafter for long transport time. For the summer season the tendency is opposite to the above, i.e., it first decreases and then increases with transport time. The data for the summer season and high density showed a significant increase of glucose with transport time. For both seasons and at the high loading density, an increase of glucose with transport is significant, but it is difficult to draw conclusion for the low-density loading. Glucose concentration level was very high for cows transported for short transport time and low stock density (Figure 10), while for bulls and calves it was highest for high stock density and short transport.

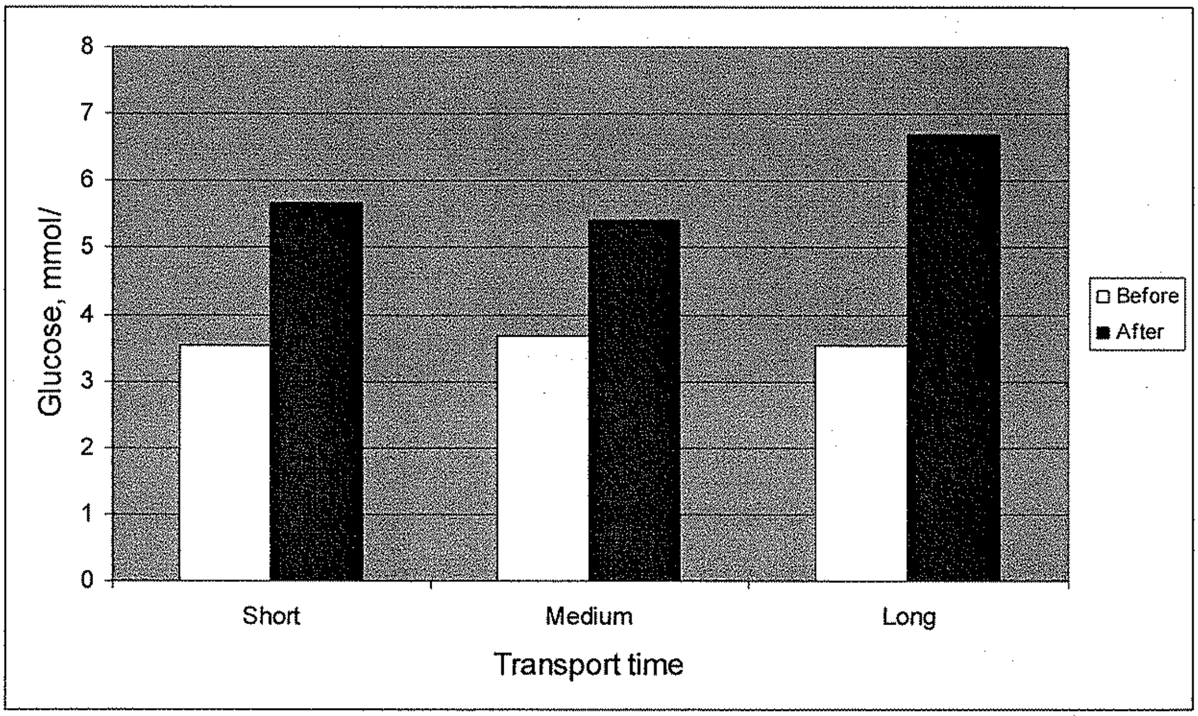


Figure 10. Glucose concentration before and after transport in cows when loaded at low and high stock density

4.2.3. Creatine kinase, CK

Calves

For winter season, high density and summer season low-density loading, CK increased with transport time and particularly this is significant for longer transport (Figure 11). For winter, low density loading, the result is the reverse. It decreased from short distance to medium and increased from medium to long time. Data for summer and high density doesn't allow drawing any conclusion.

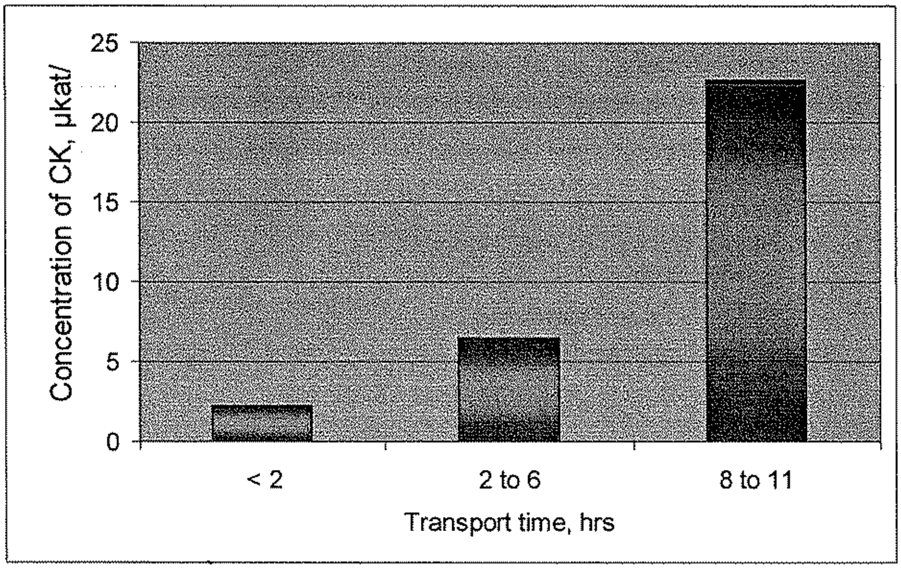


Figure 11. Effect of transport time on concentration variation of CK in calves

Bulls

For both seasons and high-density loading CK increased with transport time. However, the highest increase of CK was observed for medium transport time, summer season at low density loading. As a whole, there is a strong correlation between an increase of CK and transport time.

Cows

For both winter and summer seasons at low loading density, a linear relation between CK and transport time was observed, i.e., CK increases with transport time. However, for high density loading for both seasons, the correlation of CK with transport is not linear. Lowest and highest values of CK were noted for medium and longer transport time respectively.

4.2.4. Lactate

Calves

The results showed that the relation between level of lactate concentration and transport time depends on stock density. For both seasons, the level of lactate concentration increased with an increase of transport time and this relation was vis-versa for high stock density.
As for the effect of season, the rate of increase of lactate is higher in summer season than winter. But the rate of decrease is higher during winter (Figure 12).

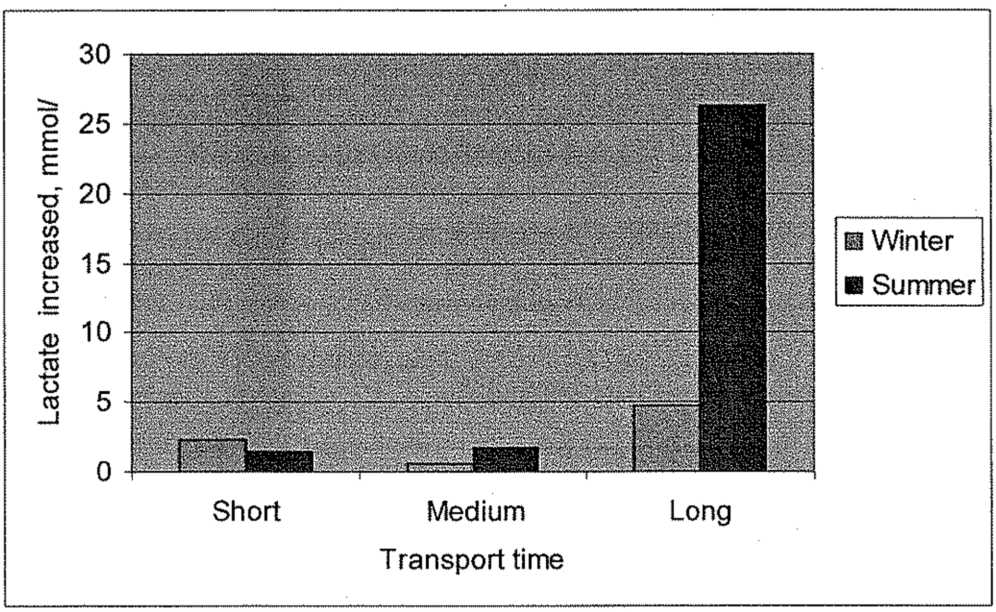


Figure 12. Effect of transport time on variation of lactate concentration in calves when loaded at low density

Bulls

The lowest and highest peaks of lactate concentration were observed for medium and long time transport respectively for winter experiment (Figure 13). It can be noted also that stock density has significant influence on the aforementioned relation. For summer experiment, the behaviour of the lactate and transport time relation is similar for both loading densities. But for this season, the highest and lowest peaks were observed for short and medium transport time respectively.

Though an increase of lactate noted for short transport time than for the medium, an increase of transport time caused lactate to increase for the cold season. The highest peak value were noted for long time transport. For the summer season, the highest peak value was noted for short transport time. That means, season has impact on the behaviour of the relation between transport time and lactate.

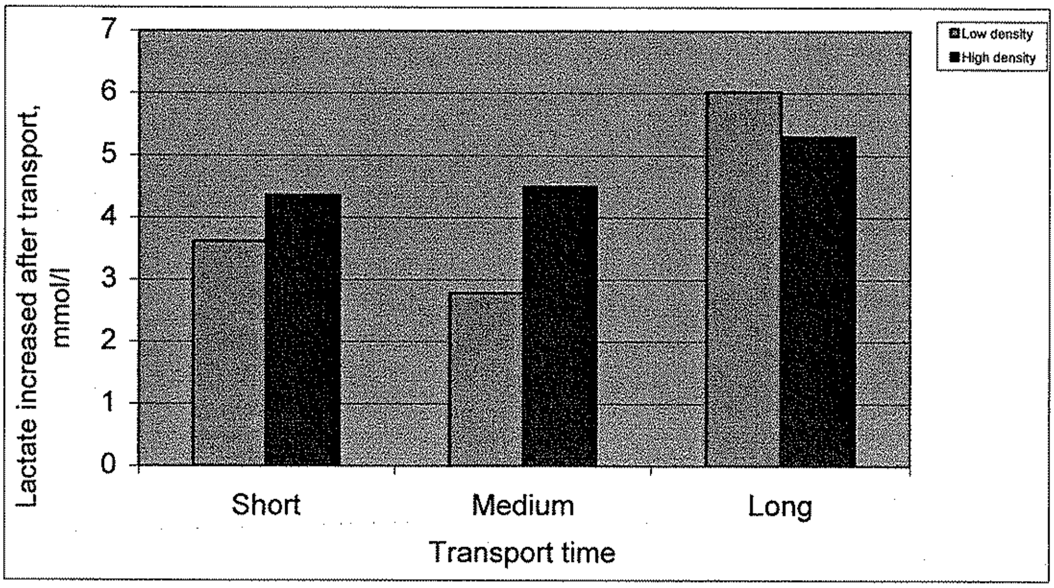


Figure 13. Effect of transport time on lactate concentration in relation to loading densities in bulls

Cows

The result of both seasons fluctuated and it is difficult to draw any conclusion from the data collected. For high-density loading, winter season, lactate concentration increased with an increase of transport time, while the opposite behaviour can be observed for summer and low-density loading.

4.2.5. Summary of results of blood samples

A summary of the physiological parameters in relation to animal class, transport time and density is given in Table 12. The symbols "**" and "* " in Table 11, denote significance level of relation between transport time and concentration level of physiological parameters, and "ns" means not significant. Results from 59% of the trip showed a strong correlation between stress level and transport time, and only 10% of the experiment showed non-significant relation between transport time and physiological parameters. It should be noted that transport time has effect more on calves and bulls than cows.

Table 11. Summary of the physiological parameters

Animal	**Physiological parameters**	**Increased with transport time, winter**		**Increased with transport time, summer**	
Cows		Low density	High density	Low density	High density
	Cortisol	ns	*	*	*
	Glucose	ns	**	*	**
	CK	**	**	**	**
	Lactate	ns	**	*	*
Bulls					
	Cortisol	*	*	**	ns
	Glucose	**	*	**	**
	CK	**	**	**	**
	Lactate	**	**	*	*
Calves	CK	*	'**	**	ns
	Cortisol	**	**	**	**
	Glucose	**	**	*	**
	Lactate	**	*	**	*

4.3. Behaviour

As mentioned earlier, in this project a total of 196 animals were included of which 70 were cows, 66 were young bulls and 60 were calves. The animals were loaded either led one by one or driven in groups (See Table 12). Almost all calves were loaded loose while cows and young bulls were mostly led onboard the vehicle.

Table 12.Animal class and loading style.

Animal category	*Number of animals*	*% of animals loaded led*	*% of animals loaded loose*
Cow	70	71.4	28.6
Bull	66	78.8	21.2
Calve	60	16.6	83.3

Total loading score (see Figure 14) was highest for young bulls, followed by cows then calves. For unloading the score was higher for cows than bulls and calves.

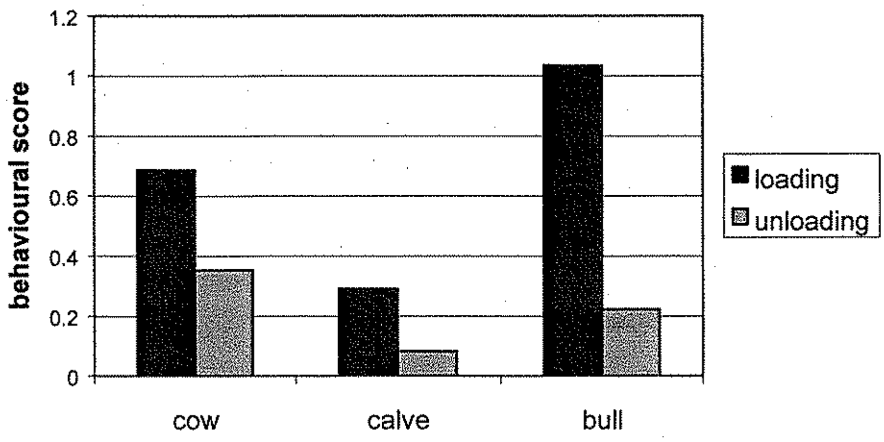


Figure 14. Mean scores for loading and unloading per animal category (cow, calve and bull).

During loading and unloading there were similarities in behaviour between animal categories (Table 13). It was very common for all to stop during both loading an unloading. Slips and falls were more common during loading and for calves and bulls compared to unloading and cows. Cows on the other hand vocalised during loading, a behaviour that was rare among calves and bulls.

Table 13. The three most common events during loading and unloading for cows, calves and bulls.

Animal category	*Most common behaviour during loading*			*Most common behaviour during unloading*		
Cow	vocalisation	turns	stops	stops	slips	falls/turns
Calve	stops	slips	falls	stops	defecations	
Bull	stops	slips	falls	Stops	turns	reversals

During loading and unloading it was sometimes difficult to see all that was happening. The quality of the video recordings from the transportation varied greatly. Due to high humidity in some of the transports the recording became foggy. In the winter time it was dark during most of the transports, although there was light in the vehicle the quality of the recordings was not good.

For animals transported for along time (8-11 hours) the frequency of lying down varied (Figure 15). No calves lay dawn during transports. Young bulls spent more time lying than cows during the long transports. For medium and short transports no animals lay down.

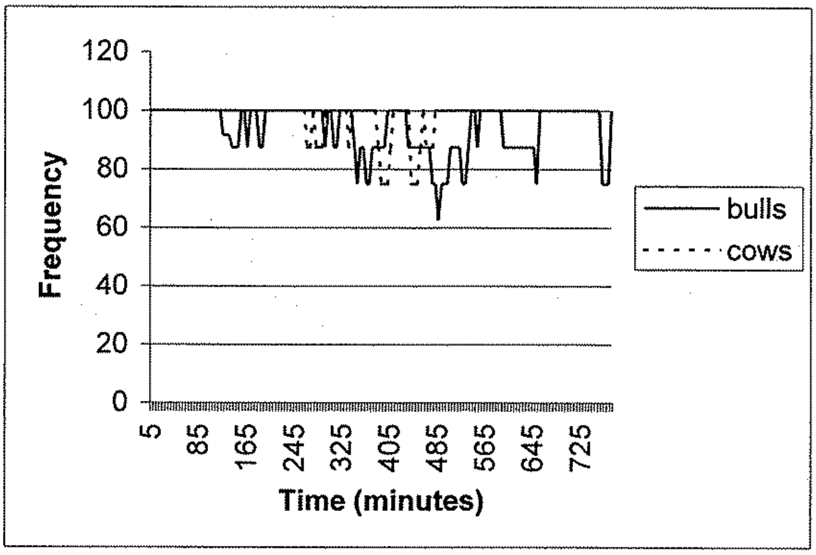


Figure 15. Frequency of lying for bulls and cows.

Bulls lay down between 0 and 10.2% of the time (see Figure 16). It took the first animal between two and eight hours to lye down for the first time. Bulls lay down more with low densities compared to high densities. Bulls tended to lye down more after some hours of transport.

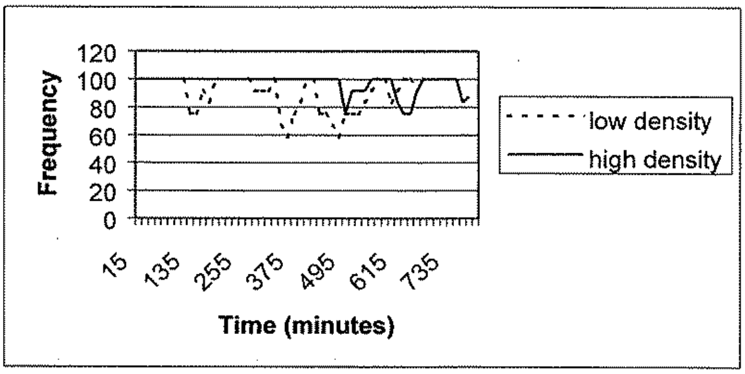


Figure 16. Frequency of standing for bulls during long transports, high or low loading density.

Cows spent most of the transport standing up (see Figure 17), on average they lay down for 2.6 % of the time during long transports, however it varied between 0.68% for high loading density and 4.1% for low loading density. It took about two hours for the first cow to lye down at low density and about 7.5 hours during high loading density. On one occasion, one cow lye down and the cow next to it somehow managed to get its back legs over the lying cow. It resulted in difficulties for the standing cow to obtain balance, as it could not counteract movements in the truck. After a few minutes the standing cow managed to step over the lying cow, which immediately got up.

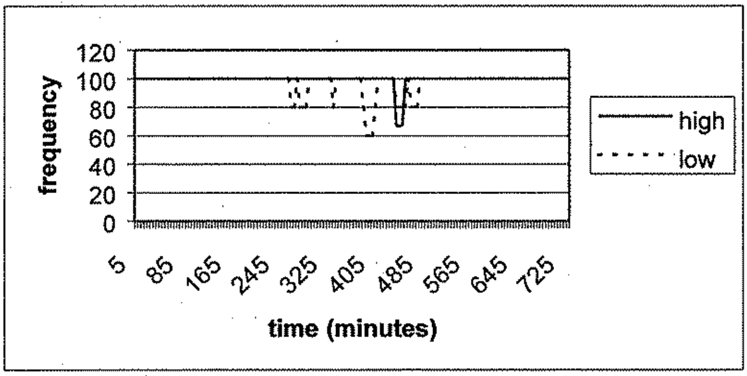


Figure 17. Frequency of standing for cows during long transports, high or low density.

Both bulls and cows showed a similar frequency of interrupted lying behaviour (see Figure 18) during the time of transport. However, the interrupted lying down was slightly more common among cows than young bulls and cows spent more of the time standing up.

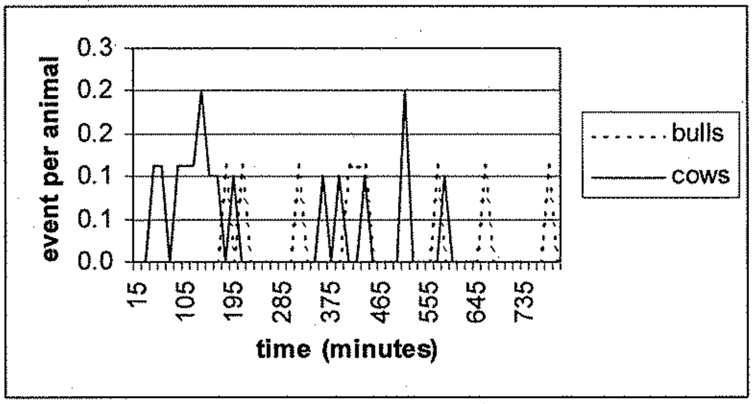


Figure 18. Interrupted lying down during long transports for young bulls and cows.

Calves transported for different times showed a similar pattern in restlessness (Figure 19). The animals moved around a lot in beginning (15 changes of position in 5 minutes) of the transport but settled down after approximately 1.5 hours. However the calves never settled down completely (2.5 changes of position in 5 minutes).

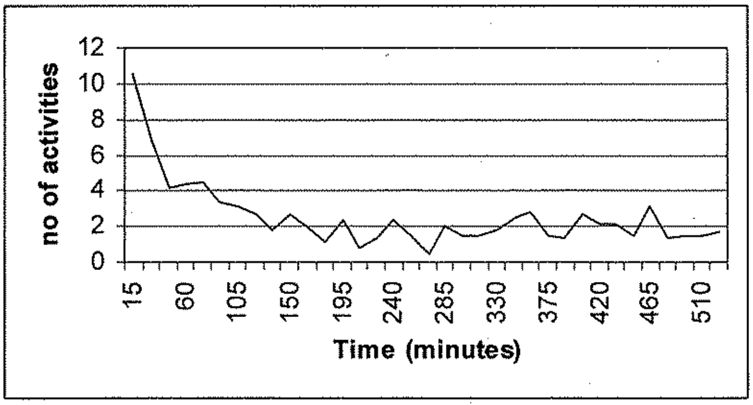


Figure 19. Average number of changing position in calves during different transport times.

Calves changed their position more frequently than bulls. For the first hour, the calves changed position often. There were no differences between the frequencies between different transport times. Bulls had a low but steady frequency during the entire transport, never settling down entirely. Several bulls displayed an unexpected and disturbed behaviour of pulling back hard in the rope and halter (Figure 20). The animals were throwing their heads or their entire bodies backwards. This behaviour was studied in several bulls during all transport times. The frequency was high in the beginning of most transports. For long transports the frequency declined but did not cease entirely.

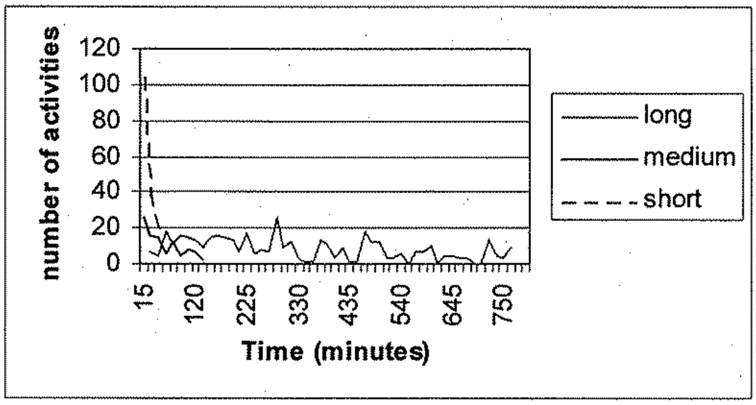


Figure 20. No of times that bulls pull back in the rope and halter during different transport times.

4.4. Air quality

4.4.1 Temperature and relative humidity

Temperature and relative humidity measurements were made during winter and summer conditions. Table 14, 15 and 16 report summary for all temperature and relative humidity results. There were no big differences in temperature and relative humidity depending of transport time.

Table 14. Temperature and relative humidity in the vehicle during summer experiments for different transport times

Transport time	Value	Temperature	Relative humidity
>2h	Average	16.7	79.0
	Max	19.2	90.8
	Min	13.3	66.0
3-4h	Average	15.8	83.9
	Max	19.9	96.7
	Min	14.1	72.1
10-11h	Average	16.2	82.5
	Max	23.3	97.8
	Min	11.5	63.8

Table 15. Temperature and relative humidity in the vehicle during winter experiments for different transport times

Transport time	Value	Temperature	Relative humidity
>2h	Average	5.7	94.2
	Max	11.6	99.7
	Min	0.3	82.8
3-4h	Average	7.1	91.5
	Max	13.4	99.9
	Min	0.3	71.0
10-11h	Average	4.5	90.0
	Max	10.3	99.5
	Min	-2.4	77.8

Table 16. Temperature and relative humidity measured during summer and winter experiments for different animal classes.

Animals	Seasons	Value	Temperature, °C	Relative humidity, %
calves	Summer	Average	16.9	78.8
		Max	26.7	99.9
		Min	9.5	45.7
	Winter	Average	3.3	89.2
		Max	19	99.9
		Min	-12	58.0
Cows	Summer	Average	17.4	83.0
		Max	23.5	99.9
		Min	10.5	58.8
	Winter	Average	5.21	97.3
		Max	17.4	99.9
		Min	-16	75.9
Young bulls	Summer	Average	14.5	86.5
		Max	22.9	99.9
		Min	8.3	59.9
	Winter	Average	6.1	90.3
		Max	15.8	99.9
		Min	-8.9	67.8

The difference between the temperature outside the vehicle and the temperature inside the vehicle during summer experiments never exceeded 3.8°C. During the winter experiments, the highest difference was observed when the outside temperature was very low. The difference was 14 and 16°C when outside temperature were below –10°C, otherwise it ranged from 1.8 to 9°C.

4.4.2. Evenness of temperature in the vehicle

For summer experiment two medium and two long journeys measured temperature in all places. For winter experiment 11 journeys had measured temperature in different places successfully. In Table 17 temperatures in different places in the vehicle is shown during summer experiments and in Table 18 there are temperatures during winter experiments.

Table 17. Temperature in 5 different places during summer experiment.

	a (Pen 1) (°C)	b (Pen 2) (°C)	c (Pen 2) (°C)	d (Pen 3) (°C)	e (outside) (°C)
Average	15.7	16.9	15.1	16.4	13.1
Max	24.7	26.7	21.1	23.4	24.0
Min	9.3	10.9	8.3	10.5	7.8

Table18. Temperature in 5 different places during winter experiments

	a (Pen 1) (°C)	b (Pen 2) (°C)	c (Pen 2) (°C)	d (Pen 3) (°C)	f (outside) (°C)
Average	5.1	4.7	3.1	1.9	-2.0
Max	15.9	13.6	17.1	18.8	12.7
Min	-15.8	-13.6	-15.3	-16.2	-24.3

Figure 21 and 22 illustrate typical temperature in different places in the vehicle where one journey in summer and one journey in wintertime are shown.

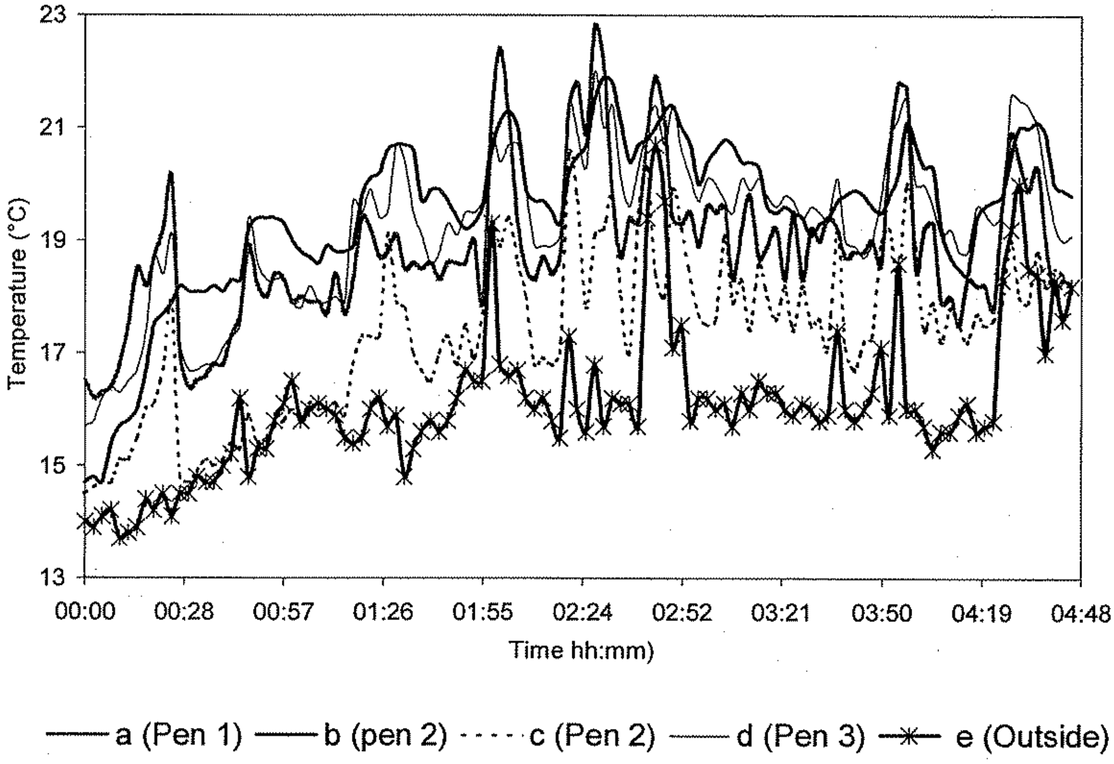


Figure 21. Temperature in 5 places during one experimental summer journey.

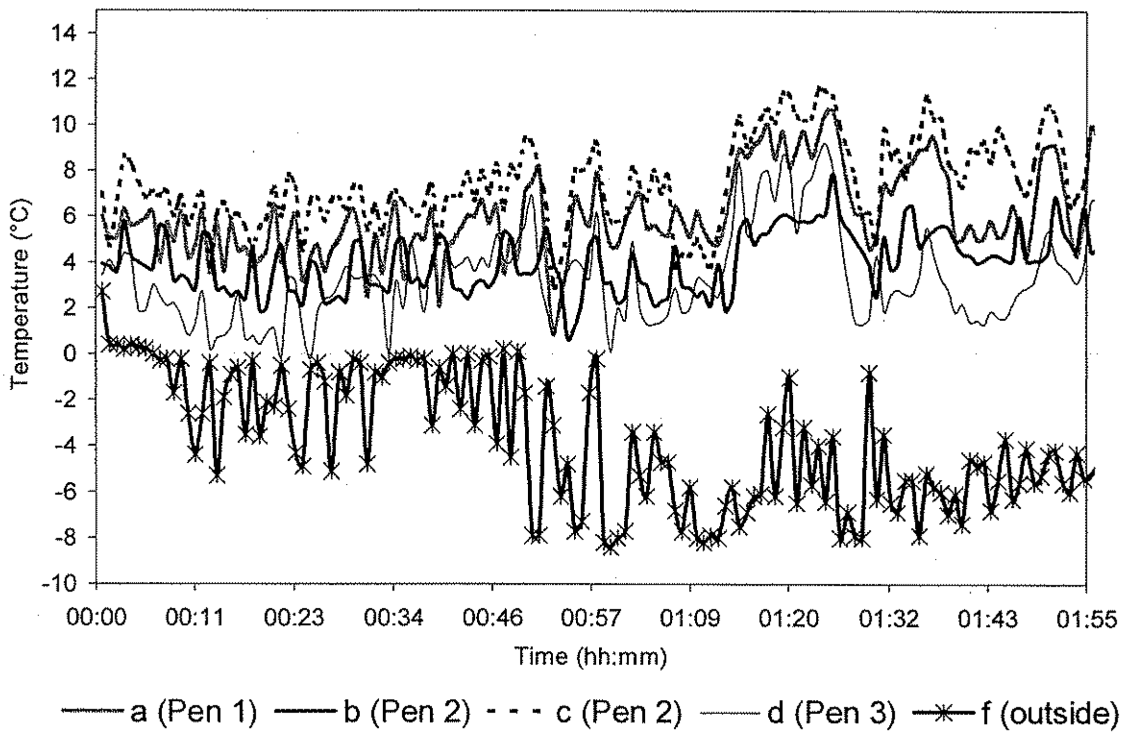


Figure 22. Temperature in 5 places during one experimental winter journey.

For different transport times the average temperature in different places in the vehicle are shown in Figure 23 and 24, average transport time, number of times new animals were loaded and total density on the vehicle are shown in Table 19 and 20.

Table 19. Number of journeys, average transport time, number of times new animals were loaded, total density for different transport times during summer experiment

	Number of journeys	Average transport time (h)	Stops	Density (%)
Medium	2	4.7	5.5	57.5
Long	2	10.8	1.5	44.0

Table 20. Number of journeys, average transport time, number of times new animals were loaded, total density for different transport times during winter experiment

	Number of journeys	Average transport time (h)	Stops	Density (%)
Short	3	1.2	0.0	84.0
Medium	6	3.0	2.3	60.5
Long	2	12.7	1.0	39.0

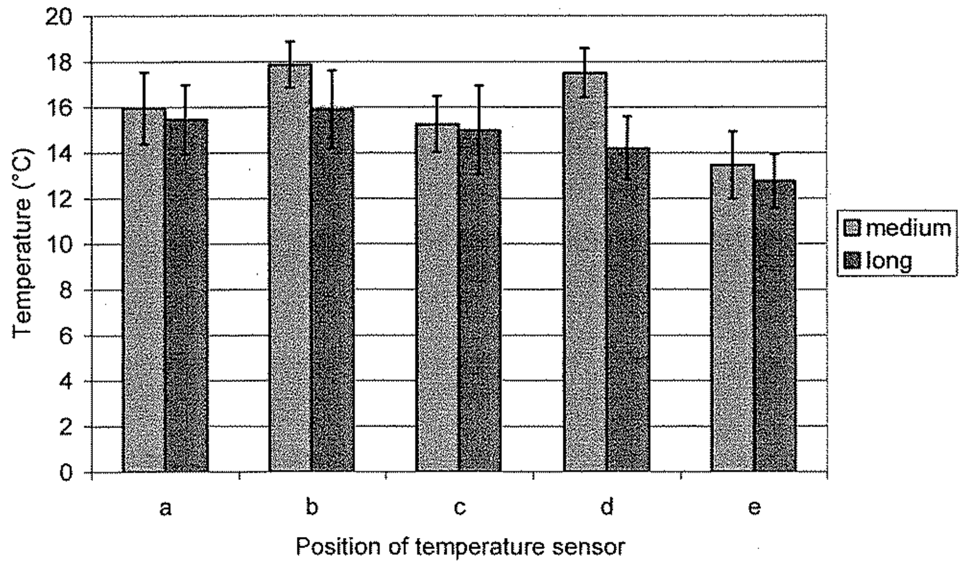


Figure 23. Average temperature and standard deviation in 4 different places inside the vehicle and temperature outside the vehicle during summer experiments

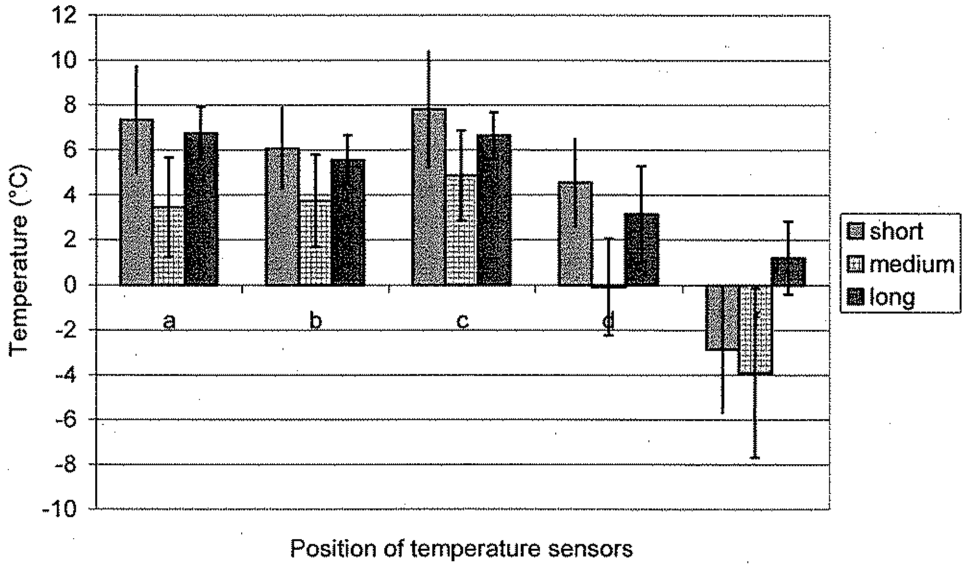


Figure 24. Average temperature and standard deviation in 4 different places inside the vehicle and outside temperature during winter experiments

Number of stops could be divided into three categories (no stop, 1 and 2 stop, 3 and 4 stop), (Table 21). The temperature in all places (except outside temperature) was lower during the winter experiment when more stops to load new animals were made; this is shown in Figure 25.

Table 21. Data for number of stops to load new animals during winter experiments.

Number of stops	Number of journeys	Average transport time (h)	Density (%)
No stop	4	1.5	85.0
1 and 2	4	7.9	48.8
3 and 4	3	3.2	52.7

Total density on the vehicle could also be divided into three categories (26-52 %, 64-72 %,

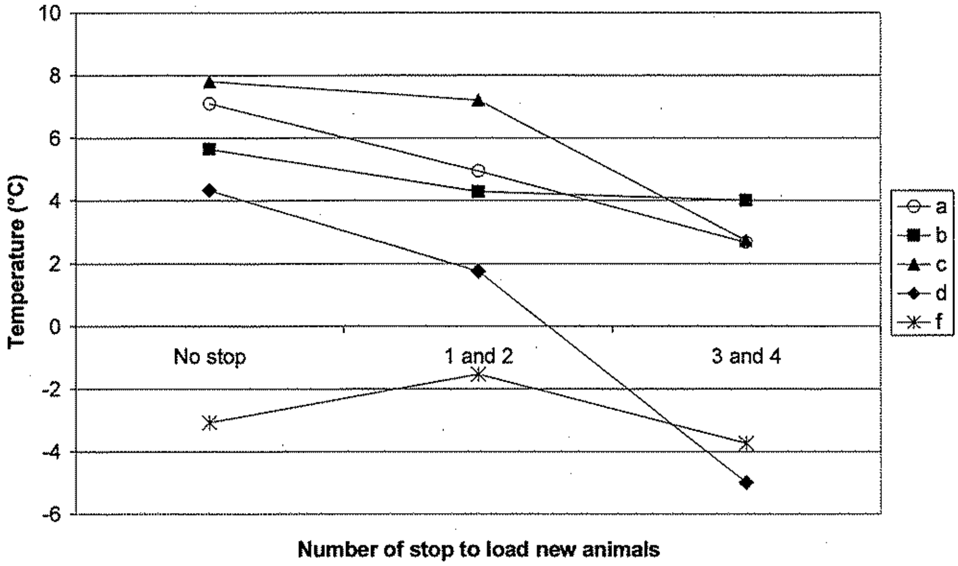


Figure 25. Temperature divided to stop where new animals were loaded

81-100 %), (Table 22). Temperature in all places during winter experiments was higher when the total density on the vehicle increased; this is shown in Figure 26.

Table 22. Data for total density on the vehicle during winter experiments.

Density (%)	Number of journeys	Average transport time (h)	Stop
26 – 52	5	7.1	2.2
64 – 72	3	2.5	1.7
81 – 100	3	1.5	0.0

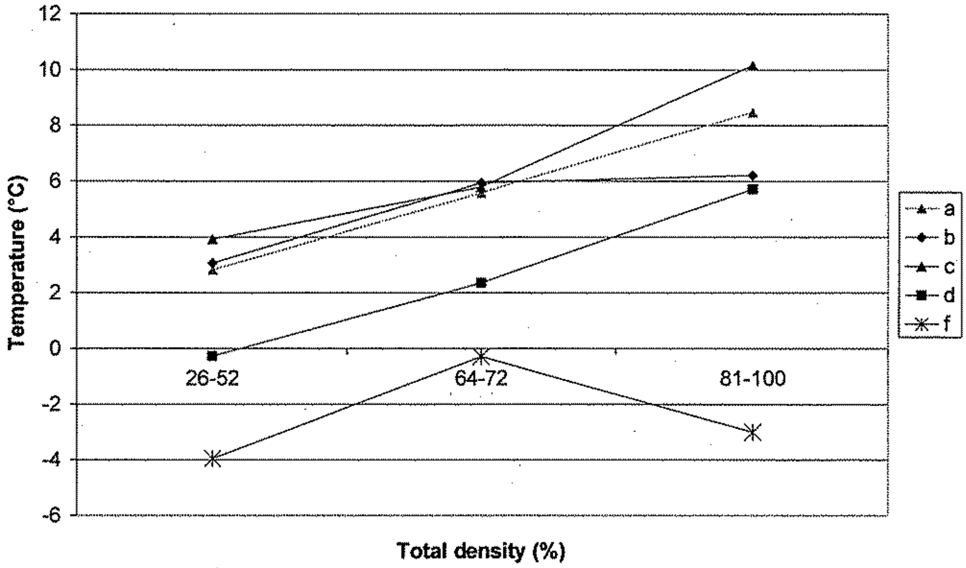


Figure 26. Temperature during winter experiment divided into three categories of total density

4.4.3.Methane, carbon dioxide and oxygen

Methane, carbon dioxide and oxygen levels in the air were measured during summer experiments. No detectable methane values were observed during the experiments. Carbon dioxide measurements gave an average value of 0.03% with a maximum at 0.3 and a minimum at 0%. Oxygen gave an average of 19.8% and that ranged from 18.7 to 20.8. The results are listed in Table 23 and 24.

Table 23. Methane, Carbon dioxide and oxygen levels measured in the vehicle while calves, cows and young bulls were transported

Animal class	Value	Methane (%)	Carbon dioxide (%)	Oxygen (%)
	Average	0	0.03	19.7
Calves	Max	0	0.30	207
	Min	0	0.00	18.7
	Average	0	0.02	19.9
Cows	Max	0	0.30	20.8
	Min	0	0.00	19.1
	Average	0	0.03	20.0
Young bulls	Max	0	0.30	20.7
	Min	0	0.00	19.1

The transports that were 3-4 h resulted in highest amount of oxygen. Carbon dioxide had the highest values during the short transports.

Table 24. Average values during different transport times of methane, carbon dioxide and oxygen during summer experiments

Transport time	CH4	CO2	O2
>2h	0	0.033	19.72
3-4h	0	0.021	20.31
10-11h	0	0.023	19.62

4.5. Meat quality

Before the samples were transported from the abattoir to the laboratory they were stored in +4°C. The glycogen samples were stored in the same room but in dry ice (CO2). It was the purpose that the transport to the laboratory during summer time should keep +4°C in the transportation compartment. However, the temperature increased to +7°C in some of the cases. This made the dry ice melt, hence some of the glycogen samples had started to thaw. During the winter field test this problem was not repeated. Veterinaries on the abattoir were responsible for classifying bruising, however this was only done on some of the experimental animals.

4.5.1 pH fall

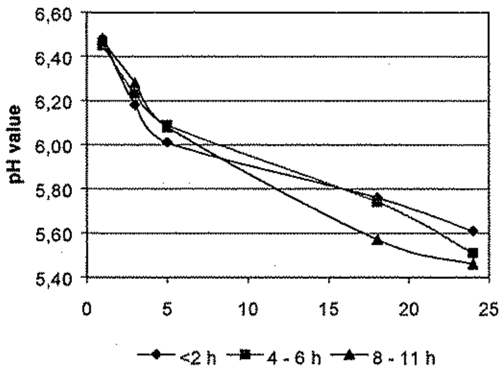
Usually the pH decrease is slower in calves compared to cows and young bulls the first hours after slaughter. This depends on that carcasses from calves enter the same blast chiller as the bigger carcasses. Hence, the temperature drops quicker and the metabolism in the carcass slows down.

4.5.2. Transport time

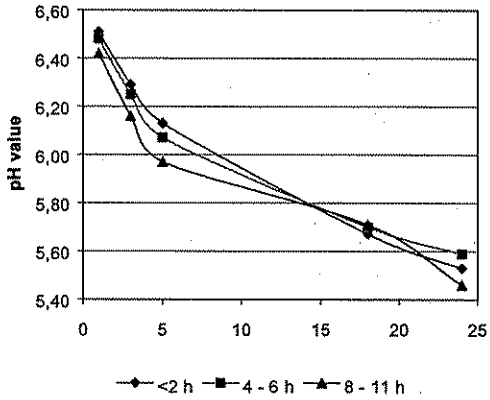
The result of the pH fall regarding transport times showed that carcasses from calves decreased slower than carcasses from cows and young bulls, the first hour after slaughter (Figure 26c). The pH fall in calves transported for 8 – 11 hours was slower than the pH fall in calves transported differently. At 24 hours pm, the pH values were still higher (5.66) in those transported 8 – 11 hours compared to the ones transported less than 2 hours (5.44) and 4 – 6 hours (5.48).

The pH falls for young bulls transported different times were similar. Within 5 hours pm, the pH in those transported 8 – 11 hours had fallen below 6, and within 10 hours, the other ones had a pH value below 6. At 24 hours the pH in the meat from the three transport groups had a pH below 5.6.

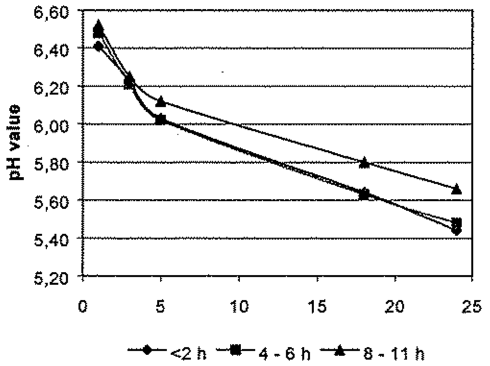
The pH fall in cows transported different transport times had a similar pH fall up to 5 hours pm. After that the pH in the carcass from cows transported 8 – 11 hours decreased fastest and got a pH value of 5.46 at 24 hours pm. This did not differ compared to the value in the carcasses from those transported for 4 – 6 hours (5.51) and less than 2 hours (5.61).



a) cows



b) young bulls



c) calves

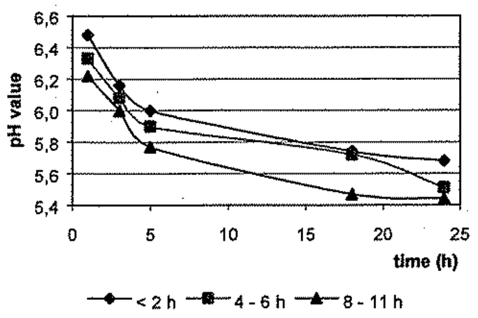
Figure 26c. Mean pH fall in a) cows, b) young bulls and c) calves transported during summer and winter.

Summer field test

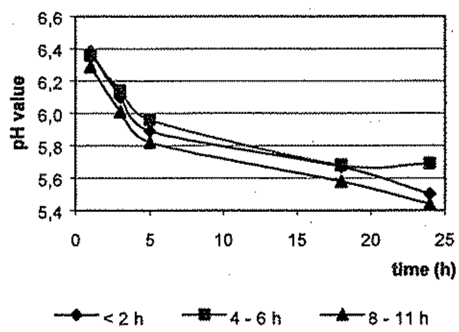
The pH fall in carcasses from calves transported 8 – 11 h during summer decreased slower than the other calves transported differently (Figure 27). The reason was that 3 of 5 calves had a much lower pH decrease. At 5 hours pm the mean pH value was above 6.0. At 24 hours pm the pH value was significantly different (5.75) compared to calves transported less than 2 hours and 4 – 6 hours, 5.45 and 5.43 respectively.

Up to 18 hours pm, the pH values decreased similar in young bulls transported differently. At 24 hours pm both those transported less than 2 hours and 8 – 11 hours fell to 5.50 and 5.44 respectively 24 hours pm. At the same time the carcasses from young bulls transported 4 – 6 hours had not fallen any further compared to the pH value at 18 hours pm, which is 5.68. The reason due to this result was that 4 of 5 young bulls had a lower pH decrease and ended at a higher pH24 value

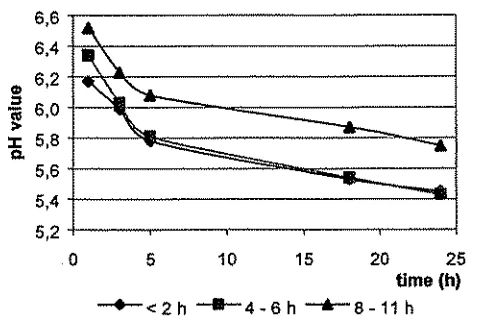
The pH fall in cows transported 8 – 11 hours decreased faster after 5 hours pm. At 24 hours pm, they had a pH value of 5.44, which did not differ significantly compared to cows transported 4 – 6 hours. Those transported less than 2 hours, at the same time, decreased to just 5.68, which seemed to be an ultimate value.



a)cows



b) young bulls



c) calves

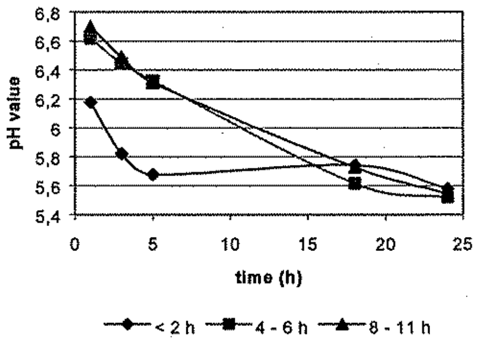
Figure 27. pH-fall in a) cows, b) young bulls and c) calves transported during summer season.

Winter field test

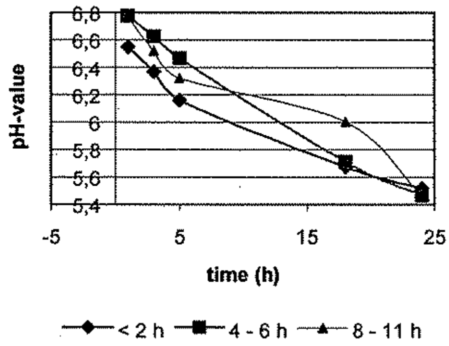
Animals transported during the winter time showed a different pH fall than those transported during summer time (Figure 28). They had higher initial values compared to those transported during the summer, but ended up with a lower ultimate pH value.

The pH value in cows transported less than 2 hours had a low initial value and decreased fast. Already at 3 hours pm, the value was below 6.0. The pH falls for the other cows was not as fast but were similar to each other. However, at 24 hours pm the pH's were at the same level as cows transported less than 2 hours, approximately 5.55.

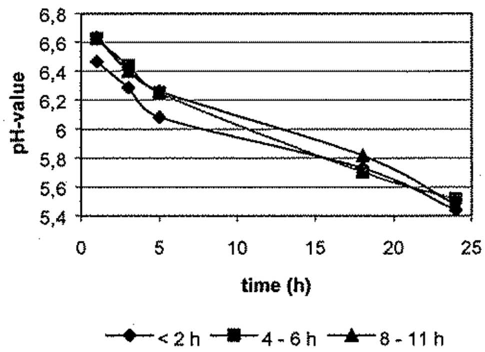
The pH's in young bulls 24 hours pm were similar, 5.52 for those transported less than 2 hours and 5.46 for those transported 4 – 6 and 8 – 11 hours. The value at 18 hours pm in those transported 8 – 11 hours was measured higher than the other ones. Calves transported different times showed a similar pH decrease at all the measuring points. At 24 hours pm, all values had decreased to an almost ultimate value, below 5.5.



a) cows



b) young bulls

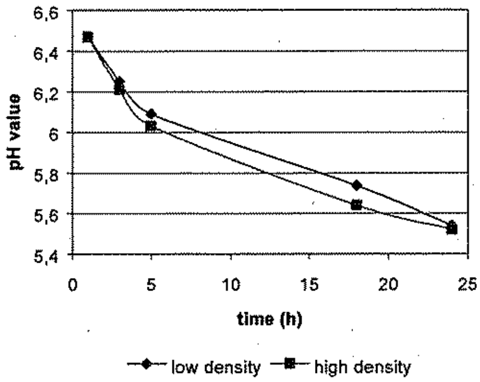


c) calves

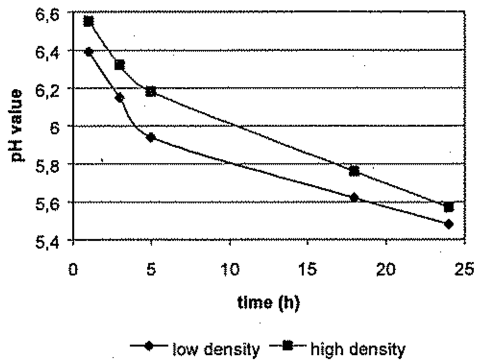
Figure 28. Mean pH fall in a) cows, b) young bulls and c) calves transported during winter season. The numbers under the diagram is the time the animals were transported before slaughter

4.5.2. Stock density

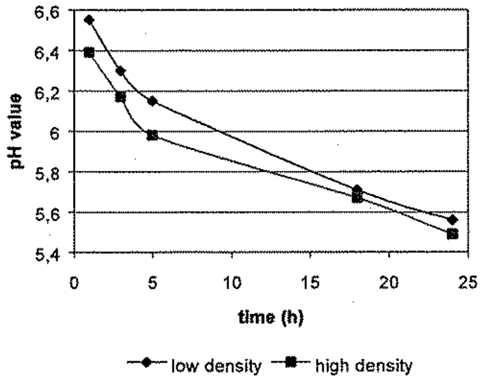
The pH fall regarding high and low stocking densities in the transport vehicle were similar between the different animals. The pH value in young bulls transported at high density decreased slower up to 5 hours pm, compared to the ones transported at low density. The values 5.48 and 5.57 at 24 hours pm, for low and high density respectively, were not significantly different (figure 29). The pH fall in both cows and calves transported in different densities did not differ significantly either and had pH values at 24 hours pm of between 5.50 and 5.55.



a) cows



b) young bulls



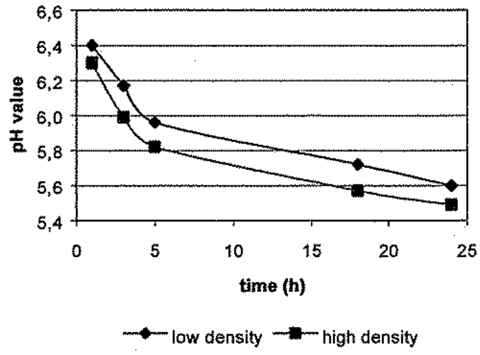
c) calves

Figure 29. Mean pH-fall in a) cows, b) young bulls and c) calves transported in low and high densities.

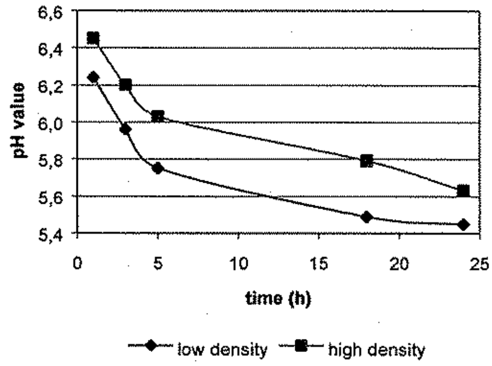
Summer field test

The pH values in young bulls transported at low density decreased faster than young bulls transported at high density. At 5 and 18 hours pm, the values differed significantly. However, at 24 hours pm, the difference between the two groups had decreased. Those transported at high density had a pH value of 5.63 and the ones transported at low density had a pH value of 5.45 (Figure 30).

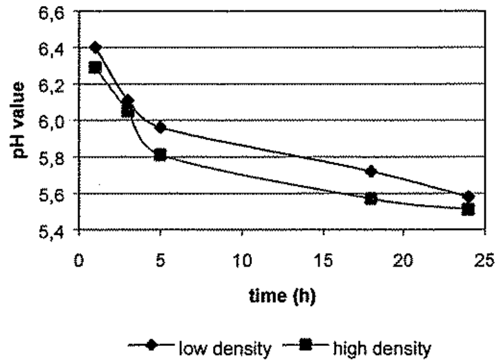
The pH falls between the two different stock densities in cows and calves did not differ significantly at any measuring points. At 24 hours pm the pH in the different groups had decreased to a value between 5.5 and 5.6.



a) cows



b) young bulls

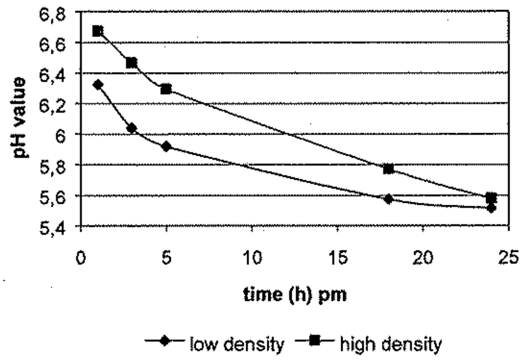


c) calves

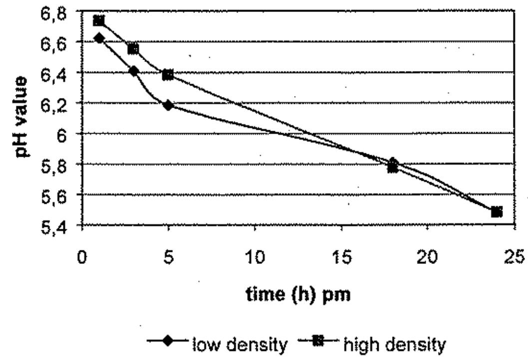
Figure 30. pH-fall in a) cows, b) young bulls and c) calves transported in low and high densities prior to slaughter during summer season.

Winter field test

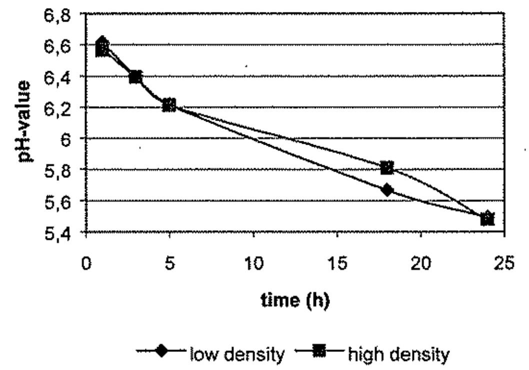
For animals transported at high or low stock densities during wintertime, the pH fall did not differ significantly. However, there was a tendency that cows transported at high density had a higher pH value up to 5 hours pm compared to cows transported at low density (Figure 31). At 24 hours pm the pH in both groups had decreased below 5.6. The pH value was at the same time 5.44, for both groups of young bulls and calves.



a) cows



b) young bulls



c) calves

Figure 31. pH fall in a) cows, b) young bulls and c) calves transported during winter season.

4.5.3. Combined effect of transport time and density on various animal classes

When the three variables were combined only glycogen content differed significantly ($p = 0.036$), as shown in Table 25. However, there were tendencies that young bulls transported for 8 – 11 hours at low density had a lower glycogen content (16.8 mmol/kg) in the meat compared to corresponding group transported at high density (23.6 mmol/kg). The shear force values in these two groups did also tend to differ. Those transported at low density received a higher shear force value, 100.5 N, than the ones transported at high density, which had a shear force value of 87.1 N in the meat.

Similar results were seen in young bulls transported for less than 2 hours. However, where the results contrary to young bulls transported for 8 – 11 hours. Those transported at high density had a shear force value of 100.1 N and a glycogen content of 17.1 mmol/kg, compared to 87.4 N and 22.8 mmol/kg for those transported at low density.

The glycogen content in the meat from calves transported for less than 2 hours was 15.0 mmol/kg compared to 25.5 mmol/kg for calves transported at high density. The shear force values for these two groups were more even than in the two groups of transported young bulls mentioned above, 96.6 N for low density and 91.0 N for high density. Cows transported for 4 – 6 hours had a glycogen content which tended to be lower, 15.5 mmol/kg, in those transported at low density compared to 24.9 mmol/kg in those transported at high density. The shear force values, 92.3 and 95.2 for low and high density respectively, did not tend to differ.

Generally shear force values in calves should be lower than in cows and young bulls primarily due to development of connective tissues. That was not seen in this study. Drip losses and pH values at 24 hours pm were similar both between the categories and within the categories. They varied from approximately 2.5 – 3.0 % and 5.47 – 5.57, respectively.

Table 25. LS means and standard deviation for shear force, drip loss, glycogen and ultimate pH in respect of three parts interaction.

animal class	trp time (h)	density	no animals	shear force (N)	drip loss (%)	glycogen (mmol/kg)	PH_{24}
			180	93.8±38.7	2.6±1.5	20.2±13.9	5.52
	<2	low	9	97.3±26.0	2.6±1.1	22.9±9.3	5.51
	<2	high	9	90.2±21.2	2.7±0.7	17.6±13.4	5.52
cows	4 – 6	low	14	92.3±30.6	2.4±0.8	15.5±10.0	5.55
	4 – 6	high	9	95.2±34.2	2.9±0.8	24.9±7.7	5.48
	8 – 11	low	7	91.6±23.8	3.0±0.7	22.2±6.8	5.49
		high	10	95.9±35.3	2.3±1.4	18.2±8.8	5.55
	<2	low	10	87.4±32.5	2.6±0.9	22.8±12.9	5.56
	<2	high	10	100.1±35.6	2.7±1.1	17.6±7.3	5.48
young bulls	4 – 6	low	5	93.4±12.4	2.9±1.7	21.1±3.2	5.47
	4 – 6	high	15	94.1±37.6	2.4±0.7	19.5±12.9	5.57
	8 – 11	low	15	100.5±21.4	2.4±2.8	16.8±16.4	5.53
	8 – 11	high	8	87.1±19.3	2.9±0.6	23.6±16.3	5.51
	<2	low	10	96.6±51.6	2.8±1.6	15.0±8.2	5.48
	<2	high	5	91.0±28.9	2.5±2.3	25.5±12.2	5.55
	4 – 6	low	11	95.5±61.5	2.6±0.8	24.1±18.5	5.54
calves	4 – 6	high	20	92.0±51.6	2.7±1.0	18.8±16.1	5.50
	8 – 11	low	4	89.9±37.8	2.5±0.7	20.6±18.0	5.54
	8 – 11	high	10	98.3±38.5	2.8±1.3	18.8±14.3	5.50
			p value	0.780	0.562	0.036	0.640

Coloration of the meat did not differ significantly (Table 26). Lightness (L* value) had a p-value of 0.066. The values varied between 39.8 and 42.9. These values appeared within the same category of animals and transport time, i.e. calves transported less than 2 hours. Redness (a*-value) and yellowness (b*-value) did not differ significantly. It is noteworthy that meat from calves had the same colour values as meat from cows and young bulls. Normally, calves have lighter meat compared to older animals.

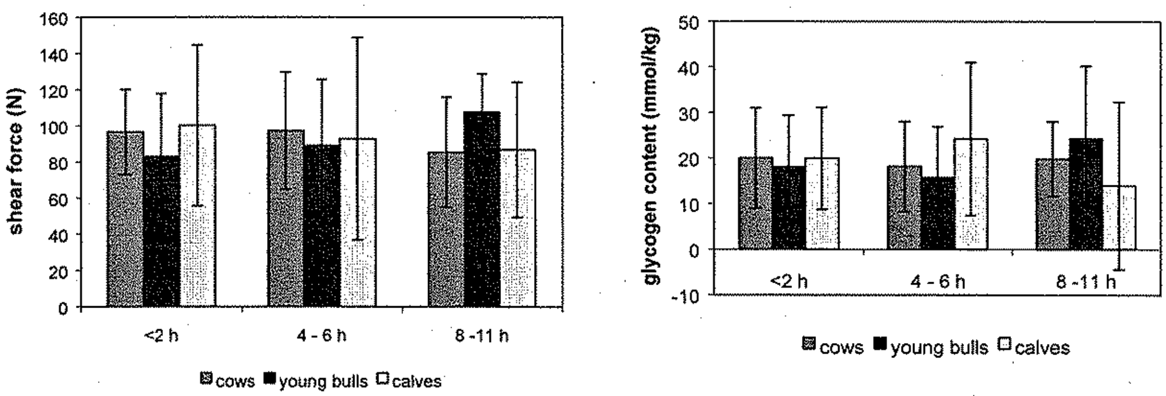
Table 26. LS means and standard deviation for colour in respect of three ways interaction, categories, transport time and density, both season

animal class	trpt time (h)	density	n	L*	a*	b*
			172	41.3	18.1	14.1
	<2	low	9	40.4	19.2	14.3
	<2	high	9	42.3	17.0	13.9
cows	4 – 6	low	14	41.4	17.3	13.8
	4 – 6	high	9	41.3	18.9	14.4
	8 – 11	low	7	42.3	17.8	14.2
		high	10	40.4	18.3	14.0
	<2	low	10	40.8	18.1	13.6
	<2	high	10	41.9	18.1	14.6
young bulls	4 – 6	low	5	42.3	18.1	14.7
	4 – 6	high	15	40.4	18.1	13.5
	8 – 11	low	15	40.9	18.1	14.1
	8 – 11	high	8	41.7	18.0	14.2
	<2	low	5	42.9	17.0	14.5
	<2	high	5	39.8	19.2	13.9
	4 – 6	low	6	40.3	18.9	14.0
calves	4 – 6	high	20	42.3	17.3	14.4
	8 – 11	low	5	40.8	18.3	14.0
	8 – 11	high	10	41.9	17.8	14.2
			p value	0.066	0.109	0.468

Animal classes and transport time

Both pH value 24 hours pm (p = 0.000) and glycogen content (p = 0.024) differed significantly when animal class and transport times were evaluated, see table 27.
The highest pH values 24 hours pm was measured in calves transported 8 – 11 hours (5.66). The value was significantly different than other calves transported differently. Also cows transported less than 2 hours (5.61) and young bulls transported 4 – 6 hours (5.59) had a higher, but not significantly different pH value 24 hours pm, compared to the other groups from the same category.

The glycogen content (Figure 32b) in the meat from calves were also significant lower (13.9 mmol/kg) compared to calves transported 4 – 6 hours, 24.2 mmol/kg and had a tendency to be lower than those transported less than 2 hours, 19.8 mmol/kg.



a) b)

Figure 32. Shear force values (a) and glycogen contents in the meat from cattle transported summer and wintertime.

The glycogen content in young bulls transported 4 – 6 hours tended to be lower (15.7 mmol/kg) compared to young bulls transported less than 2 hours (18.1 mmol/kg) and 8 – 11 hours (24.2 mmol/kg).

Shear force values did not correspond with glycogen and pH values (Figure 32a). Meat from calves transported 8 – 11 hours had a shear force value of 86.8 N, compared to 107.8 N for calves transported 4 – 6 hours. That group had 24.2 mmol/kg glycogen in the meat and a pH value at 24 hours pm of 5.48.

Table 27. LS means and standard deviation for shear force, drip loss, glycogen and ultimate pH from

animal class	trpt time (h)	no animal	shear force (N)	drip loss (%)	glycogen (mmol/kg)	PH_{24}
	<2	18	96.6±23.6	2.3±0.9	$20.0^{ab}\pm11.0$	5.61^{cd}
cows	4 - 6	23	83.1±32.4	2.5±0.8	$18.0^{ab}\pm9.9$	5.51^{abc}
	8 - 11	17	100.2±30.4	3.1±1.3	$19.9^{ab}\pm8.2$	5.46^{a}
	<2	20	97.31±34.8	2.8±1.2	$18.1^{ab}\pm11.4$	5.53^{abc}
young bulls	4 - 6	20	89.1±36.6	2.5±1.6	$15.7^{ab}\pm11.2$	5.59^{bcd}
	8 - 11	23	92.9±21.1	2.6±2.2	$24.2^{ab}\pm16.0$	5.46^{a}
	<2	15	85.4±44.4	2.8±1.8	$19.8^{ab}\pm11.2$	5.43^{a}
calves	4 - 6	31	107.8±56.0	2.9±0.9	$24.2^{b}\pm16.8$	5.48^{ab}
	8 - 11	14	86.8±37.5	2.2±1.3	$13.9^{a}\pm18.4$	5.66^{d}
		p value	0.096	0.256	0.024	0.000

animal classes and transport time.
abc) mean values in the same column with different superscript differ significantly

The colour of the meat from animals transported different times differed significantly (Table 28). The p-value was 0.007 for lightness, for redness 0.000 and 0.039 for yellowness.

Meat from calves transported 4 – 6 hours were significantly lighter (42.9) than meat from calves transported 8 – 11 hours (40.1). The yellowness (b*-value) did also differ significantly between the two groups. Those transported 4 –6 hours were more yellow than the other ones. Redness (a*-value) did not differ significantly between these two groups.

However, meat from calves transported 8 – 11 hours had significantly less red meat than the ones transported less than 2 hours. In this case lightness did not differ significantly. Lightness differed significantly between cows transported 4 – 6 hours and the ones transported 8 – 11 hours. That meat was darker (40.1) than the ones transported 8 – 11 hours (42.4). Redness and yellowness did not differ significantly.

L*a*b* values did not differ in meat from young bulls. However, there were tendencies that those transported 8 – 11 hours had a redder meat (19.2) than those transported less time (approximately 17.5).

Table 28. LS Means and standard deviation of colour from the different animal class and transport time

animal class	trpt time (h)	no animals	colour L*	colour a*	colour b*
cows	<2	18	$41.0^{ab} \pm 1.5$	$16.4^{a} \pm 2.3$	$13.1^{ab} \pm 1.0$
	4 - 6	23	$40.1^{a} \pm 1.8$	$19.2^{bcd} \pm 2.0$	$14.1^{bc} \pm 1.2$
	8 - 11	17	$42.4^{b} \pm 3.1$	$18.5^{abc} \pm 1.2$	$14.9^{bd} \pm 1.6$
young bulls	<2	20	$41.9^{ab} \pm 2.3$	$17.6^{ac} \pm 1.3$	$14.3^{bcd} \pm 1.3$
	4 - 6	20	$40.5^{ab} \pm 4.5$	$17.4^{abc} \pm 3.7$	$13.3^{ac} \pm 3.7$
	8 - 11	23	$41.0^{ab} \pm 1.6$	$19.2^{cd} \pm 1.5$	$14.5^{cde} \pm 1.3$
calves	<2	10	$40.5^{ab} \pm 2.8$	$20.2^{d} \pm 0.9$	$14.7^{bde} \pm 1.2$
	4 - 6	26	$42.9^{b} \pm 2.7$	$17.5^{ab} \pm 1.5$	$14.7^{cde} \pm 1.6$
	8 - 11	15	$40.1^{a} \pm 4.0$	$16.5^{a} \pm 3.3$	$12.7^{a} \pm 3.6$
	p value		0.007	0.000	0.001

abc) mean values in the same column with different superscript differ significantly

Summer field test

The results from the summer field test are shown in Table 29. Observation of bruising on the carcasses did not differ significantly ($p = 0.548$). The values varied between 1.4 and 1.8 on a scale between 1 (no bruising) to 3 (severe bruising). Parameters that differed significantly between the different groups were pH24 ($p = 0.000$) and glycogen content ($p = 0.024$). The glycogen content varied a lot in the study, both within the groups and between the groups. However, when Tukey's test was evaluated it did not show any differences. The shear force ($p = 0.058$) value had a tendency to differ between the groups.

Table 29. LS means and standard deviation of shear force, drip loss, glycogen and ultimate pH of the animals transported during summer time

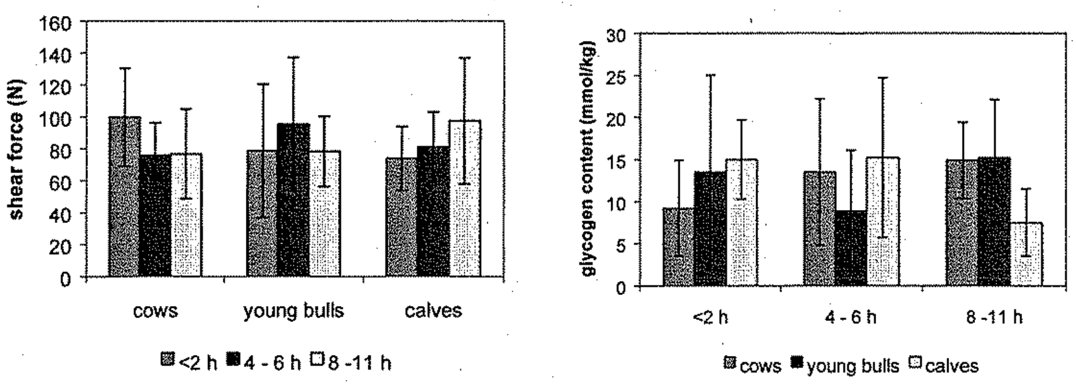
animal class	trpt time (h)	no animal	shear force (N)	drip loss (%)	glycogen (mmol/kg)	bruisings	PH_{24}
	<2	10	99.7±30.7	2.4±0.8	9.2±5.7	1.5	5.68^{bc}
cows	4 - 6	15	75.8±20.3	2.1±0.7	13.5±8.7	1.5	5.51^{ab}
	8 - 11	9	76.7±28.0	3.0±0.7	15.0 ±4.5	1.7	5.44^{a}
	<2	10	78.7±41.8	2.6±1.4	13.5±11.5	1.4	5.50^{ab}
young bulls	4 - 6	10	95.3±41.8	2.7±2.0	8.9±7.2	1.7	5.69^{bc}
	8 - 11	14	78.2±21.9	2.2±0.9	15.2±6.9	1.5	5.44^{a}
	<2	5	73.8±20.0	2.5±1.4	14.9±4.7	1.8	5.45^{a}
calves	4 - 6	15	81.1±25.9	2.6±0.9	15.2±9.5	1.5	5.43^{a}
	8 - 11	10	97.3±38.3	2.3±1.6	7.5±4.0	1.4	5.75^{c}
		p value	0,058	0,473	0.024	0.548	0.000

abc) mean values in the same column with different superscript differ significantly.

Meat from young bulls transported 4 – 6 hours resulted in lower levels of glycogen content, 8.9 mmol/kg, compared to those transported less than 2 hours and 8 – 11 hours, 13.5 and 15.2 mmol/kg respectively (Figure 33b). The shear force value in that group was 95.3 N, which was higher but not significantly, than the other ones (Figure 33a). The group did also have a significantly higher pH24 value compared to those transported 8 – 11 hours (5.44) and tended to have higher value than the ones transported less than 2 hours (5.50).

Similar results were seen in calves transported 8 – 11 hours. The glycogen content was lower, 7.5 mmol/kg, compared to calves transported less times, 14.9 and 15.2 mmol/kg for those transported less than 2 hours and 4 – 6 hours respectively. The shear force value had a tendency to be higher, 97.3 N, compared to the other two groups, 73.8 and 81.1 N for young bulls transported less than 2 hours and 4 – 6 hours. The pH24 value in this group was also significantly higher (5.75) compared to the other two groups, 5.45 and 5.43.

Also cows transported less than 2 hours received similar values, as young bulls transported 4 – 6 hours and calves transported 8 – 11 hours. However in cows, it was those transported less than 2 hours that received higher pH24 (5.68) and shear force (99.7 N) values and lower glycogen value compared to cows transported longer times.



a) *b)*

Figure 33. LS means and standard deviation for a) shear force values and b) glycogen contents in the meat from different categories of animals in relation to transport time

It is peculiar that those groups that received meat that differed compared to other groups within the same category had not been transported the same time.

The colour of the meat from young bulls transported for 4 – 6 hours was darker (37.1), less red (16.3) and yellow (11.4), compared to other young bulls transported differently (Table 30). Similar results were obtained between calves transported 8 – 11 hours and 4 – 6 hours. Those transported 8 – 11 hours did also have darker, less red and yellow meat than the 4 – 6 hours transported ones.

The results were verified by the reflectance curve, where fractions of the different myoglobin forms were calculated i.e. deoxymyoglobin (Mb), oxymyoglobin (MbO) and metmyoglobin (MetMb).

Meat from young bulls and calves had a lower fraction of MbO, 0,73 and 0,69 respectively, than meat from other animals in the same category transported differently. Approximately 0.80 for young bulls transported less than 2 hours and 8 – 11 hours and 0.85 for calves transported 4 – 6 hours. The colour of the meat from cows did not differ between the groups. Colour evaluation of meat from calves transported less than an hour could not be performed because lack of samples.

Table 30. LS Means and standard deviation of colour from the different categories of animals transported during summer time

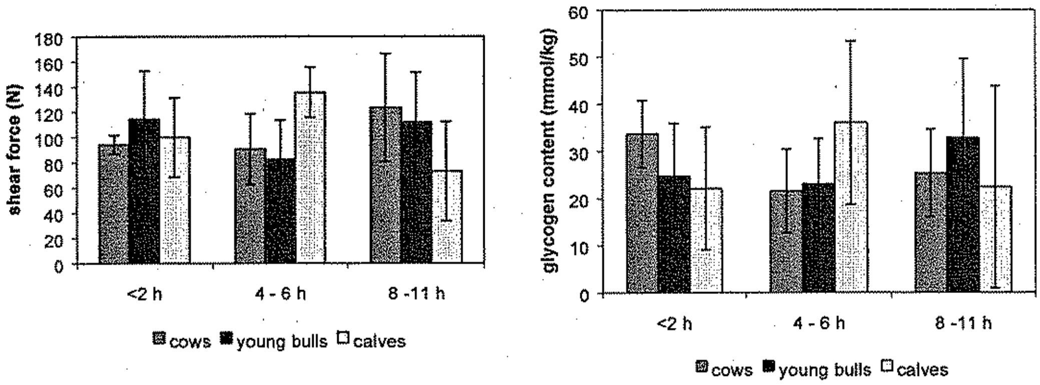
animal class	trpt time (h)	no animal	colour L*	colour a*	colour b*	fraction of MetMb	fraction of Mb	fraction of MbO
cows	<2	10	$40.8^{bcd} \pm 1.4$	$15.5^{abc} \pm 1.1$	$12.7^{ab} \pm 0.6$	0.24^{de}	0.00^{b}	0.76^{ab}
	4 - 6	15	$38.9^{ab} \pm 1.7$	$19.1^{e} \pm 2.1$	$13.6^{bc} \pm 1.2$	0.25^{e}	0.00^{b}	0.75^{ab}
	8 - 11	9	$40.7^{bc} \pm 3.2$	$18.7^{cde} \pm 0.8$	$14.3^{bc} \pm 1.7$	0.24^{de}	0.00^{b}	0.76^{ab}
young bulls	<2	10	$43.4^{de} \pm 2.8$	$17.2^{bcde} \pm 1.5$	$14.9^{c} \pm 1.7$	0.19^{ab}	0.00^{b}	0.81^{b}
	4 - 6	10	$37.1^{a} \pm 4.6$	$16.3^{abd} \pm 4.3$	$11.4^{a} \pm 4.2$	0.22^{cd}	0.05^{ab}	0.73^{ab}
	8 - 11	14	$40.0^{ac} \pm 1.7$	$19.8^{e} \pm 1.5$	$14.3^{c} \pm 1.6$	0.20^{bc}	0.00^{b}	080^{ab}
calves	<2	-	-	-	-	-	-	-
	4 - 6	10	$44.4^{e} \pm 2.0$	$17.9^{de} \pm 1.1$	$15.6^{c} \pm 1.2$	0.15^{a}	0.00^{ab}	0.85^{b}
	8 - 11	10	$39.8^{bc} \pm 3.7$	$14.8^{a} \pm 2.8$	$11.9^{a} \pm 3.2$	0.18^{ab}	0.13^{a}	0.69^{a}
		p value	0.000	0.000	0.000	0.013	0.006	0.005

abc) mean values in the same column with different superscript differ significantly

Winter field test

The results of the meat quality parameters from animals transported during wintertime are shown in Table 32. The results were different from the results evaluated in animals transported during summer time.

Shear force values differed significantly ($p = 0.001$) between the different groups (Figure 33 and Table 30). The mean distribution was increased compared to the summer field test. Young bulls transported 4 – 6 hours had a shear force value of 82.3 N. The value was significantly lower compared to 114.3 N and 111.9 N, which were the values obtained in meat from young bulls transported less than 2 hours and 8 – 11 hours respectively.
Calves transported 4 – 6 hours had a shear force value in the meat of 135.5 N, which is supposed to be very tough. The value was significantly higher compared to meat from calves transported less than 2 hours and 8 – 11 hours, 99.9 and 73.0, respectively.



a) b)

Figure 32. LS means and standard deviation for shear force in the meat from different categories of animals transported different times.

Glycogen content did not differ significantly (Figure 32 and Table 31). The calves that had the highest shear force values did also tend to have higher glycogen content (32.8 mmol/kg) in the meat compared to calves transported 8 – 11 hours (22.4 mmol/kg). It is also worth mention that these calves had the lowest shear force value in the meat.

Similar results obtained in young bulls transported 8 – 11 hours compared to young bulls transported less time. The glycogen content in the meat was higher (36.0 mmol/kg), but not significantly, compared to 21.5 and 23.0 mmol/kg in young bulls transported less than 2 hours and 4 – 6 hours, respectively.

The shear force values in meat from cows transported differently did not differ significant between each other. However, cows that had the highest values, 123.5 N (8 – 11 hours' transportation) also had the same amount of glycogen content in the meat as the ones that received lowest shear force values, 90.7 N (4 – 6 hours transportation). However, the glycogen values did not differ significantly.

Table 31. LS means and standard deviation of shear force, drip loss, glycogen and ultimate pH of the different categories of animals in respect of transport time.

animal class	trpt time (h)	no animals	shear force (N)	drip loss (%)	glycogen (mmol/kg)	PH_{24}
	<2	8	$94.2^{ab}\pm7.4$	2.1±1.1	33.7±7.1	5.52
cows	4 - 6	8	$90.7^{ab}\pm38.5$	3.0±0.7	24.7±8.9	5.48
	8 - 11	8	$123.5^{bc}\pm31.5$	3.0±1.5	22.1±9.3	5.50
	<2	10	$114.3^{bc}\pm27.9$	3.1±1.0	21.5±11.2	5.53
young bulls	4 - 6	10	$82.3^{a}\pm31.3$	1.9±0.8	23.0±9.6	5.49
	8 - 11	9	$111.9^{abc}\pm19.9$	3.1±3.4	36.0±16.8	5.49
	<2	10	$99.9^{abc}\pm42.7$	2.9±1.8	25.3±13.0	5.45
calves	4 - 6	16	$135.5^{c}\pm39.6$	3.1±1.0	32.8±17.3	5.53
	8 - 11	5	$73.0^{a}\pm39.4$	2.0±0.5	22.4±21.4	5.52
		p value	0.001	0.098	0.017	0.226

abc) mean values in the same column with different superscript differ significantly

The colour of the different meat samples differed significantly only in a* value (redness). Meat from calves transported less than 2 hours was redder (19.7) than meat from calves transported 4 – 6 hours (16.8). L* and b* values did not differ significantly (Table 32). Meat from cows had similar L*-values as meat from calves, between 41 and 42. The values for cows were expected to be lower because they have more myoglobin in their muscles.
The results of L*, a* and b* values were verified by the reflectance curve, which did not differ significantly.

Table 32. LS Means and standard deviation of colour from the different categories of animals in respect of transport time

animal class	**trpt time (h)**	**no animal**	**colour**			**fraction of**		
			L*	**a***	**b***	**MetMb**	**Mb**	**MbO**
cows	**<2**	**10**	41.7 ± 1.7	17.4^{ab} ± 3.3	13.7 ± 1.3	0.22	0.02	0.76
	4 - 6	**15**	41.1 ± 1.8	19.7^{ab} ± 1.9	14.7 ± 1.2	0.22	0.00	0.78
	8 - 11	**9**	42.6 ± 3.1	18.3^{ab} ± 1.1	14.9 ± 1.5	0.20	0.00	0.80
young bulls	**<2**	**10**	41.6 ± 1.5	18.3^{ab} ± 1.1	14.5 ± 0.8	0.21	0.01	0.78
	4 - 6	**10**	42.7 ± 2.0	18.9^{ab} ± 1.1	14.8 ± 1.2	0.21	0.01	0.78
	8 - 11	**14**	41.1 ± 1.4	18.3^{ab} ± 1.0	14.1 ± 0.9	0.22	0.01	0.77
calves	**<2**	**5**	42.2 ± 2.8	19.7b^{b} ± 0.9	15.2 ± 1.2	0.21	0.00	0.79
	4 - 6	**5**	41.6 ± 1.7	16.8^{a} ± 1.5	13.8 ± 1.1	0.21	0.02	0.77
	8 - 11	**15**	41.7 ± 3.8	18.9^{ab} ± 3.1	14.4 ± 2.9	0.21	0.02	0.77
		p value	0.647	0.021	0.065	0.715	0.259	0.407

abc) mean values in the same column with different superscript differ significantly

Animals class and stock density

The result of the different variables regarding categories of animals and stock density is shown in Table 27. Drip loss differed significantly between the groups, but within the groups, only young bulls differed. Meat from young bulls transported at low density had significantly higher drip loss (3.1 %) than meat from those transported at high density (2.1 %). Shear force values did not differ within young bulls and calves transported at low or high density. The shear force values in cows transported at high or low density were more evenly distributed, 94.4 and 92.3 N, respectively.The glycogen contents in the meat did not differ significantly. The levels varied most between 17.9 mmol/kg for cows transported at low density and 20.9 mmol/kg for cows transported at high density. The pH24 level was almost ultimate in all transported animals. The values varied from 5.48 in young bulls to 5.56 in calves, both transported at low density.

Table 33. LS means and standard deviation for shear force, drip loss, glycogen content and pH24 from the different categories regarding density in the transport boxes. (n = number of animals in the study, except for glycogen content, which is gly. n.)

animal class	density	no animal	shear force (N)	drip loss (%)	glycogen (mmol/kg)	PH_{24}
cows	low	30	94.4 ± 26.0	2.2^{abc} ± 0.8	17.9 ± 9.1	5.54
	high	28	92.3 ± 32.5	3.0^{bc} ± 1.1	20.9 ± 10.4	5.52
young bulls	low	30	88.1 ± 25.6	3.1^{c} ± 2.2	19.2 ± 13.9	5.48
	high	33	98.6 ± 34.1	2.1^{ab} ±1.0	19.5 ± 12.3	5.57
calves	low	26	97.6 ± 54.3	2.5^{ac} ± 1.4	20.6 ± 18.1	5.56
	high	35	89.1 ± 46.6	2.7^{abc} ± 1.3	18.1 ± 15.9	5.49
		p value	0.411	0.003	0.571	0.051

abc) mean values in the same column with different superscript differ significantly.

The colours of the meat were similar in all animals (Table 34), although the p-value in lightness was 0.032. This was not expected even though the results correspond with the results from shear force values and glycogen content. Lightness should normally have been lower in cows than in calves. Instead the values did not vary at all. Neither did redness or yellowness.

Table 34. LS means and standard deviation for colour in the meat from the categories regarding transport boxes.

animal class	density	no animal	colour		
			L*	a*	b*
cows	low	30	41.3±2.2	17.7±1.5	14,0±1.0
	high	28	41.0±2.2	18.4±2.2	14.1±1.7
young bulls	low	30	42.0±2.2	18.2±1.3	14.5±1.4
	high	33	40.3±3.6	18.0±3.2	13.6±2.9
calves	low	16	40.2±3.6	18.3±3.0	13.6±3.0
	high	35	42.1±3.0	17.8±2.1	14.4±2.1
		p value	0.032	0.549	0.089

Summer field test

The shear force values differed significantly in the study (p = 0.024), but within the different groups, there was no differences (Table 35). However both cows and calves had tendencies to have a higher value (91.3 N and 88.5 N respectively) in those transported at low density compared to those transported at high density, 76.8 N and 79.6 N respectively. The pH24 in the same groups did also have a tendency to be higher in those transported at low density, 5.60 and 5.58 for cows and calves respectively. This should be compared to 5.49 and 5.51.

Contrary to the shear force results above, 95.7 N obtained in young bulls transported at high density was significantly higher compared to 72.4 N obtained in those transported at low density. The pH24 was measured to 5.63, which was significantly higher than 5.45 measured in young bulls transported at low density. The glycogen content, 14.3 mmol/kg for those transported at low density and 10.8 for the ones transported at high density, did not differ significantly

The documentation of bruisings, obtained during the transport or immediately prior to stunning, did not differ significantly between the groups. The animals had a mean value of bruisings between 1.4 to 1.7 measured on a 3 level scale. The bruisings were located to the tail, shoulder, leg and side.

Table 35. LS means and standard deviation for shear force, drip loss, glycogen content and ultimate pH from the different categories with respect of density in the transport boxes.

animal class	density	no animal	shear force (N)	drip (%)	glycogen (mmol/kg)	bruisings	PH_{24}
cows	**low**	**19/19**	91.3^{ab}±27.7	1.9^{a}±0.4	11.5±7.0	1.6	5.60^{cd}
	high	**15/15**	76.8^{a}±27.2	3.0^{b}±0.8	13.6±7.0	1.5	5.49^{ac}
young bulls	**low**	**20/19**	72.4^{a}±24.4	3.1^{b}±1.6	14.3±8.8	1.7	5.45^{ab}
	high	**14/13**	95.7^{b}±35.1	1.9^{a}±0.6	10.8±7.2	1.4	5.63^{d}
calves	**low**	**15/14**	88.5^{ab}±28.4	2.5^{ab}±1.7	11.8±9.1	1.4	5.58^{bcd}
	high	**15/15**	79.6^{ab}±36.3	2.5^{ab}±1.0	13.3±11.9	1.7	5.51^{abd}
		p value	0.024	0.002	0.344	0.164	0.003

abc) mean values in the same column with different superscript differ significantly

The colour of the meat from young bulls transported at high density was darker (37.6) and less yellow (12.0) compared to meat from those transported at low density, 42.7 and 15.1 respectively (Table 36). Again the results were contrary to what was seen in calves. The ones transported at low density had a darker, 38.2, and less yellow, 12.6, meat compared to the ones transported at high density, 42.1 and 14.5 respectively. These results were verified by the reflectance curve which showed that young bulls transported at high density had lower fraction of MbO, 0.75, compared to the young bulls transported at low density, 0.81. This means that young bulls transported at high density had a higher amount of Mb in their muscles. The same results were found in meat from calves transported at high and low densities, 0.76 and 0.81 respectively.

Table 36. LS means and standard deviation for colour regarding density in the transport boxes.

animal class	density	no animal	colour			fraction of		
			L*	a*	b*	MetMb	Mb	MbO
cows	low	19	$39.6^{bc} \pm 1.9$	17.2 ± 1.6	$12.9^{bc} \pm 0.9$	0.25^{c}	0.00	0.75
	high	15	$40.7^{cd} \pm 2.3$	18.4 ± 1.7	$14.1^{cd} \pm 1.4$	0.23^{c}	0.00	0.77
young bulls	low	20	$42.7^{e} \pm 2.3$	18.6 ± 1.4	$15.1^{e} \pm 1.6$	0.19^{b}	0.00	0.81
	high	14	$37.6^{a} \pm 4.0$	17.0 ± 3.7	$12.0^{a} \pm 3.5$	0.21^{b}	0.04	0.75
calves	low	5	$38.2^{ab} \pm 4.0$	17.6 ± 3.3	$12.6^{ab} \pm 3.7$	0.16^{a}	0.03	0.81
	high	15	$42.1^{de} \pm 3.0$	18.0 ± 2.2	$14.5^{de} \pm 2.6$	0.19^{ab}	0.05	0.76
		p value	0.000	0.106	0.000	0.001	0.602	0.208

abc) mean values in the same column with different superscript differ significantly

Winter field test

No parameters differed significantly when interaction between animal categories and densities were evaluated (Table 37). During the winter field test shear force values were shown to be higher than in the summer field test. This study showed that the animals in the study had an average value above 100 N. Shear force values above 100 N is supposed to be tough meat. The standard deviations for meat from calves were very high, over 45 N. Glycogen content did not differ significantly. The values were evenly distributed between the different groups of categories. Compared to the summer field test they were measured twice as high, 23.8 mmol/kg to 31.0 mmol/kg. The pH24 values had approximately reached an ultimate level, 5.48 to 5.53 and the drip loss varied only 2.4 – 3.2% between the groups.

Table 37. LS means and standard deviation for shear force, drip loss, glycogen content and ultimate pH from the different categories of animals regarding density in the transport boxes.

categories	density	N/gly. n	shear force (N)	drip (%)	glycogen (mmol/kg)	PH_{24}
cows	low	11	97.3 ± 22.7	2.6 ± 1.0	23.8 ± 8.1	5.48 ± 0.07
	high	13	118.1 ± 34.7	3.0 ± 1.2	31.0 ± 11.7	5.53 ± 0.15
young bulls	low	10	115.8 ± 24.3	3.2 ± 3.2	30.2 ± 14.5	5.52 ± 0.07
	high	19	99.5 ± 27.7	2.4 ± 1.1	24.6 ± 11.8	5.49 ± 0.07
calves	low	11	110.0 ± 45.3	2.6 ± 0.9	28.2 ± 18.9	5.52 ± 0.07
	high	20	105.4 ± 46.2	3.0 ± 1.5	26.6 ± 16.6	5.49 ± 0.10
		p value	0.287	0.254	0.317	0.214

abc) mean values in the same column with different superscript differ significantly

The only colour value that differed significantly (Table 38) was yellowness, b*, (p= 0.029). However, no differences were found when Tukey's test was evaluated. The lightness was similar in comparison with the different categories. As mentioned above, meat from cows would expect to be darker and redder than meat from calves. The results from this study showed that the L*a*b* values were similar between meat from cows and calves, which was also verified by the reflectance curve.

Table 38. LS means and standard deviation for colour of the meat from cattle transported at hihg or low stock density

animal class	density	no animal	colour			fraction of		
			L*	a*	b*	MetMb	Mb	MbO
cows	low	10	42.9 ± 2.5	18.2 ± 1.0	14.6 ± 1.1	0.20	0.01	0.79
	high	13	40.9 ± 1.9	18.5 ± 3.3	14.0 ± 1.8	0.22	0.01	0.77
young bulls	low	10	40.9 ± 1.4	17.7 ± 0.8	13.8 ± 0.8	0.22	0.02	0.76
	high	19	42.6 ± 1.9	19.0 ± 1.4	15.0 ± 1.1	0.21	0.00	0.79
calves	low	11	41.8 ± 2.0	19.2 ± 1.0	14.6 ± 1.8	0.22	0.00	0.78
	high	20	41.7 ± 2.7	17.5 ± 2.1	14.2 ± 2.5	0.20	0.02	0.78
		p value	0.128	0.093	0.029	0.069	0.078	0.208

abc) mean values in the same column with different superscript differ significantly

5. Discussion

Studies to determine stress inducing factors in cattle that have been handled and transported in commercial situations have often shown variable results (Grandin, 1997). Therefore it is difficult to explain the results from a welfare point of view. One has to have in mind that cattle are biological materials and therefore different from one to another, also within a group that have been raised together.

5.1. Heart rate measurements

The method of measuring heart rate is well established, but since the heart rate sensors are mounted just a couple of hours before transportation, the mounting itself can have influenced the resting heart rate.

5.1.1. Transport time

It was found that heart rate during transport is decreasing from loading to unloading and often reaches a lower value than before transport. The medium transports resulted in highest heart rate for all animal classes. Maybe it is the loading that causes the strongest response and that the animal calmed down after a couple of hours on the vehicle but got exhausted if the transport lasted too long.

5.1.2. Season

Significant differences in heart rate during transport due to season could be seen for cows but not for other animal categories. The lower heart rate for cows during summer than during winter can have something to do with that they are grazing in the summer and therefore are in better condition than in the winter. The large temperature differences inside the stable than in the transport during winter can also affect the animals.

5.1.3. Temperature

Temperature varied a lot both in the summer and in the winter trials. The summer in Sweden year 2000 was relatively cold so the temperature didn't reached the desired average of 20°C, but the difference between summer and winter was great anyhow, 11.5°C. Temperature in the vehicle during winter reached below –15°C several times. The relative humidity was very high in the vehicle especially in the winter trial and was just under 100% during several experiments.

5.1.4. Stocking density

We couldn't see any differences in HR due to density. May be because the range of density was too small so it didn't develop any differences. Farm Animal Welfare Council (FAWC) recommend 1.52 m^2/animal as a maximum for a cattle weighting 600 kg. Our densities (2.0 to 1.5 m^2/animal) were probably within the range where the animals don't stand too tight and have too much room so they have difficulties to hold their balance.

5.1.5. Heart rate related to time of the day

There were differences in heart rate before transport due to time of day and this affected the heart rate during transport. Heart rate before transports that occurred in the mornings were lower than transports occurring during the nights. This might depend on a normal variation in heart rate during the day. Long transport would have higher heart rates depending only on the fact that heart rate was higher in the evenings. For calves and cows this was true for long transports versus medium transports, heart rate during long transports was significantly higher.

5.1.6. Loading and unloading

According to the results of the analysis made on heart rate, the animals were most stressed during loading and unloading. These events caused the highest heart rates for all animals. Certainly some of the increase has emanated from a physical activity.

5.2. Behaviour

The results indicate that young bulls are more stressed from being loaded compared to cows and calves. The reason might be that bulls are less used to being handled than cows. If the animals are not used to handling contact with humans, without physical discomfort can stress animals, especially if they are not used to human contact (Broom, 1996). Bulls are usually lead on to the transport one by one, which arises the probability of difficulties such as refusing to go. Calves on the other hand are usually loaded loosely in groups. The loading of the calves in this study was mostly very calm and swift. Calves handled close to weaning can be easier to handle at an older age. Another explanation of the low scores for calves is that because the loading is so quick it is also hard to notice all behaviours that might occur.

Cows are the most stressed during unloading compared to young bulls and calves. This might be explained by the fact that most cows are led in to the lairage, and thereby driven harder than calves and bulls. There are many new animals, smells, high noises unfamiliar staff that the animals need to get familiar to (Grandin, 1983, Grandin, 1987). Bulls and calves are mostly released from the vehicle and are often given the opportunity to move in their own speed, at least in the beginning. This gives the animals the means to look and smell the environment after which they are more willing to move along.

Calves did not lye down at all during any transport time, instead the animals changed position constantly during the transport, this making it impossible for any calves to lye down. However, Kent and Ewbank (1983, 1986) reported that calves of different ages spent between 0-55% of the time lying down and the older the calves the shorter the lying periods. Cows lye down for short periods only. Cattle have a specific pattern when lying down which acquires space and balance, neither is the case when being transported. Cows in the current study were mostly milking cows transported to slaughter mainly because of old age or decease (mastitis or feet problems). Problems with the udder or feet/legs would lead to difficulties lying down, especially on a moving truck. Bulls lay down for up to 10% of the time, which was more than cows and calves. Young bulls are at the "peak" of their lives, young, healthy and well muscled which would make it easier for them to lye down.

It took between two and eight hours for bulls and cows to lye down for the first time, indicating that the animals need to get adapted to the environment and the instability of a moving truck. Kent and Ewbank (1983 a) reported similar findings in castrated bulls that lye more towards the end of the transport. After eight hours the animals were probably getting tired and got down even though it might have been uncomfortable and difficult to get down. However several animals didn't lie down at all during the transport, even when they got tired.

Changing position indicates restlessness and stress. The result show that calves are more restless than bulls. However most calves were transported loose and most bulls were tied. Tied bulls have less ability to move around. Calves moved around more in the beginning of the transportation implying that they got accustomed to the new environment after a period of time or that they became tired and could not move around.

When analysing the videos recorded during transport, an unexpected behaviour was observed in bulls. Several bulls were pulling hard in the halter and rope they were tied in. They were either throwing their head back or throwing their entire body backwards. This behaviour was studied in several bulls in different transport groups indicating that it is a common behaviour during transport. The frequency was highest in the beginning but did continue throughout the journey indicating that the bulls were stressed.

5.3. Air quality

5.3.1. Temperature

The temperature during summer experiments was colder than the temperature expressed in the experimental design (20°C). The average temperature for all summer experiment was 16.3°C and didn't exceed 20°C any time. The highest peak temperature that was reached was 26.7 °C during one journey. During winter some journeys were made when there were very cold. The temperature inside the vehicle was –16.1°C when the animals were loaded and reached 0°C after 2 hours.

Temperature in the vehicle during the experimental periods ranged from 8.3 to 26.7 °C with an average value of 16.3 °C in the summer and in the winter it ranged from –16 to 19 °C with an average of 4.8 °C.

The temperature inside the vehicle followed outside temperature well during the summer experiments. During winter it was much warmer inside the vehicle when it was very cold outside. The difference could be as high as 16°C.

For summer experiments, temperatures in all places were lower during medium transports than during long transports, probably because long transports were made during the nights when it was colder outside. Winter experiments had lowest temperature during medium transports. Both short and long transports had higher average temperature. No big difference could be seen for these two transport times, even if the outside temperature at short transports were 4°C colder than during long transports. The variation at the same sensor position was larger during wintertime than during summertime. During summer the variation was almost the same for every position.

Number of stops that was made to load new animals affected the average temperature inside the vehicle. Stops lowered the temperature during wintertime but raised temperature during summertime. This might depend on the fact that outside temperature was much lower than the inside temperature and outside air came into the vehicle when the ramp was opened. Temperature in the vehicle was higher when more stops were made during summer.

Total density on the vehicle was also affecting the temperature. Higher density resulted in higher temperature both in summer and in wintertime. This was excepted because more animals on the vehicle produce more heat.

The relative humidity was high during some experiments, the highest value of relative humidity was 99.9 % both in summer and winter conditions and it ranged from 45.7% with an average of 82.8 % in summer and from 58.0 % with an average of 92.3 % in winter conditions. Some journeys had average relative humidity higher than 97 %. This is probably not a problem because the temperature was pretty low.

5.2.2. Methane and other gases

Methane is produced by anaerobic breakdown of manure and by bacteria in the stomach and is a harmless gas in livestock buildings under normal conditions. Methane are probably not a problem in livestock transports that last shorter than 11 hours either. In the experiment study no detectable levels of methane were found, but the instrument could not detect levels lower than 0.5% so it could have been small amounts of methane in the air.

The highest value of carbon dioxide that was reached during the experiments was 0.3%, this is also the limits for livestock buildings (CIGR, 1992) and livestock transporters (Randall, 1993). The average values during the experiments were well below this value for all experiments.

Oxygen levels had a lower average level than is present in normal air (21%) and this can depend on higher carbon dioxide levels. The levels of oxygen was not, however, too low.

5.4. Meat quality

5.4.1. pH-fall

If the carcasses have pH24 values above 5.8 the carcasses might have been exposed to either cold shortening or some kind of stresses during handling and transportation. In this study 4 of 5 young bulls transported 4 – 6 hours at high density during summer time had higher pH24 values than 5.8. Similar values were seen in 3 of 5 calves transported 8 – 11 hours at low density.

For animals transported during summer time, the differences in pH24 values were clearer compared to those transported during wintertime. However, since the same transport time did not give the same effects on pH24 values for the different animal categories it is difficult to explain if transportation lengths may decrease pH falls. Regarding the two stock densities, there were no differences in the pH falls between the different groups.

To measure pH values early pm is difficult, because the values vary significant within short distances in the carcass. Therefore, the one who perform the measurement has to be well trained in how to measure the pH values correctly. In this study, only few differences were shown, even though it is well known that longer transport times may cause decreases in energy levels in the animals. A low energy level will lead to a higher pH value at the end, since glycogen concentration in the carcass cannot form lactate.

Therefore one may assume that transport times were not critical in this study. Another possibility might be that the pH values were not measured correctly after slaughter or that the pH meter was not calibrated correctly. However, when the samples arrived to the laboratory, the ultimate pH values were controlled. These values were not significantly different compared to pH24 values.

5.4.2. Combined effect of animal class, density and transport time

When the results from the different categories of animals transported different times at high or low densities were evaluated, only glycogen concentration differed significantly. The other parameters did not differ significantly and had high p-values. This may depend on the different groups in the study in combination with the low numbers of evaluated animals in each group.

However, there were tendencies that young bulls transported for 8 – 11 hours had a higher shear force value in the meat from those transported at low density compared to the ones transported at high density. The glycogen concentration did also tend to be lower. Young bulls transported less than 2 hours did also show similar results. However in this case, it was those transported at high density that tended to have a higher shear force value and lower glycogen concentration.

If the glycogen concentrations are low at slaughter, it is possible that the animals have been exposed to some kind of stresses during handling or transportation. A depletion of glycogen will reduce the amount of lactic acid and hence the pH cannot be decreased properly. This problem will result in darker meat compared to those that have high energy levels at slaughter.

5.4.3. Animal class and transport time

The significantly higher pH value and lower glycogen content in the meat from calves transported 8 – 11 hours compared to other calves was supposed to give meat with higher shear force value. Instead this group had similar shear force value compared to those transported less than 2 hours. The shear force value for the ones transported 4 – 6 hours tended to be higher. This group did also have a pH value and glycogen content that were lower and higher respectively, compared to calves transported 8 – 11 hours and similar to those transported less than 2 hours. The colour of the meat in the ones transported 8 – 11 hours were significantly darker and less yellow than the ones transported 4 – 6 hours. Hence one may assume that calves transported 8 – 11 hours can have been stressed at handling or transport to the abattoir.

The similar results of pH value and glycogen content in meat from young bulls transported 4 – 6 hours did also show a lower shear force value compared to young bulls transported less than 2 hours and 8 – 11 hours. The colour of this meat did not differ significantly as it did in the meat from calves transported 8 – 11 hours.

At the separate evaluation of summer field and winter field test, the glycogen levels tended to be twice as high at slaughter of the animals transported during the winter time. Hence, it may be possible that the glycogen levels have decreased during the transport to SMRD, where the samples were analysed.

The results from the summer field test showed a significantly higher pH24 value and lower glycogen concentration at slaughter as well as a tended higher shear value in both young bulls transported 4 – 6 hours and calves transported 8 – 11 hours, compared to the corresponding animals transported differently. The colours of the meat in these groups were also darker, less red and yellow, compared to the other groups. These different results indicate that the animals in these two groups may have been exposed to some stresses before slaughter. Normally, one would assume that longer transportation time would decrease the energy level in the body. This assumption would be correct for calves. Why the same result did not appear in young bulls transported 8 – 11 hours is noteworthy. These had similar shear value, glycogen concentration and a tended lower pH24 compared to young bulls transported less than 2 hours. Hence, it may not be transport time that led to stresses in these animals but other factors, such as handling or novelty.

As mentioned above, there were problems with the transport of the glycogen samples to SMRD during summer time, since the transport vehicle did not keep +4°C in the compartment as it was told. In two of these transports the dry ice had melted when they arrived to SMRD. This led to that some of the samples had started to thaw. However, if this incident did not affect the glycogen concentration, it may be possible that some of the animals adapted the transport situation and did not become stressed at all or relaxed after having been transported for a few hours.

The results from the winter field study did not show similar tendencies compared to the results of the summer field test. The pH24 values did not differ between the groups transported short, medium or long distance. The glycogen levels did not differ significantly between the different groups. The only results that differed significantly were shear force values and redness (b* values). However it were not the same groups as was seen in the summer field study that differed significantly. In this season, young bulls transported 4– 6 hours had a significantly lower shear force value compared to those transported differently. The colour of the meat did not differ at all between the different groups of young bulls. The highest shear force value in cows was seen in the group transported 8 – 11 hours. However, the results did not show any decreased glycogen concentration or higher pH24, compared to the cows transported differently, which meat tended to have lower shear force values. Nor did the colour differ significantly.

Calves transported 4 – 6 hours had a significantly higher shear force value than those transported 8 – 11 hours, which on the other hand, had the lowest shear force value in the meat. Again there were no differences in any of the other evaluated parameters. It is difficult to explain why these results occurred. Perhaps the wintertime will make animals become less stressed, possibly due to the colder climate. However, this does not explain why the shear force values were higher in some group of transported categories than in others. Neither does it explain the fact that the higher shear value obtained in meat from different transport length depending on which category of animals that were evaluated.

5.4.4. Animal class and stocking density

Transportation at low or high stock density did not affect the meat quality in any group in this study as a total. The drip loss in young bulls transported at low stock density was however significantly higher than in those transported at high density. Because no other parameters differed this higher difference did not affect the meat quality.
The significantly darker meat in calves transported at low density did not affect the quality either, since no other parameter differed significantly.

Particularly the shear and colour values are notable since one would expect that calves, in general, would have lighter and more tender meat than cows and young bulls, primarily because of the less developed collagen tissue and myoglobin. In Sweden however, the shear values can sometimes be as high as in meat from cows. This does not depend on stresses before slaughter but the effective chilling system, which can be the same as for larger animals.

When meat from animals transported during summer time was evaluated, young bulls transported at high density had a higher shear value and higher pH24 value compared to those transported at low density. The meat was also darker and less yellow. The glycogen concentration did also tend to be lower at slaughter, compared to the other young bulls. This may indicate that these animals were exposed to some stresses before slaughter. Similar results as were seen in young bulls transported at high density, were found in calves transported at low density. The pH24 value was significantly higher and the colour was darker and less red compared to the ones transported at high density. Shear force value had a tendency, although small, to be higher but there was not any difference in glycogen concentration.

In cows only shear force and pH24 value tended to be higher in those transported at low density, than the ones at high density. It is peculiar that the different stock density affects the meat from young bulls differently compared to calves and cows. The results were not repeated during the winter field test. No differences were seen in calves transported at low or high density. Young bulls had a slightly higher shear value in those transported at low density compared to those transported in high density, which was opposite of what was seen in the summer field test. No other differences could be seen. Similar results were seen in cows. However, the results were opposite of young bulls, i.e. those transported at high density had a slightly higher shear value and darker meat.

6. Conclusions

6.1. Heart rate

- Loading density has an impact on heart rate in calves and cows
- Highest heart rates were seen during loading and unloading, these events are therefore probably the events that cause most stress to the animals
- Heart rate during transport for cows were lower during summer than during wintertime
- Heart rate measured before transport were lower for experiments performed during mornings (short and medium transport times) than during evenings (long transport time)

6.2. Blood parameters

General
From the results of the analysis made using cortisol, glucose, CK and lactate, it may be concluded that transport time has significant effect on the level of stress. Fluctuations have been observed for some field test results, and among animal classes (bulls, calves and cows). However, about 59% of the trips have shown clearly that transport time has significant effect on stress level, while only 12% of the field tests (mainly cortisol concentration level) showed no transport time effect. Calves are the most sensitive to transport and handling, whereas cows are relatively less sensitive.

Bulls (cortisol)
There is a clear indication that short transport time is stressful for bulls under winter season transport. This may indicate that bulls may be sensitive for climate change and transport handling and adapt themselves as the transport time increases. However, for the summer season transport, the effect of loading density on cortisol is more significant than transport time. Highest increase of cortisol was observed for short and medium transport time at high and low density respectively.

Bulls (glucose)
For both for summer and winter seasons, loading at low density, glucose increased exponentially with transport time. However, for both seasons, loading at high density, glucose increased most for the short distance. However, it was increased with transport time from medium to long transport time. Therefore, it could be noted that transport time has significant effect on glucose variations.

Bulls(CK)
There is a significant correlation between an increase of CK and transport time. However, highest CK was noted for medium transport for low density loading for both seasons.

Calves (cortisol)
From both seasons experiment, it can be noted that transport time has significant effect on cortisol. No clear effect of loading density was observed.

Calves (glucose)
Glucose increased with transport time depicting that there is a significant effect of transport time on glucose particularly for the from the field experiment conducted in winter season at low density, and during summer season at high density loading. Very similar patterns of variations of cortisol and glucose were observed in relation to density and transport time was observed.

Calves (lactate)
The behaviour of correlation between lactate and transport time is influenced by loading density. For low density, lactate increased with transport time, while, lactate decreased with an increase of transport time. The rate of increase of lactate is higher in summer season than winter. But the rate of decrease is higher during winter.

Cows (cortisol)
In general concentration of cortisol level was increased up to 20% after handling and transport. However, no linear relation between transport time and level concentration was observed.

Cows (glucose)
For both seasons and at the high loading density, an increase of glucose with transport is significant. However, it is difficult to draw conclusion for the low-density loading.

Cows (CK)
There is significant correlation between CK and transport time.

6.3. Behaviour

- Bulls are more stressed during loading than cows and cows are more stressed during unloading.
- The lying behaviour was only observed during long transports indicating that the animals need a certain time to get adapted and/or the animals become tired. Calves did not lye down during any transportation (up to 11 hours). Cows lay between 0.68-4.1% of the time and young bulls lay down for up to 10% of the time during long transports.
- Calves changed position during the transports (independent on transport time) indicating restlessness. The changing of position decreased as the transport time increased.
- Many of the groups of young bulls repeated a behaviour of pulling back in the halter and rope. The frequency of this behaviour was highest in the beginning of transports, but didn't continue during the journey.

6.4. Meat quality

The lack of significant effects which was seen when animal class, transport time and stock density were evaluated together may depend upon the amount of different groups and the low number of animals in the project. There were only tendencies that long transport times gave lower glycogen content in the meat.

Young bulls transported for 4 – 6 hours and calves transported for 8 – 11 hours during summer time were supposed to have been exposed to stress since glycogen content and L*a*b* values had a tendency to be lower and pH24 higher compared to those transported differently. The higher shear force values in calves transported in winter may not depend on transport or handling, since no other parameter showed similar tendencies. Instead it is more likely that it was the slaughter process that resulted in such high shear force values. Since the standard deviation were quite high in each evaluated parameter it is difficult to make any final conclusions about the transport time. However it seems like the transport times did not affect the meat quality considerably according to this study.

The tendencies that discussed in respect of stock density were irregular considered which category of cattle that were transported. The high p-values in most of the meat quality parameters regarding stock density showed that meat quality were not affected differently when cattle were transported in high or low density. Like transport times it is also difficult to make any conclusion regarding stock density. Due to the high standard deviation results did not differ significantly. However, the tendencies that were found showed that the stock densities used in this study did not affect the meat considerably.

One reason of the lack of differences in the study might depended on the fact that the transport company and the personnel were aware of that they transported research animals, and hence handled the cattle more careful than normal.

6.4. Air quality

- Average temperature inside the transporting vehicle was under 20°C for all experimental journeys during the summer and the highest measured temperature was 26.7°C
- Lowest temperature during summer was seen at the long transports, that also had less stops and less total loading density than the medium long transports
- Lowest temperature during winter was seen at the medium long transports and highest at short transports, even if medium transport times had much higher total loading density than long transports
- An increasing number of stops lead to lower winter but slightly higher summer temperature
- It was coldest in the back of the vehicle for long transports during summer and for all transport times during winter, in the summer during medium transport times it was coldest at the side in the second pen
- It was warmest in the second pen both in summer (at the side) and winter (in the middle)
- Temperature increased during most journeys and the increase could be as high as 16°C
- The relative humidity were high, especially in wintertime
- Methane levels in the vehicle was below 0.1%

6.5. General conclusion

- Transport conditions, as a whole is stressful for animals and compromise their welfare.
- Loading and unloading activities are the most stress inducing factors identified using the heart rate measurements and behaviour observations

- Result of the analysis of blood parameters, showed that level of stress correlates with transport time. Calves are most sensitive to transport time followed by bulls, and cows are relatively less sensitive to transport length.
- Transport time after six hours is stressful for the animals when transported with usual vehicles without special equipments. However, less detrimental effect of transport time on meat quality has been observed,
- The evenness of temperature in the loading pens depends on season and number of stops
- Concentration level of ammonia and carbon dioxide increase with transport time and it occasionally passes the acceptable level

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2003-07-01 skedde en sammanslagning av Institutionen för biometri och informatik och Institutionen för lantbruksteknik.

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Licentiatavhandling

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Kompendium

2004:01 Publicering 2000-2003.

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81 Olsson, U. & Sikk, J. Fourth Nordic-Baltic Agrometrics Conference, Uppsala, Sweden, June 15-17, 2003. Conference proceedings.
80 Edlund, T. Pluripolar Completeness of Graphs and Pseudocontinuation. Licentiatavhandling.
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73 Huber, K.T:, Moulton, V. & Semple, C. Replacing cliques by stars in quasi-median graphs.
72 Huber, K.T. Recovering trees from well-separated multi-state characters.
71 Holland, B.R., Huber, K.T., Dress, A. & Moulton, V. δ-plots: A tool for analyzing phylogenetic distance data.
70 Huber, K.T., Koolen, J.H. & Moulton, V. The Tight Span of an Antipodal Metric Space: Part II – Geometrical Properties.

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03:01 Sjöberg, C. Lokalt omhändertagande av restprodukter från enskilda avlopp i Oxundaåns avrinningsområde.
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