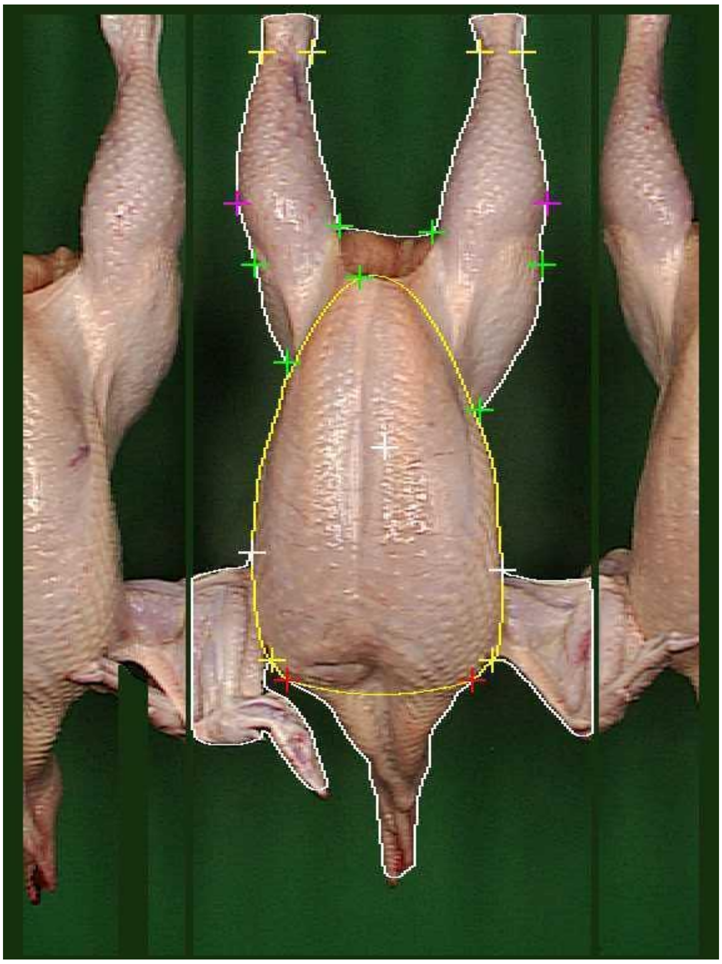
Danish Meat Research Institute

DANISH TECHNOLOGICAL INSTITUTE

Vision classification and value-based payment of broiler chickens
Final report



30 November 2010
Project No. 1379720

Kort sammendrag og anbefalinger

Projektets mål har været at udvikle og dokumentere et objektivt målesystem til værdibaseret afregning af slagtekyllinger. Et vision-baseret klassificeringssystem (VTS2000 fra E+V Technology GmBH) er udviklet og testet på Rose Poultrys slagteri i Vinderup og på Lantmännen Danpos slagteri i Aars.

Projektet har vist, at det udviklede VTS2000 klassificeringssystem er egnet til implementering på de danske kyllingeslagterier og at afregningen til kyllingeproducenterne kan baseres på systemets målinger på flokniveau. Klassificeringssystemet anbefales som basis for etablering af et nyt afregningssystem, som inkluderer ny information om slagtevægt og total brystfiletudbytte. Herved kan afregningen afspejle både størrelse og kvalitet (kødindhold) og dermed værdien af kyllingerne bedre end det nuværende afregningssystem. Baseret på principperne beskrevet i projektet kan et nyt afregningssystem etableres. Ved brug af målesystemet og en ny afregning forventes det muligt at optimere den samlede økonomi i slagtefjerkræbranchen. Der kan gives nye kvalitetsinformationer til producenterne, som dermed kan tilpasse produktionen og slagterierne får meget bedre mulighed for på et objektivt grundlag at differentiere afregningen efter den produktkvalitet, der leveres.

VTS2000 måler ved at tage et billede af for- og bagside af hver kylling på slagtelinjen efter plukning og før organudtagning (evisceration). Målingerne er baseret på analyse af disse billeder ud fra kyllingens dimensioner og former. Udstyret består af 2 kameraer monteret i hver sin målekabine omkring slagtekæden og 2 standard pc'ere, som beregner resultaterne. Målingen berører ikke kyllingen og er ved omhyggelig kalibrering meget robust. Visionsystemer er i dag velafprøvet teknologi og meget udbredt til overvågning, kvalitetsmåling og sortering i industrien. I kødindustrien har de været i rutinemæssig brug til lovpligtig klassificering og afregning af især kvæg i 13 år. Visionsystemer til kvæg anvendes f.eks. i Danmark, Irland og Frankrig, hvor der er en meget lang erfaring med systemerne som driftsikre, med lang teknisk levetid og med robuste komponenter.

Klassificeringssystemet måler slagtevægt, total brystfiletvægt og total filetudbytte, baseret på billeder af den enkelte slagtekylling. Det kan måle alle kyllinger ved aktuelle slagtehastigheder (op til 12.000 kyllinger/time) og kan i normal drift levere måleresultater for ca. 98 procent af kyllingerne. Ved den høje slagtehastighed vil præsentationen af den enkelte kylling ikke altid være optimal og tolkning af billederne ikke tilstrækkelig sikker og derfor er antal målte kyllinger ikke helt 100 %. Ved en afregning på flokniveau, som i Danmark, er præcisionen ud fra det målte antal kyllinger dog mere end rigelig.

Afregning baseret på klassificering med VTS2000 kan ved flokke på f.eks. 2.000 kyllinger ske med en præcision af flokkens gennemsnit på 3,1 gram for slagtevægt, 0,06 % for filetudbytte og 1,7 gram for filetvægt. Ved en flokstørrelse på 30.000 kyllinger vil resultaterne tilsvarende være 0,8 gram for slagtevægt, 0,02 % for filetudbytte og 0,4 gram for filetvægt (se tabellen) Med præcision menes, at den sande værdi med 95 % sandsynlighed ligger inden for målingen ± den angivne præcision. Det ses, at afregningen vil være endog meget præcis for både store og små flokke.

	Præcision af flokgennemsnit med 95 % sikkerhed		
Flokstørrelse	Slagtevægt	Total filetudbytte	Total filetvægt
2.000	3,1 gram	0,06 %	1,7 gram
30.000	0,8 gram	0,02 %	0,4 gram

Etablering af et fair afregningssystem forudsætter desuden, at der er høj grad af tillid til, at klassificeringssystemet sikrer ensartet klassificering mellem udstyr/slagterier og over tid. Udviklings-projektet har dokumenteret, at slagtevægt, filetvægt og filetudbytte inden for små marginaler kan måles ens på forskellige udstyr opstillet på forskellige slagterier. Som forventet er det dog også vist, at større ændringer og variationer i slagteprocesserne frem til udstyret kan påvirke målingerne. Det er derfor vigtigt, at klassificeringen løbende overvåges med henblik på at påvise og justere for eventuelle skred i målingerne så tidligt som muligt. Systemovervågning af målesystemer til klassificering er velkendt fra både svin og kvæg. Det foreslås at etablere en uafhængig kontrol af klassificeringen baseret på de principper, som er beskrevet i projektet.

Afregning baseret på VTS2000 klassificering har flere væsentlige fordele i forhold til den nuværende afregning, som er baseret på brovægten af transportbiler med levende kyllinger. For det første bliver afregningen uafhængig af den usikkerhed, som vejning af levende kyllinger i biler medfører, samt den variation som forskelle i fodring, vejrlig og staldforhold ved levering kan afstedkomme. I stedet afregnes der efter målesystemets standardiserede vægtestimat for de slagtede kyllinger, hvilket bedre afspejler kyllingernes værdi. For det andet måles også vægt og udbytte af brystfileten, som udgør en stor del af kyllingens salgsværdi. Det giver mulighed for at afregne mere værdifulde kyllinger (med mere brystfilet) højere. De nye informationer om mængde, kvalitet og værdi kan umiddelbart anvendes som tilbagemelding til slagtekyllingeproducenterne i forbindelse med afregningen. I takt med at der opnås erfaring med klassificeringsparametrene og der træffes beslutning om modeller for en afregning baseret på slagtevægt og filetudbytte kan det nye og det gamle afregningssystem med fordel køre parallelt i et stykke tid inden der skiftes til det nye afregningssystem. Herved kan konsekvenserne for producenterne på forhånd vurderes.

Klassificeringssystemets målinger er kalibreret overfor referenceopskæringer af Ross 308 kyllinger med stor variation i vægt (ca. 1.000 – 3.000 gram slagtevægt) og total brystfiletudbytte (ca. 27 – 34 %). Præcisionen af målingerne af *den enkelte kylling* er vist i tabellen.

	Målefejl	Præcision med 95 % sikkerhed
Slagtevægt	70 gram	± 140 gram
Total brystfiletvægt	38 gram	± 76 gram
Total brystfiletudbytte	1,38 %	± 2,76 %

Det er i projektet undersøgt om målingerne er tilstrækkeligt præcise til sortering på slagteriet til forskellig anvendelse eller forskelligt indstillet procesudstyr. Præcisionen af slagtevægt vurderes at være tilstrækkelig til *individuel sortering* på slagteriet. Præcisionen af filetvægt og -udbytte vurderes ikke at være tilstrækkelig til individuel sortering af kyllinger, men der kan muligvis opnås en fordel ved at sortere flokke baseret på deres gennemsnitsværdier. Udnyttelsen af målinger på enkeltkyllinger internt på slagteriet vil forudsætte, at der etableres fuld sporbarhed i proceslinjerne eller opsætning af ekstra måleudstyr umiddelbart før sorteringen. Tabellens tal illustrerer, at afregning på enkeltkyllingniveau ikke vil være hensigtsmæssig, hvorimod afregning på flokniveau vil være udmærket, da præcisionen på flokniveau som anført tidligere er meget høj.

Klassificeringssystemet kan desuden give supplerende informationer af værdi for producenter og slagterier. I projektet har en mindre undersøgelse vist, at det er muligt at registrere defekter på vinger og skind på brystet. Dette kan øge informationsniveauet og anvendes som benchmark for producenter, indfangning og transport. Registreringerne er begrænset af, at overlappende vinger medfører, at ikke alle billeder kan analyseres. Desuden er den visuelle reference for defekterne svær at etablere. Det vurderes dog, at de nye informationer om defekter på flokniveau har en kvalitet, som kan bidrage til at producenter, fangere, transportører og slagterier kan benchmarke deres resultater og dermed forbedre deres produktion. Slagteriet kan desuden benchmarke sin daglige drift f.eks. ved overvågning af tomme bøjler, som også registreres automatisk.

Projektet er afsluttet i november 2010 hvor en enig styregruppe har tilsluttet sig denne vurdering af mulighederne for den danske slagtefjerkræbranche ved brug af objektiv måleteknologi og værdibaseret afregning.

Short summary and recommendations

The project's goal has been to develop and document an objective measurement system for value-based payment of broilers. A vision-based classification system (VTS2000 from E+V Technology GmBH) was developed and tested at Rose Poultry's slaughterhouse in Vinderup and Lantmännen Danpo's slaughterhouse in Aars.

The project has shown that the developed VTS2000 classification system is suitable for implementation on Danish poultry slaughterhouses and that the payment to the chicken producers can be based on system measurements on flock level. The classification system is recommended as a basis for establishing a new payment system, which includes new information on carcass weight and total breast fillet yield. This allows the payment reflect both size and quality (lean meat) and thus the value of the chickens better than the current payment system. Based on the principles described in the project, a new payment system can be established. Using the measurement system and a new payment, it is expected possible to optimize the overall economy in the broiler industry. There may be new quality information to the producers, which then can adjust production and the slaughterhouses get much better chance on an objective basis to differentiate the payment after the product quality delivered.

The VTS2000 is measuring by taking a picture of the front and back of each chicken on the slaughter line after plucking and before evisceration. The measurements are based on analysis of these images from the chicken dimensions and shapes. The equipment consists of 2 cameras mounted in a measuring cabin each around the slaughter line and 2 standard PCs, which calculates the results. The measurement does not affect the chicken and by careful calibration is very robust. Vision systems are well proven technology and widely used for surveillance, quality measurement and sorting by the industry. In the meat industry they have been in routine use for regulatory classification and payment of mainly cattle for 13 years. Vision systems for cattle are used for example in Denmark, Ireland and France where there is a very long experience with the systems as reliable, with long life span and with robust components.

The classification system measures carcass weight, total breast fillet weight and total fillet yield, based on images of each chicken. It can measure all chickens by current slaughter rates (up to 12,000 chickens/hour) and are capable of delivering measurements during normal operations for approx. 98 percent of the chickens. At the high slaughter rate the presentation of each chicken will not always be optimal and interpretation of the images not sufficiently secure and therefore the number of measured chickens are not quite 100%. In a payment on flock level, as in Denmark, the precision of the measured number of chickens is, however, more than enough.

Payment based on classification with VTS2000 can, by flocks of for example 2.000 chickens, be with a precision of the flock average of 3.1 grams of carcass weight, 0.06% for fillet yield and 1.7 grams of fillet weight. At a flock size of 30.000 chickens, the results will be equivalent to 0.8 grams for carcass weight, 0.02% for fillet yield and 0.4 grams of fillet weight (see table below) Precision means that the true value with 95% probability lies within the measurement ± the indicated precision. It can be seen that the payment will be very accurate for both small and large flocks.

	Precision of flock mean by 95 % probability		
Flock size	Carcass weight	Total fillet yield	Total fillet weight
2.000	3.1 gram	0.06 %	1.7 gram
30.000	0.8 gram	0.02 %	0.4 gram

Establishing a fair payment system also requires that there is a high degree of confidence that the classification system ensures uniform classification between equipments/abattoirs and over time. The project has demonstrated that carcass weight, fillet weight and fillet yield within small margins can be measured the same on different equipments installed in different slaughterhouses. As expected, it is also shown that major changes and variations in the slaughter process before the equipment can affect the measurements. It is therefore important that the classification is monitored continuously to detect and adjust for any drift in measurements as early as possible. System monitoring of measurement systems for the classification is well known for both pigs and cattle. It is proposed to establish an independent control of the classification based on the principles outlined in the project.

Payment based on VTS2000 classification has several significant advantages compared with the current payment, which is based on transport cars with live chickens being weighed on weighbridges. First, the payment is independent of the uncertainty by weighing live chickens in cars and of the variation caused by differences in feeding, weather and stable conditions at delivery. Instead the payment is based on the measuring system's standardized weight estimate for the slaughtered chickens, which better reflects the chickens' value. Secondly, the weight and yield of the breast fillet, which constitute to a large portion of chicken sales value, is also measured. It allows for paying more valuable chickens (with more breast fillet) higher. The new information on the quantity, quality and value can be directly used for feedback to the broiler producers in connection with the payment. As experience is gained with the classification parameters and models for a payment based on carcass weight and fillet yield it is decided, the new and the old payment system advantageously can run parallel for a while before changing to the new payment system. Thereby the consequences for the producers can be assessed in advance.

Classification system measurements are calibrated on reference cuttings of Ross 308 chickens with large variation in weight (approximately 1,000 to 3,000 grams of carcass weight) and total breast fillet yield (approx. 27 - 34%). The precision of the measurements of each chicken is shown in the table.

	Measurement error	Precision with 95 % probability
Carcass weight	70 gram	± 140 gram
Total breast fillet weight	38 gram	± 76 gram
Total breast fillet yield	1.38 %	± 2.76 %

The project has examined whether the measurements are precise enough to sort for different uses or different setting of process equipment at the slaughterhouse. The accuracy of carcass weight is estimated to be sufficient for individual sorting at the slaughterhouse. The precision of fillet weight and yield is assessed not to be adequate to individual sorting of chickens, but there may possibly be a gain by sorting flocks based on their average values. The utilization of measurements on single chickens internally at the slaughterhouse will require the establishment of full traceability in process lines or installation of additional equipment immediately before sorting. The table's figures illustrate that the payment at individual chicken level would not be appropriate, whereas payment on flock level will be excellent, since the precision on the flock level as mentioned earlier is very high.

The classification system can also provide additional information of value to producers and slaughterhouses. During the project a small study showed that it is possible to detect defects on the wings and the skin of the breast. This may increase the level of information and be used as a benchmark for producers, catchers and transportation. Registrations are limited by overlapping of wings, which causes that not all images can be analyzed. Moreover, the visual references of the defects are difficult to establish. It is estimated however that the new information on defects at flock level has a quality to help producers, catchers, transporters and slaughterhouses to benchmark their performance and thereby improve their production. The slaughterhouse can also benchmark its daily operation for example by monitoring the empty hangers, which are also automatically recorded.

The project is completed in November 2010 where the project steering group has agreed with this assessment of the prospects for the Danish broiler industry through the use of objective measurement technology and value-based billing.

Contents

Background

In the Danish poultry industry, payment of broiler chickens is by live weight in flock. The trucks with live chickens are weighed on a bridge scale and the weight of the truck and the cages are subtracted. That gives a high degree of uncertainty in the estimation of the weight of the chickens. To a varying degree, rain, snow, chicken manure etc. is also being paid for.

Furthermore, only the weight of the whole chickens is being paid for, but the value of a chicken also depends on especially the amount of the most valuable part – the breast fillet. The breast fillet yield as percent of the chicken is influenced by the nutrient content in the feed for example represented by the amount of wheat. Presently producers that use special feed with better nutrient composition can get an extra payment but generally producers who want to do something extra for the value of the chickens (for example by feeding) are not rewarded for that extra quality.

By introducing a quality classification of chickens, it will be possible to base the payment on quality characteristics that are important for the product value. By rewarding chickens with higher product value, it will be possible to improve the quality and thereby the value of the entire raw material for the benefit of both slaughterhouse and producer.

Moreover, the classification can be used in sorting of the raw material for different use (products) and thereby the most optimal use of a given raw material can be achieved.

Classification and payment by quality is known from the pig and cattle industry. Vision technique is used in classification in the cattle industry.

The project included classification of Danish broiler chickens (Ross 308). Vision technique was tested as measuring method.

Aim

The aim of the project was to develop and test a vision-based classification system for assessing the carcass composition of broiler chickens. The system was to be installed on the slaughter line at Danish poultry slaughterhouses.

A system for quality assurance of the classification was to be developed. On the basis of classification data, a payment model based on the sales value of carcasses was to be developed. The objective of the classification and payment system was to create the basis for a fair payment to the producers as well as optimized supply of raw material, utilization of raw material and consequently improve earnings in the entire chicken industry.

The project

Partners

The project was carried out in a cooperation between:

- The Danish Poultry Council
- E+V Technology GmBH
- Rose Poultry A/S
- Lantmännen Danpo
- Danish Agricultural Advisory Service
- DMRI, Danish Technological Institute

Financing

Financially the project was supported by:

- The Danish Innovation Law
- The Danish Poultry Levy Fund
- Rose Poultry A/S
- Landmännen Danpo
- E+V Technology GmBH

Content summary

In this chapter the content of the project is described as a summary. More details including detailed results will follow in the next chapters.

The project was carried out in four phases:

0. Specification of requirements
1. Development of methods and proposal of classification model
2. Functional test and proposal for payment model
3. Control system and implementation plan

Phase 0

Phase 0 included a two day brainstorm meeting with representatives for the chicken producers and the project partners. This phase also included a technical review and description of the four Danish chicken slaughterhouses owned by Rose Poultry and Lantmännen Danpo. The purpose was to evaluate where and how the vision equipments could be installed.

Phase 1

In phase 1, a test version of the vision equipment was installed and tested at the Rose Poultry slaughterhouse in Vinderup. A special production of chickens was measured with the equipment resulting in two pictures of each chicken. Based on the pictures a number of measurements were calculated (the “predictors”). After the measurements, the chickens were cut in parts and the parts were weighed (“reference cutting”). Based on weighing data and the predictors, the first equations for prediction of slaughter weight, total breast fillet weight, total breast fillet yield and weight and yield of a number of other parts were developed (the “classification equations”). The precision of the equations were evaluated.

After phase 1, the preliminary results were evaluated by the project and the steering group. It was decided that the results were so promising that the project could continue.

Phase 2

In phase 2, a second vision equipment was installed and tested at the Lantmännen Danpo slaughterhouse in Aars.

Chickens from four houses at one producer were split in half and slaughtered and classified with the vision equipments in Vinderup and Aars ("split delivery") and the classification results for the two equipments were compared.

Both systems were tested under normal production conditions and were adjusted to make them measure as equal as possible.

A new reference cutting was performed to validate the first classification equations. A special production of chickens was produced, the group was split in half and slaughtered and measured with the vision equipments in Vinderup and Aars respectively. The chickens were cut and weighed as in phase 1. Based on the results it was decided to develop new classification equations based on the phase 2 reference cutting.

A system for classification of skin and wing damages was developed and tested.

A model for payment to the chicken producers based on the classification were discussed and described. The payment model is not ready to use as some commercial parameters needs to be implemented before it is complete. Furthermore final correlations between slaughter weight and total breast fillet yield need to be established.

Phase 3

In phase 3, the robustness of the developed classification equations was tested when selected production parameters were changed.

A system for independent control of the classification was described.

In case the Danish chicken industry chooses to implement vision classification and payment based on the classification, an implementation plan was proposed.

Specification of requirements

Brainstorm seminar

One of the first activities in the project was a two-day brainstorm seminar in June 2007 with representatives from the slaughter companies, the producers and the project.

Three persons from Rose Poultry, three persons from the Rose Poultry producer association (LRP), two persons from Lantmännen Danpo, one person from the Lantmännen Danpo producer association (Prodan), one person from E+V Technology, two persons from Danish Agricultural Advisory Service and four persons from Danish Meat Research Institute (now Danish Technological Institute, DMRI) participated in the seminar.

The purpose of the brainstorm seminar was to discuss and identify both short and long term benefits from using a classification system for payment, processing and sorting. That implied that not all identified ideas necessarily would be included in the development project as they might be too technically complex, too expensive or otherwise lie outside the scope of the project. The brainstorm results served as background for determining the first draft of the Requirement specification, which was followed by a technical review of what was feasible on all the Rose and Danpo plants.

The seminar agenda was divided in four areas (work groups):

1. Payment by quality – why, what (and how)?
2. Definition of population (animal material)
3. Sorting and process control
4. Technique (capacity, % classified animals, up time, output/reports)

In the following the main results from the four areas are described in key words.

1. Payment by quality – why, what (and how)?

Payment today

Live weight of all animals in trailers - weighbridge.
Some supplements and deductions for weight, zoonoses, quality of foot pad, etc.

- advantages

- Simple and easy to do.
- Accepted by the producers.
- Weight is measured before the chickens enter the abattoirs – payment is independent of traceability and handling in the abattoir.
- Same way on all abattoirs.

- disadvantages

- Dirt, water etc. are included in the weight (more payment on days of rain or snow!).
- No (or almost no) payment by product quality.
- A cheaply produced chicken (e.g. by excessive addition of whole wheat in feed) can be “expensive” for the abattoir.
- Flock uniformity (small standard deviation) of e.g. weight cannot be rewarded.
- Many supplements and deductions are based on subjective evaluations on very few samples of a large batch.
- Follow up and guidance to farmers by consultants in the industry is not related to product quality.

Future payment parameters

- Grill weight (weight of carcass without intestines/viscera, feathers, head and feet).
- Weight of breast filet.
- Uniformity (depending on raw material demand from the abattoir).
- Shape of breast filet?
- Discolorations.
- Scratches and other skin damages.
- Foot pad damages / discolorations.
- Burns on hocks.
- Wing damages.
- Damages from machines.
- Meat percentage, distribution of meat in carcass, breast, drumsticks, wings.
- Fat content (abdominal fat).
- Second class (Definition?).
- Sex?

Comments

- Keep weighbridge as a control for a period after introduction of classification system!
- Introduce an independent control body to secure uniform classification (and payment).
- The payment should be related to what the abattoirs can sell in a changing market. Quality demands depend on consumer preferences.
- It is important to keep in mind at which weight production costs are minimized. Bigger animals will result in an increased need of nutrients for maintenance.

2. Definition of population (animal material)

Animal size today and in the future

Today:

- 750 – 3200 gram live weight (lower and upper limits).
- Mean weight is about 2150-2200 gram.
- Today there is a limitation of 3200 gram because of machines.

Future:

- 750 – 4500 gram live weight (lower and upper limits).
- Mean live weights:
  0-5 years: 2200 – 2300 gram
  5-10 years: 1600 – 2500 gram*

  *We expect that much more product differentiation is demanded in the future. The abattoirs need to handle different sizes on the same day according to customer demands.

- Different breeds: Ross, Hubbard, others (maybe slower growing breeds)? Expect different colours and shapes.
- Variation will be higher as the weight increase.
- We expect more chickens to be cut up and de-boned.

Factors of variation	Animal • Age • Sex • Breed Parent stock • Age of parent stock • Diseases in the parent stock • Frequency of floor eggs • Vaccination program in parent stock • Feeding of parent stock Hatchery • Storage conditions and storage time (eggs) • Hatching time (from start of hatch to end of hatch) – risk of dehydration • Sorting (eggs and hatched birds) • Transportation time (from hatchery to farmer) – chill and dehydration • Mixing parent stock age when chickens are placed Management in the starter period • Temperature and humidity – risk of dehydration • Air quality (CO_2) level • Water quality and availability • Time of feeding after hatching • Feed quality (nutrient content, physical structure, hardness) and availability • Light programmes Management in the remaining growing period • Temperature and humidity (too high temperature decreases feed intake) • Air quality (high NH_4 levels reduce feed intake) • Water quality and availability • Feed quality (nutrient content, physical structure, hardness) and availability • Light and feeding programmes • Insufficient killing of small and unfit birds • Stocking density Diseases / Hygiene • IB • Coccidiosis (clinic and subclinic) • Necrotic enteritis • E. coli (to late treatment) • Leg health (Femoral head necrosis, rachitis, TD) • Influenced by cleaning and disinfection • Bad litter quality • Empty period between flocks

Vaccination

- IB (Infectious Bronchitis)
- Coccidiosis

Partial depletion - difficult to continue high feed intake in the remaining flock of birds.

Comments

Variation at the abattoir

- Variation in slaughter shrinkage is ½ - 1 % on daily basis
- Variation in breast yield is 0 - ½ % on daily basis

Most important factors of variation

- Sex
- Diseases
- Management in the starter period (temperature, water and feed availability)
- Mixing birds with different parent stock age
- Nutrient content in the feed
- Hatchery conditions

3. Sorting and process control

Potential sorting attributes

- Carcass weight (= grill weight)
  - Estimated
  - Weighed
  - Precision: A guess is 25-50 gram (average weight needs to be more precise for a payment system)
  - Best estimation by vision after plucking (before evisceration)
- Weight of breast meat etc.
  - Precision: 0.1 % (gut feeling), Caps: 20-30 g.
  - Breast weight relative to grill weight
  - It is of great importance to have quality info e.g. on grill weight , caps and thighs 1½-2 hours before cutting in order to adjust the production dynamically according to the flow. This information is available too late today to use with present sorting systems.
- Weight of wings
- Weight of drumsticks. Drumsticks are presently dynamically weighed 280/minute but the procedure is not optimal to match 1 kg packages. Early information on weight / percent may improve this sorting and thereby losses due to overweight.
- Feet burns/colour. Resources are spent on sorting and quality evaluation. It was discussed whether *early* measurement/sorting could be of value for the final sorting or to the producer or if it is necessary to measure *late* in the process for final product quality and correct scoring.
  - Sorting, payment, welfare.
  - Today 4 classes.
  - Sorting and packing after plucking.
- Wings broken and missing, different colours depending on time of damage. Both a quality and welfare issue. Useful information to improve catching team performance and avoid “red spots on wings”. Broken/damaged wings may occur from incorrect setting/performance of the slaughter process. Early warning and

alarms to readjust will allow reduction of damage. Today resources are spent in manual sorting. Feathers remaining on the wings are also of customer importance and influence allocation of wings e.g. cooking/sawing.

- Skin damage - scratches on the back from other birds.
  - Commercial value?
  - Welfare.
- Are heads not taken of? -> Alarm
- Empty hangers
- Missing hangers
- Acceptable plucking
- Animal welfare control
- After spraychiller: A and B quality (definitions?)
- Veterinary quality inspection. It was discussed that the system may aid the visual inspection which is very difficult at high speeds. However this may be followed up and accepted better in a dedicated joint project with the authorities. For the meat plant however, it could be of high importance to remove birds/carcasses from the line even before veterinary inspection. This would reduce potential contamination; ease the task for both the veterinary inspection and further quality sorting in the process. Therefore it would be interesting if the camera system could point out birds that would never be fit for consumption/marketing early to be used for an automatic system that would sort out these birds early in the process. A stored image of the bird with quality defects visible should be sufficient documentation for the farmer if there are disputes on the payment of removed/condemned birds by the vision system.

New products / market opportunities

- Uniformity?
- Higher quality?

Process control

- Better definition of sorting groups for machines
- In the short term, some plants will have several sorting systems (dynamic weighing scales etc.) and will apply buffer storage prior to e.g. caps cutting. In the longer term, lines will be more integrated and the benefits of having precise information for processing the individual bird will become even more important. Therefore any information that can contribute to reducing number of processes and manual handling are of importance
- Adjustment of cutting and deboning machines to the individual bird.
  - An important factor is individual identification throughout the production line. Linking vision results to the individual carcass further in the slaughter/deboning/cutting/packing process requires traceability between the different conveyor parts. It should be assessed to what level this is feasible and how the complexity level and costs of doing so are. Based on reports of this it should be decided to what extent it becomes part of the project. (Adjustment times for cutting machines for chickens at 300 ms/animal (12.000 animals/hour) should be possible for simple knife adjustments)

- Information on raw material 1½ hour before packing. Allows for some adjustment in the production

Comments

- Special camera for feet measurement might be a solution.
- It is recommended that measurements are done the same way and at the same place in all abattoirs. Individual solutions are too costly.
- If control of head taken of is included in the same picture, the solution (accuracy) of the rest of the carcass is less. Therefore, a special camera/sensor may be an option.
- Can the full wings be seen by camera? In a trial using attached yellow id bands on wings showed that they were difficult to find again.

4. Technique (capacity, % classified animals, up time, output/reports)

Capacity

12.000 carcasses/hour (300 ms/carcass).
Up to 4.500 g live weight. Range 750-4500g.

% classified

If the presentation is correct: 95 % for both payment and internal use at the abattoir.

Individual attributes may have different priority, if computer capacity is a limiting factor.

Wings may overlap and reduce % classified with up to 50 %. How information is to be used (batch figures, dynamic process adjustment or adjustment to processing the individual bird) will determine the measuring methodology (number of cameras, angles, distances, presentation of carcass, or carcass part).

Response time

Demands for response time depend on type of information.

It is possible to calculate weight yield, broken wings etc. in 300 ms (equal to 12,000 chickens/hour). Computer capacity is increasing very fast so even if calculations that are more complex are included it is not expected to be a problem.

Down time (time where system is not working)

We were not able to give a final demand on down time. It depends on the alternative actions/options to be taken for missing results.

In practice the down time will probably be very small since there are no moving parts and cameras are very robust. Experience is that most down time is caused by simple mistakes like cleaning water on the camera lenses, changes in the lighting etc. Things which can be corrected by the plant technicians assisted by remote monitoring and service advice

Service contracts, local store of spare parts and online connection from E+V to abattoir will greatly reduce the down time.

Estimated down time is in total 1 day / year.

Interfaces
- Change between flocks – signal to Navision.
- Data saved by flock / farmer for 31 days.

In the final system, it is not possible to save the individual pictures on the same computer as the calculated classification attributes – not enough capacity. An alternative may be video recording (tape or other) by a separate video output from the cameras (as seen at Velisco). During the project, all individual pictures will of cause be saved.

Output, reports, statistics
- For payment.
- Curves of distributions.
- Means over e.g. 2000 animals.
- Report on A and B quality.
- Output to spreadsheets.
- Standard output plus individual output made ad hoc. by abattoir.

Conclusion
The above results served as inspiration for the project. Many of the issues were taken into account in the project as described later. Other issues were decided left out of the project and the above list can serve as inspiration for future focus areas.

Among the more important issues left out are veterinary control, foot pad quality and implementation of sorting based on classification data.

The slaughterhouses

Technical documentation

The three Rose Poultry slaughterhouses in Padborg, Vinderup and Skovsgaard (Brovst) and the Lantmännen Danpo slaughterhouse in Aars were all visited in July 2007 for a documentation of the technical environment where the vision equipment were to be installed.

A report for each slaughterhouse was written. The following was concluded:

1. The actual line speed varied between 142 and 170 chickens/minute. All plants aim at 200 chickens/minute in the future.

2. At the time of the year and time of the day of the visiting at the four plants, no heavy steam was observed. However, high humidity found especially in the plucking area can divert into fog and steam in case of a temperature drop at a different time and situation.

3. In Aars, Vinderup and Brovst the head cutter is positioned before or in-between plucking. Only in Padborg the head cutter was after plucking in this case even after the feet cutter/re-hanger after the plucking room in order to keep the heads separate from the feet, which also is in discussion in the three other slaughterhouses.

4. In all four slaughterhouses in each area documented, no "daylight" has been found which could affect a vision system.

5. In each slaughterhouse an atmosphere of continuously new planning and rebuilding was found. Therefore the technical documentation should be reviewed from time to time.

6. In all four plants the distance between shackles in the kill line was 6 inches, whereas further on the shackle distance varied between one line with 6 inches and two lines with 12 inches (see table below).

Distance between shackles in inches

Plant	Kill line	Evisceration line	Chill line	Weighing line
Padborg	6	6	(water chill)	8
Vinderup	6	6	6	8
Brovst	6	6	6	2 x 12
Aars	6	6	6	8

7. All four plants have a network in place with a possibility for a VPN-connection.

The vision equipment

The vision equipment is a chicken classification and grading system VTS2000 with two cameras produced by E+V Technology GmbH (www.eplusv.com). The equipment is placed on the slaughter line after plucking and before evisceration. The two high speed video cameras are taking a picture of the back and a picture of the front of the chicken (figure 1). The pictures are analysed by software which calculates a number of points, distances, areas and volumes resulting in a total of 256 “predictors”. The predictors are the basis for the classification equations (see later). The equipment can handle line speeds up to 12,000 chickens/hour. For technical description see below.

Figure 1. Pictures of back and front of the chicken taken by VTS2000 system

Integration

The equipment stores pictures, predictors and classification parameters on the equipment computers but data can also be transferred to the administrative systems of the slaughterhouse.

Education of personnel

Education of the operators of the two test vision equipments in Vinderup and Aars was carried out by E+V. Rose and Danpo will themselves write educational material for future operators and for the technical maintenance personnel based on the technical documentation and the user manual.

Technical description of the chicken classification and grading system VTS2000

1. Generals

The VTS 2000 is a fully automatic system for classification and grading of chicken carcasses. The system is based on digital video image analysis.
The major components are:

- the cameras
- the lamps
- optical sensors
- image analysis computers
- stainless steel boxes with green back plates

2. Procedure of measuring and data management

The system consists of two camera stations. The first camera will take a picture from the back and the second from the front of the chicken. The detection of the carcasses/shackles is made by optical sensors just passing the grab position with no stop of the line or carcass.

The image analysis system analyses the digitised images.

The analysed data of the first (back view) station will be sent to the second (front view) station. The image analysis program at the second station commands all vision parameters and calculates all weight results and quality parameters. The results will be sent by standard network communication (socket) to the host and parallel for safety reason will be stored in ASCII data files on the local hard disk.

The essential requirement for a successful evaluation is complete synchronization. That means that both stations have to start their own evaluation processes with the same chicken carcass and keep the correct assignment of the carcasses until end of slaughter. In order to achieve that the first station (back view) sends all important control and flow information (start, stop, flock change) using the network (TCP) to the second station (front view) where it is handled with an appropriate delay to account for the different physical positions of the two stations on the line. In the rare case of an asynchrony between the two stations a test routine makes sure that this situation is recognized any synchrony is restored automatically. All tracing information is monitored and written to a protocol file in ASCII text format so that the normal working of the programs can be verified at any time.

The result information for every carcass is sent in the background to the plant IT. While doing that it is regularly checked whether the connection to the IT still exists. If the connection is lost all not yet transmitted data records are buffered and if the connection is re-established are automatically sent later to catch up. If the program is closed while there are still records to send those are stored locally on the hard drive and the user has the possibility at the next start of the program to choose whether these stored records should still be used for sending. This should prevent any kind of data loss.

The program contains the feature to save an image of every chicken on each of the two stations for archiving purposes. This allows a later visual analysis by the user and for instance the detection of broken wings. The program keeps track of these archive images and deletes them automatically after a certain period of time which can be set in the program.

A flock change is initiated on the first station using serial or TCP communication. This is in the cause of the personnel using a switch at the hanging station. There also the flock number is created. Using the internal shift register of the plant the flock change signal is sent immediately before the first VTS station. By using the internal communication between the two stations it is forwarded to the second station so that it takes effect there at exactly the same chicken when it reaches that station.

3. Data of the machine

type	:	VTS2000 Chicken
year of manufacture	:	xxxx
machine number	:	Ixxxxxxxxx

image analysing program

program version	:	VTS2000 Chicken Denmark, 10,9,15,0 – 1.3.0.0

4. Specification of the components

camera

number	:	2
type	:	true colour 3CCD RGB camera
resolution	:	>768x572
i.e.	:	Hitachi HV-D20

lamps

number	:	4 lamps, 4 light tubes for each station
type	:	tube luminaires (Waldmann RL70CE-136); IP67
ballast	:	electronically high frequency output

light tubes	:	Osram Dulux L 2G11 36W/840

optical sensor

number	:	4
type	:	Turck/Banner M18SP6DQ
cable	:	FB-WWAK4-10-FB /S2300

imaging PC

number	:	2
type	:	DELL standard PC 2800 MHz or higher
frame grabber	:	true colour, >768x572, i.e. ITI IC2- RGB
I/O card	:	I/O Port, optical connector
OS	:	Windows XP

5. Technical requirements

Electrical power : 220VAC 2500W

Telephone or network connection for remote control system and data exchange.

No air pressure or water is needed.

6. Other requirements

The maximum cable length from the camera to the vision computer is 20 m. Therefore the computer station should be near the camera stations. If it is necessary, the computers can be placed in an enclosure. Also even as the system is fully automatic during the operation it will need a system check every morning, where an operator needs to operate with the computer.

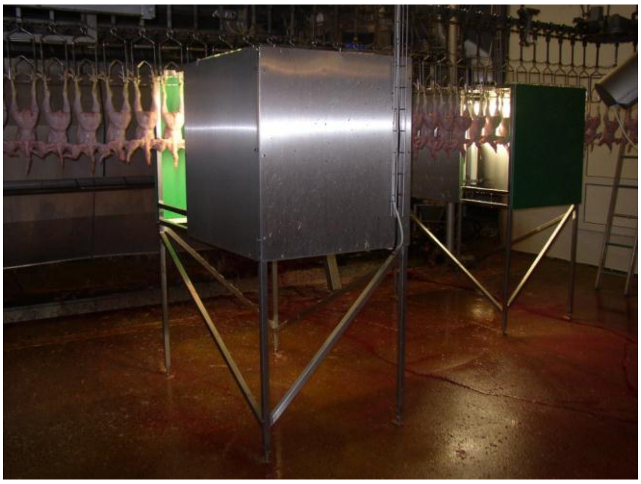
7. Standard functional measurements

The system requires a limited layout for all components in relation to each other. Usually the both stations are installed just one after the other. In this case there is only one lamp in the middle, 3 in total. However if necessary, depending on space, both stations can be separated.

8. Tolerances and possible adaptations

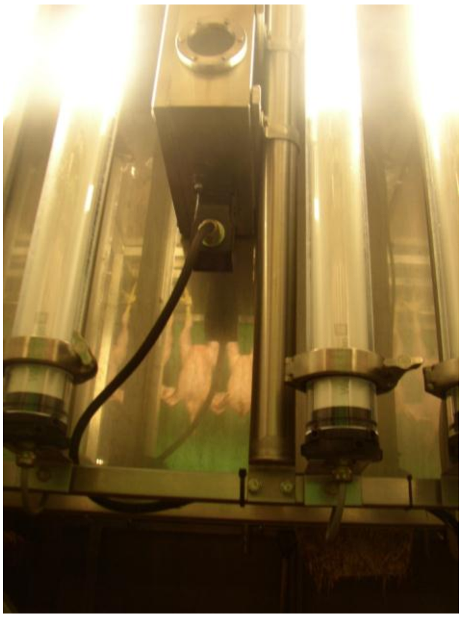
In most of cases the system will fit in a kill line with no or very minor changes with the standard functional measurements.

9. Pictures



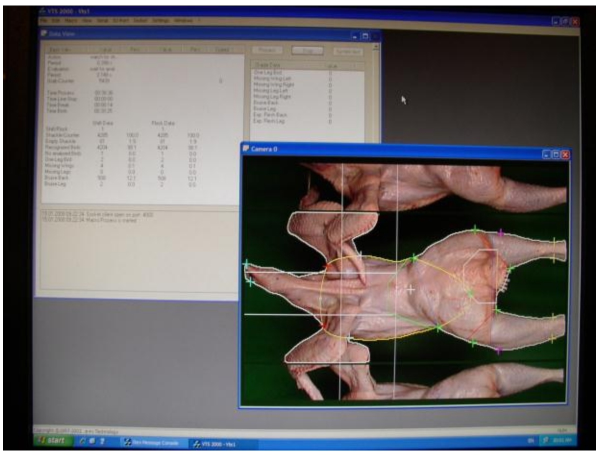
Picture 1. Stainless steel boxes: First station – back view, second station – front view

Picture 2. Box with camera, lamps and green back plate

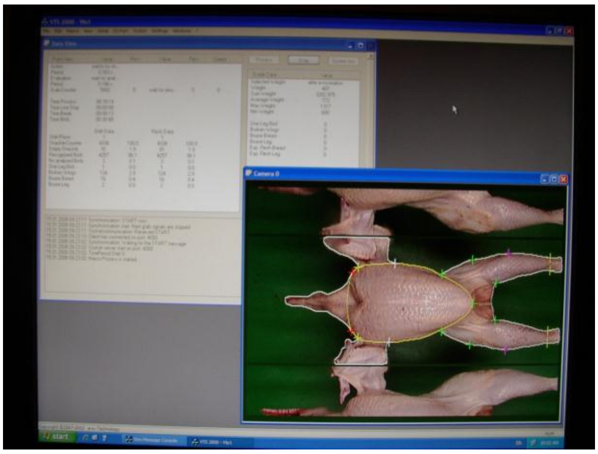


Picture 3. Camera and lamps in the box

Picture 4: Optical sensors

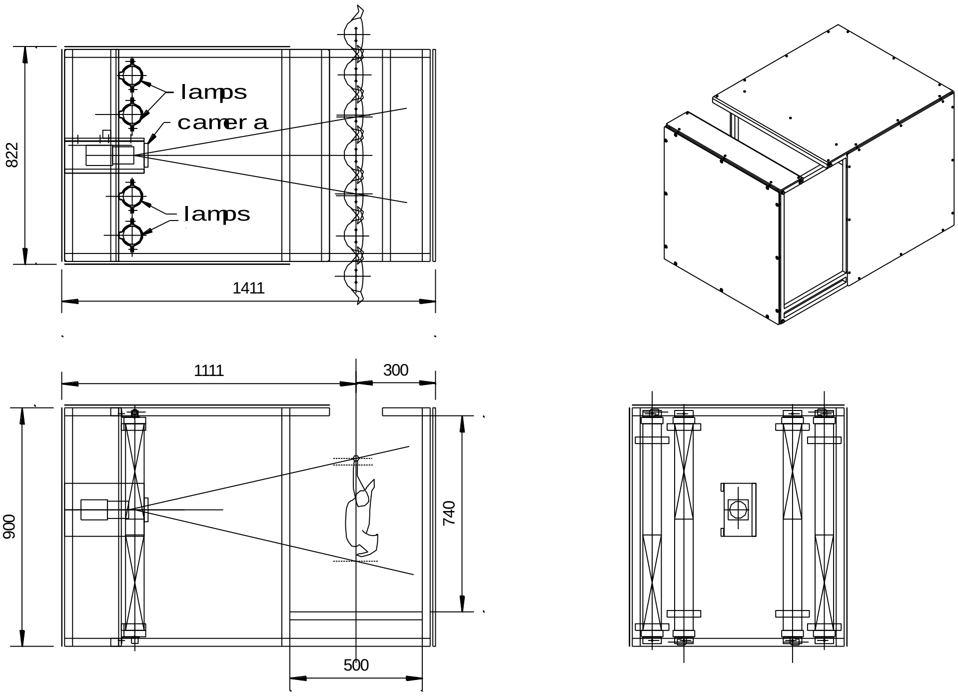


Picture 5: Program window back view



Picture 6. Program window front view

10. Layout



10. Further documentation

Further documentation includes:

- Quick Reference (see Appendix 3)
- Short manual (see Appendix 4)
- Menu overview (see appendix 5)

Equipment stability test

The two test equipments in Aars and Vinderup were tested for stability in daily production for one month reported below.

Test Period

01.07. -03.08.2010

Vinderup: 24 production days

Aars: 22 production days (on 13.07. and 03.08. no production)

Vision Program Version and Test Conditions

It ran the same program version under identical conditions on both systems:

- All archive images saved
- Deactivated virus scanner
- Activated Auto-Synchronisation
- Feature “Auto-Synchronisation-Restart” was activated beginning with the 12th of July
- Logging the data of the flocks and day production
- Aars: sending the record sets of all objects to the plant data base via company network

- Vinderup: sending the record sets of all objects to the data base on a separate computer via network.

Auto-Synchronisation

The front view station controls the Synchrony between the both stations and carry out correcting actions when asynchronicity is detected. A displacement of one or two objects can be readjusted. The main cause for asynchronicities are hooks, snaked with another, identified as one hook on one station and as two hooks on the other station.

Auto-Synchronisation-Restart

When the offset is greater than two objects the Auto-Synchronisation is not able to readjust. When such a condition is detected automatically a synchronised Restart is initiated: Both systems are restarted with the same object without assistance of an operator however the counters are not reset as done at ordinary start of production. It is assumed that the cause for such events is based in reorganisation processes of the computer operation system which the system is blocking for some minutes (an offset of 60 objects in three minutes was found).

All Auto-Synchronisation operations are logged.

Application of the VTS – Systems in Production Process

The VTS-system was started by operators on begin of the production days. However operating failures occurred what inhibited the data writing on such production days. In part this is caused by employment of inexperienced operators in vacation time.

Vinderup: On 8 of 22 days of production the same failure occurred on system start. After system check this macro was not stopped so that the macro continues ran and all objects were evaluated as calibration bodies. This caused the saving of about 80GB TIFF images on the disk drive. After two days the disk drive was completely filled.

Aars: On 8 of the 22 days of production no data could be obtained:

04.07: The photo eyes of the front view station did not work. After the repair the sensors had to be adjusted. This was realised in consultation with the slaughterhouse.

08.07. and 11.07: The system was non-synchronous started by the operator.

21.-27.07: The plant data base server was down for five days. As a result the record-sets of the vision program were saved on the local disk drive. But on a program start all non-sent record-sets on local disk drive are read in what consumes several time. The operator was not instructed about this fact. He assumed the program is crashed and terminated the program start.

Program Stability – Program Crashes

There were no program crashes in the equipments.

Synchronicity

Aars:

Evaluable data of production days: 14

Synchronicity till the end of the production day: 13

Asynchronicity: 1

Auto Corrections per production day:

  Minimum: none

  Maximum: 7

  Average: 1.07

Auto-Synchronisation-Restart: 4 days (4 x 1 case)

Vinderup:

Evaluable data of production days: 16

Synchronicity till the end of the production day: 15

Asynchronicity: 1

auto corrections per production day:

  Minimum: none

  Maximum: 4

  Average: 0.81

Auto-Synchronisation-Restart: 2 days (1 x 3 cases, 1 x 2 cases)

Evaluation Rates (rate of evaluated objects from detected objects) per production day

Aars:

Front View System

  Minimum: 99.70

  Maximum: 99.93

  Average: 99.86

Back View System

  Minimum: 99.43

  Maximum: 99.69

  Average: 99.59

Vinderup:

Front View System

  Minimum: 95.55

  Maximum: 99.84

  Average: 99.30

Back View System

  Minimum: 95.68

  Maximum: 99.84

  Average: 99.52

Conclusions

Stability: The system is applicable for daily production.

Asynchronicity: It was proved that the systems are able to run stable and synchronous the whole day using the Auto-Correction options. The both asynchronicities (Aars and Vinderup) occurred before the 12th of July (day of the activation of the Auto-Synchronisation-Restart feature). After this such restarts resulted a synchronized state.

Evaluation Rates: The evaluation rate is normally over 99.40%. Outliers (Vinderup on 13th of July: 95.55% and 95.68%) was caused by not cleaned camera windows in the break.

Operating Failures: We recommend doing an additional training for all operators including those who just operate the system during vacation time.
In both plants the normal trained operators have been in vacation.
Aars: The fallen down server was not restarted for more than one week.
Vinderup: The temporary operators were not trained in avoiding operating failures.

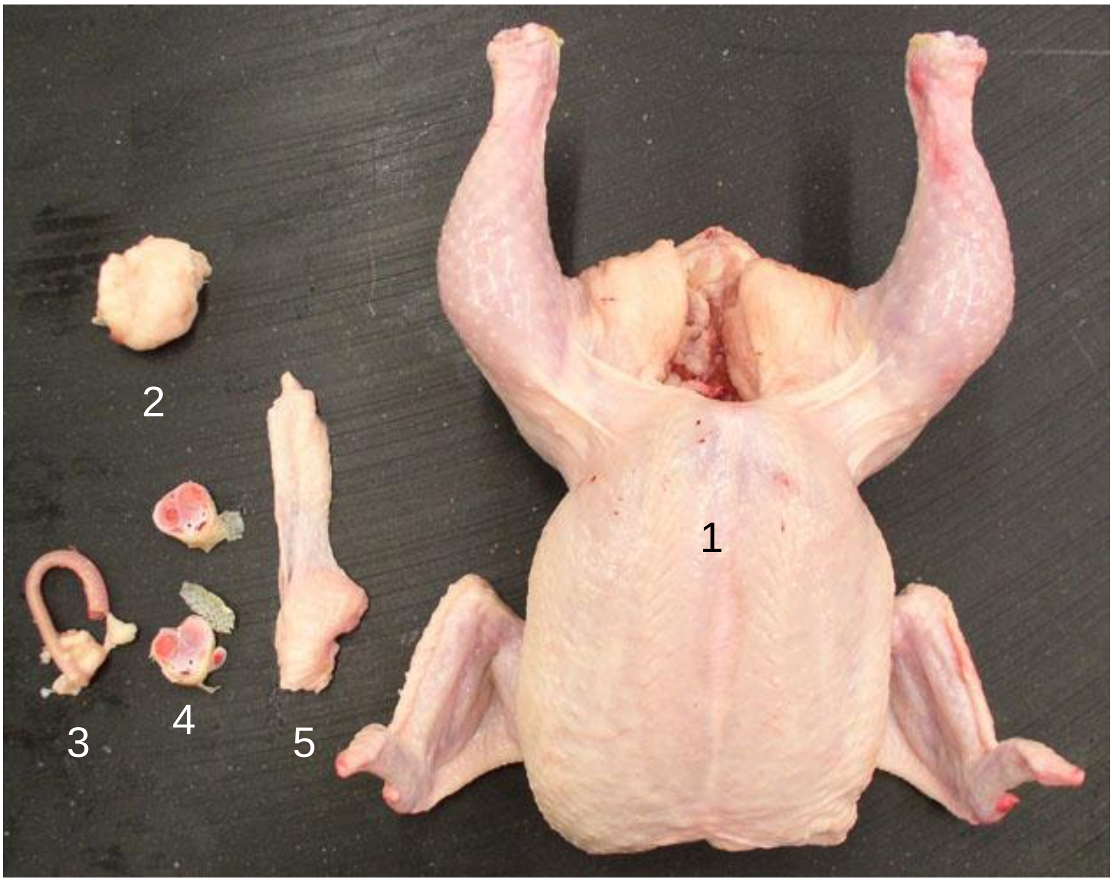
Recommendation: In order to avoid operator failures changes in program can be implemented:

- Deactivation of the reading of non-sent data from local disk drive
- Automatically termination of the system check when a chicken is detected as object

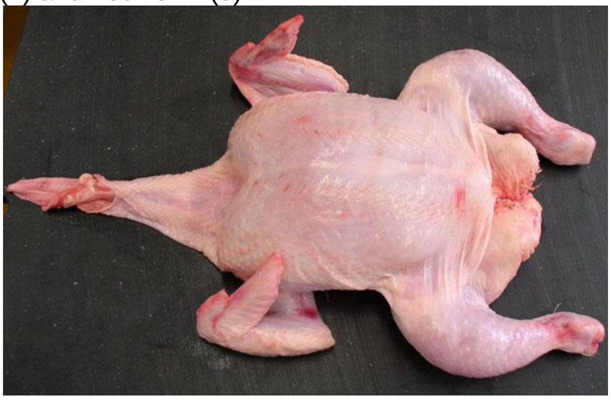
Classification equations for weights and yields

References

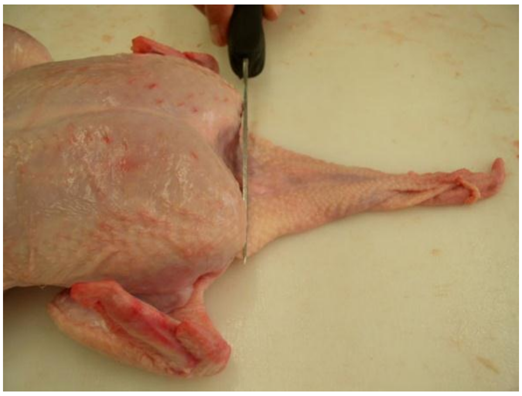
In order to make the vision equipments able to predict weights and yields of different parts of the chickens, references are needed. A standard reference cutting was therefore defined. At the reference cutting the slaughtered chickens were first cut to a “standard presentation” as shown in figure 2.



Standard presentation of chicken (1). Cut off are the rests of leaf fat (2), neck and oesophagus (3), feet (4) and neck skin (5).



The chicken is slaughtered, bled and plucked. Without head, feet and viscera.



The neck and neck skin are cut off in a straight line across where the filet is attached to the shoulder.

Remains of feet are cut off in the upper joint towards the drumsticks (= joint between *Tibiotarsus* og *Tarsometatarsus*).

Figure 2. Standard presentation of chicken

The weight of the chicken in standard presentation (weight of 1 in figure 1) is *the reference for the classification carcass weight*. But why measure/predict the carcass weight with the vision equipment? Why not just weigh the chickens on a scale? A predicted weight can – of course – never be as precise as a weight measured by a scale. A scale is very precise! The point is that a predicted weight allow the slaughterhouses to use different presentations of the carcass (more or less neck skin on, more or less feet on etc. etc.) but the farmers can still be paid by the same well defined weight (*the carcass weight in standard presentation*). The alternative is that all abattoirs *must* use the same – or almost the same – standard presentation of the carcass and the farmers can then be paid by a weight measured by a scale. The latter is done in the pig industry with *small* corrections made in order to compensate for differences in the slaughter process.

The chickens were then cut into parts as shown in figure 3.

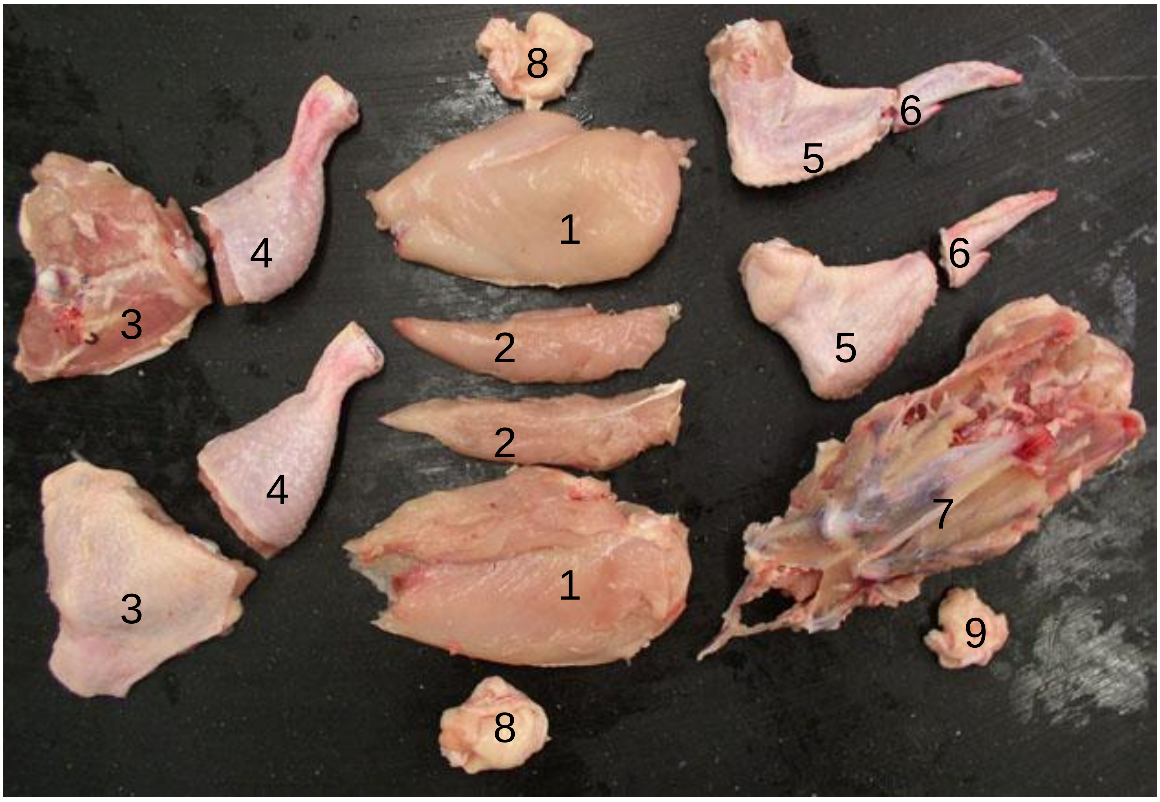


Figure 3. Reference cutting of chickens into parts. Outer and inner filet (1, 2) without skin and fat, thigh (3), drumstick (4), wing 2-joints (5) and wing tip (6), carcass shell (7) (seen from abdomen side), scraps (skin and fat) from filet (8) and scraps (skin and fat) from thigh (9)

All parts were weighed and after that the thigh and the drumstick were deboned as shown in figure 4 and the parts were weighed.

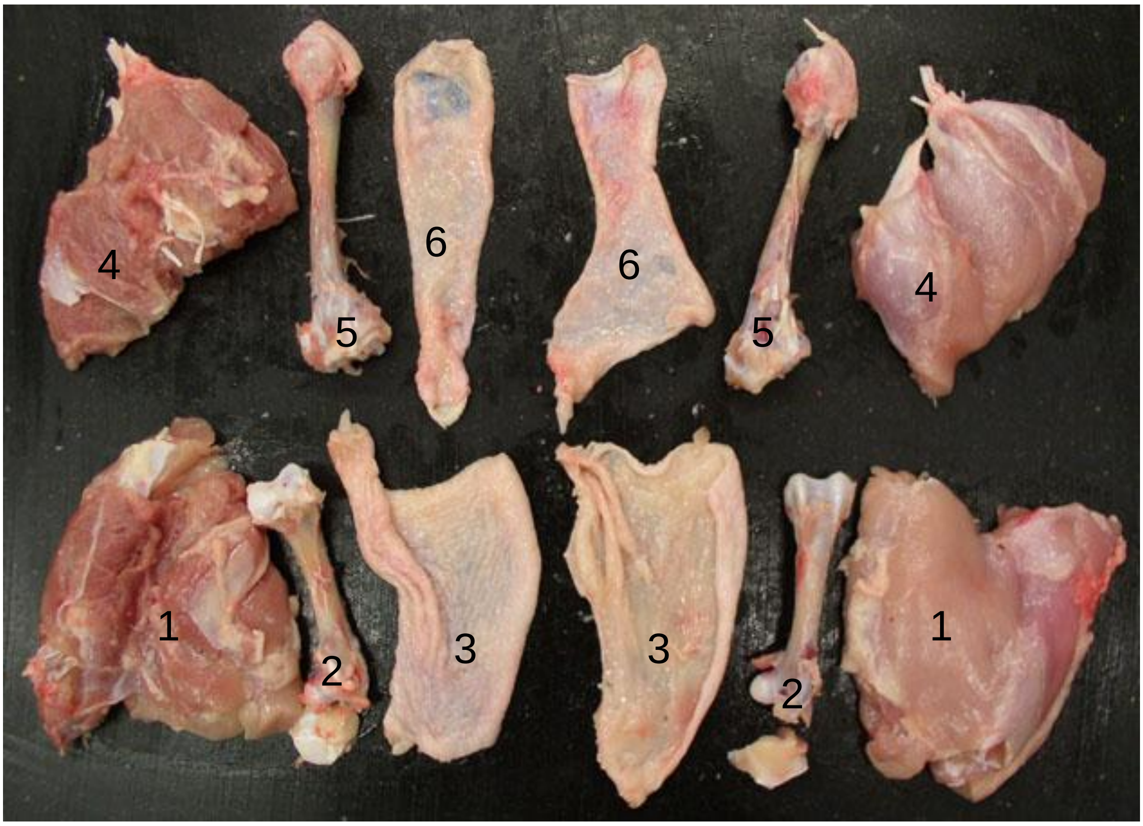


Figure 4. Deboning of thigh and drumstick. Boneless thigh without skin and fat (1), thigh bone (2), skin and fat from thigh (3), boneless drumstick without skin and fat (4), drumstick bone (5), skin and fat from drumstick

All the weights serve as references for vision equipment predictions of the weights. Furthermore the weights as percent of the carcass weight (in standard presentation) serve as references for the prediction of yields.

How good are the references?

Before any reference cuttings were made, the reference cutting method was evaluated in a pre-trial. The cuttings were made by two butchers at DJF, Foulum. They can of cause not make the cuttings totally exactly alike and the same way each time. This is important because it cannot be expected to make classification with any equipment more precisely than the references are made. The precision of the cutting can be expressed by the *repeatability* and the *reproducibility*. The repeatability describes how well the individual butcher can repeat his/her cuttings of the same animal. The reproducibility describes how alike different butchers can cut the same animal. The repeatability is included in the reproducibility.

In the pre-trial 60 chickens with large variation in weight were selected from Roses slaughterhouse in Vinderup. The chickens were cut to standard presentation as described above and then weighed. The mean carcass weight was 1,476.8 gram. The distribution of the carcass weight can be seen in figure 5.

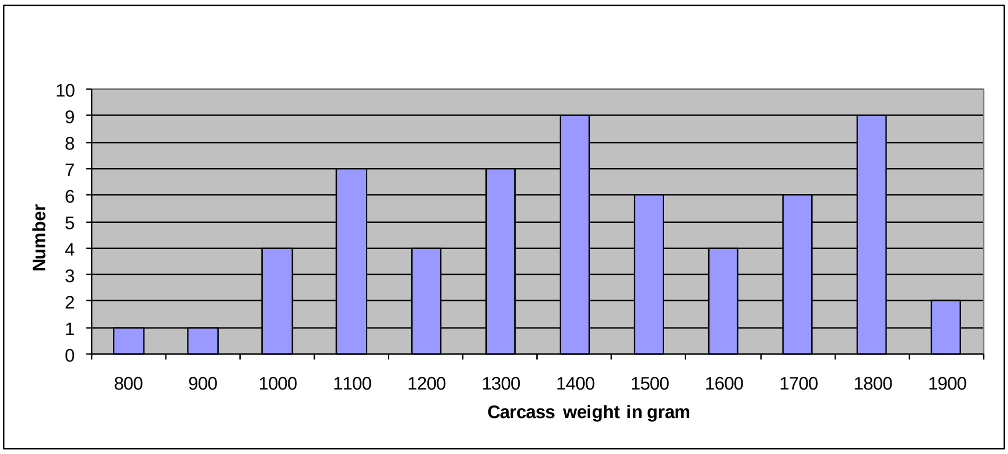


Figure 5. Pre-trial. Distribution of carcass weight

The 60 chickens were divided randomly in two groups of 30 chickens. Each chicken was split in a left and a right half. One group of 30 chickens was used in a *repeatability trial* where each butcher cut both halves of 15 chickens in a random order. The other group of 30 chickens was used in a *reproducibility trial* where the right side of 15 chickens were cut by one butcher and the left sides were cut by the other butcher and vice versa for the remaining 15 chickens. The trial design is illustrated in figure 6.

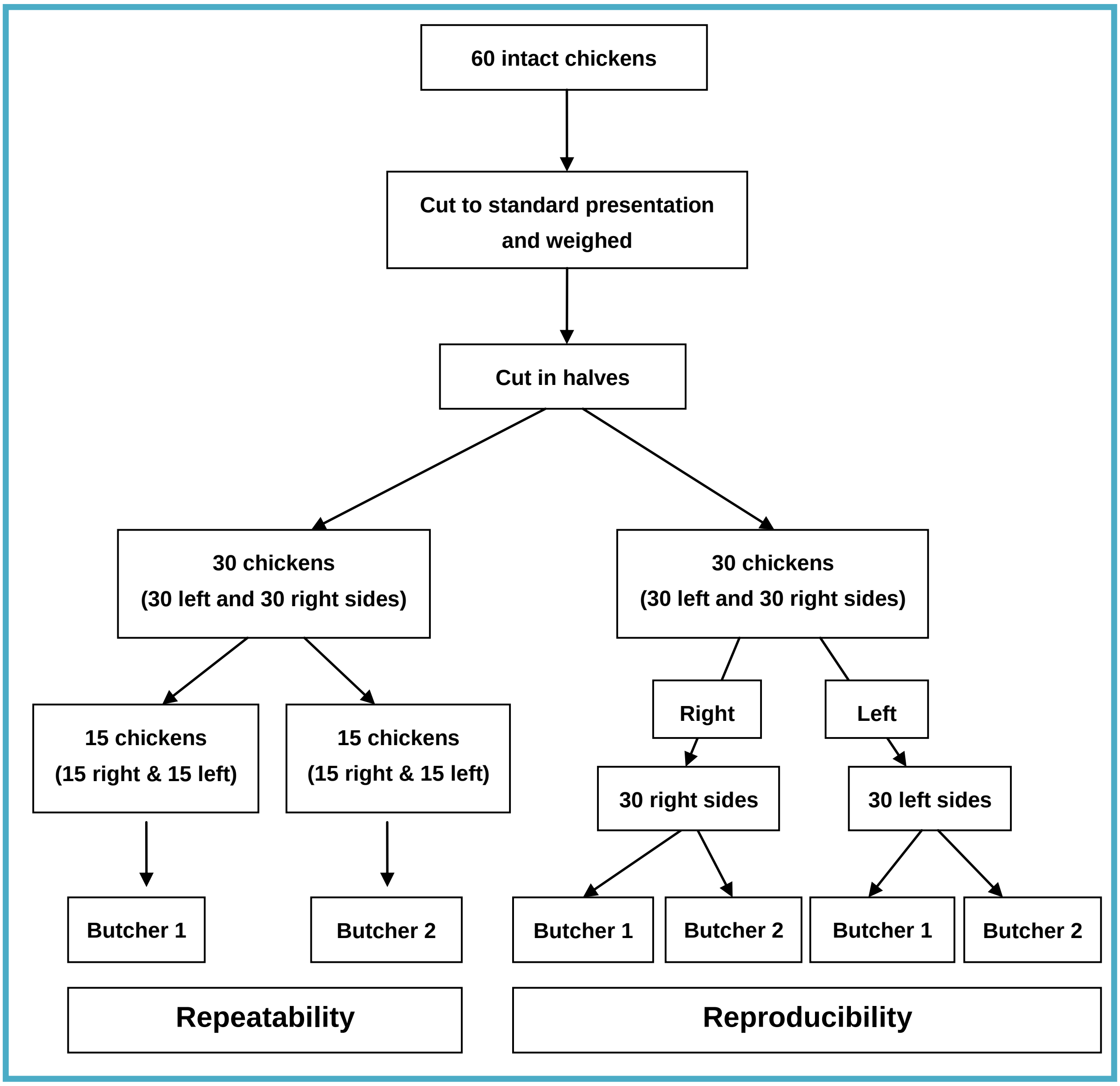


Figure 6. Design of the pre-trail

For each side the following parts were cut and weighed:

1. Outer fillet
2. Inner fillet
3. Thigh
4. Drumstick
5. Wing without wing tip
6. Wing tip
7. Deboned thigh (meat)
8. Deboned drumstick (meat)
9. Carcass shell
10. Scrap from fillet (skin and fat)
11. Bones from thigh
12. Skin and fat from thigh
13. Bones from drumstick
14. Skin and fat from drumstick

The weight and yield of the 14 parts are shown in table 1.

Table 1. Weight (one side) and yield percent (both sides) of parts

	Weight in gram		Yield percent	
Product	**Mean**	**Standard dev.**	**Mean**	**Standard dev.**
Outer fillet	183,3	45,8	24,6	2,1
Inner fillet	38,6	8,8	5,2	0,6
Thigh	141,2	28,0	19,1	0,9
Drumstick	102,7	18,9	14,0	0,8
Wing without wing tip	67,6	11,0	9,2	0,5
Wing tip	9,8	1,8	1,3	0,1
Deboned thigh	109,5	22,6	14,7	0,7
Deboned drumstick	68,1	12,7	9,2	0,6
Carcass shell	165,5	30,1	22,5	1,0
Scrap from fillet	21,9	4,1	3,0	0,4
Bones from thigh	17,0	3,4	2,3	0,2
Skin and fat from thigh	16,4	3,5	2,3	0,4
Bones from drumstick	27,9	5,5	3,8	0,3
Skin and fat from drumstick	8,0	1,6	1,1	0,2

The yield percents sum to only 98.9 %, because of cutting loss and saw dust.

Left and right side

The mean weight of the left side is 739.8 gram and of the right side 727.5 gram and the difference of 12.3 gram is statistically significant (t-test: $p<0.0001$). That is surprising. Theoretically the cause can be an uneven split of the chickens or a systematic anatomical difference between left and right side. Table 2 shows the difference between left and right side in the weight of the parts.

Table 2. Pre-trail. Difference between weight of parts from left and right side in gram (p indicates statistic significance)

Produkt	Mean difference between left and right side	p
Outer fillet	**7,8**	**<0,0001**
Inner fillet	0,6	0,3
Thigh	0,5	0,5
Drumstick	0,1	0,8
Wing without wing tip	**1,3**	**0,002**
Wing tip	0,03	0,8
Deboned thigh	0,1	0,9
Deboned drumstick	0,02	0,9
Carcass shell	-1,4	0,4
Scrap from fillet	**3,2**	**<0,0001**
Bones from thigh	-0,2	0,4
Skin and fat from thigh	0,4	0,4
Bones from drumstick	0,04	0,9
Skin and fat from drumstick	0,2	0,3

The left outer fillet weighs on average 7.8 gram more than the right, the wing 1.3 gram more and the scrap from fillet 3.2 gram more. This sums to 12.3 gram. If the split of the chickens were uneven we would expect that the left and the right side of the carcass shell were different but that is not the case (p= 0.4), so if the split is uneven, it is only in the soft parts.

A small trial at Rose in Vinderup where outer and inner fillets from10 chickens from three different lines were selected showed the *right* fillets were approx. 12 gram heavier than the left fillets (data not shown). “Right” and “left” are in both cases the anatomical right and left.

These results indicate that the difference in sides is not anatomical but rather a result of different processes (manual cutting and automated cutting respectively). See under CT scanning for further information.

If there is a *systematic* anatomical difference between left and right in the pre-trail, it does not affect calculation of repeatability and reproducibility since that is based on the *standard deviation* and not the *mean* of the differences. On the other hand, if a large random difference occurs quite often then the repeatability and reproducibility will be overestimated. Since we do not know if that is the case, we have to assume that the difference between the two sides is either small or systematic. In other words we have to assume that there are *not* many chickens with much larger left sides *and* many chickens with much larger right sides.

Repeat-ability

The repeatability is calculated like this:

$$repeatability = \frac{standard\ dev(left - right)}{\sqrt{2}}$$

Table 3 shows the repeatability of the two butchers' cutting of the parts.

Table 3. Repeatability in gram by reference cutting for each butcher and the two put together.

Product	**Butcher 1**	**Butcher 2**	**Both**
Outer fillet	4,80	4,56	4,6
Inner fillet	2,57	3,15	2,87
Thigh	3,77	3,41	3,59
Drumstick	2,18	2,04	2,11
Wing without wing tip	2,64	1,65	2,20
Wing tip	0,74	0,62	0,68
Deboned thigh	3,69	2,81	3,28
Deboned drumstick	2,23	1,67	1,97
Carcass shell	7,09	9,67	8,48
Scrap from fillet	2,77	2,90	2,84
Bones from thigh	1,10	0,79	0,96
Skin and fat from thigh	1,26	2,27	1,83
Bones from drumstick	1,27	0,96	1,12
Skin and fat from drumstick	1,21	0,98	1,10

The butchers are thus able to cut an outer fillet (mean weight 183 gram) with a precision of a little more 4.5 gram and an inner fillet (mean weight 38 gram) with a precision of approx. 3 gram etc. There are no big differences between the two butchers.

Reproduc-ibility

Since we use two butchers, the individual butchers' precision is not enough to describe the precision of our references. We have to include the difference between the two butchers. That is done with the reproducibility (that includes the repeatability). The reproducibility is calculated like this:

$$reproducibility = \sqrt{\frac{a}{2} + \frac{b}{2}}$$

where a is the estimated effect of butcher and b is the residual effect.

Table 4 shows the reproducibility for the different parts.

Table 4. Pre-trail. Reproducibility in gram, 95 % confidence interval in gram and reliability

Product	Reproducibility	95 % confidence interval	Reliability
Outer fillet	7,79	± 15,59	0,97
Inner fillet	2,84	± 5,68	0,86
Thigh	5,21	± 10,42	0,97
Drumstick	2,67	± 5,35	0,98
Wing without wing tip	2,35	± 4,70	0,95
Wing tip	0,77	± 1,55	0,78
Deboned thigh	3,43	± 6,86	0,98
Deboned drumstick	3,05	± 6,09	0,95
Carcass shell	12,22	± 24,44	0,84
Scrap from fillet	3,05	± 6,10	0,62
Bones from thigh	1,26	± 2,52	0,86
Skin and fat from thigh	2,86	± 5,72	0,60
Bones from drumstick	2,04	± 4,07	0,88
Skin and fat from drumstick	0,62	± 1,25	0,86
Sum of outer and inner fillet	**8,33**	**± 16,66**	**0,97**
Yield percent: Sum of outer and inner fillet	**0,97**	**± 1,93**	**0,80**

For example, we see that outer fillet can be cut with a precision of 7.79 gram which means that our reference for the outer fillet has a precision of ± 15.59 gram with 95 % certainty as indicated in the next column.

The precision can also be described with the reliability (last column), which expresses the butchers precision compared to the total variation of the animals:

$$reliability = \frac{(animal\ std)^2}{(animal\ std)^2 + (reproducibility)^2}$$

The reliability is between 0 and 1 – the higher the better. A rule of thumb is that reliability over 0.8 is acceptable. The reliability is fine for all parts except for scrap from fillet and skin and fat from thigh.

At the bottom of table 4 the precision of the *sum of the outer and inner fillets* is shown. This is of interest since we want to classify that sum of fillets with the vision equipment. The precision of the reference of outer and inner fillet is 8.33 gram (reproducibility) or ± 16.66 gram. This is important since the classification never can be more precise than the reference.

We also want to classify the yield of the total fillet as percent of the carcass weight. The precision of that is also shown in table 4. The precision is 0.97 % (reproducibility) or ± 1.93 %. Therefore, the classification of total fillet yield can at the very best be with a precision of ± 1.93 % (in practice never that good). The precision of the carcass weight reference is not tested. Variation will come from the cutting of the rests of leaf fat, neck, oesophagus, feet and neck skin. The precision is probably within a few grams.

The conclusion is that the two butchers at DJF, Foulum can cut the chickens so precise (although not extremely precise) that it can be used as reference for the classification. Compared to the pre-trail, it is expected that the precision is at least as good if not better in the cutting trials where the chickens were not split in left and right side before cutting.

CT scanning as reference

DMRI owns a CT scanner that is considered to serve as reference for pig classification. During the phase 1 cutting trial (described below) it was tested if the scanner can be used as reference to chicken classification instead of the manual cuttings.

Before cutting into parts, 279 chickens in standard presentation were scanned in the CT scanner. During CT scanning the chickens were scanned in pairs. As pre-processing of the CT data each individual chicken is isolated in a separate file with the scanning background removed resulting in a so called “Hounsfield spectrum” – a three dimensional image of the chicken. The image has a resolution of 0.78x0.78x3.0 mm (the dimensions of each three dimensional pixel or *voxel*). The intensity of each voxel depends on the tissue (bone, fat, muscle). Theoretically it should be possible to measure the volume and the weight of the whole chicken and different parts of the chicken. The spectra were then used for prediction of the carcass weight in standard presentation and the breast fillet weight with manual cuttings by the two butchers at DJF, Foulum as reference.

Prediction of the carcass weight by multivariate PLS was not very good but it has to be said that the CT scanner software is not developed for chickens and further development may make the prediction of chicken carcass weight much better.

The present resolution of the CT spectrums of 0.78x0.78x3.0 mm is not fine enough to identify the membrane between outer and inner breast fillet. Therefore the total breast fillet volume must be segmented as a whole. Prediction of the total breast fillet weight by multivariate PLS showed a RMSEP (Root Mean Square Error of Prediction) of 100 gram or ± 200 gram with 95 % certainty which is not impressive. Therefore another approach was tried. A semiautomatic program (PEG) was designed to guide a manual segmentation of the two breast fillets (left and right). The two breast fillets of 138 chickens covering the range of weight variation were segmented using the software tool. After segmentation the average volume was multiplied with an average density [g/cm^3] to estimate an average weight of manually dissected breast meat. The average density was estimated to 1.2082 g/cm^3. This value of cause includes various contributions from different error sources, segmentation, dissection, scale calibration and so on. The correlation (R) between the predicted and the reference weight was 0.998. The residual deviation (≈ RMSEP) was 15.4 gram. Since the error on the manual cutting is approx. 8 gram, the error of the virtual dissection of total breast fillet may be assumed to be of the same order of magnitude. The PEG software needs considerable time to use for each chicken, so for the moment this method is not an alternative to a total manual cutting.

It was concluded that the CT scanner needs to be developed further before it can be used as reference for classification of chickens. So far the manual cutting is the best alternative.

- Left and right side

As described earlier, the reference cuttings showed a difference in weight of the left and the right side of the chickens. Using the data from the use of the PEG software, the weight of the total breast fillet from the left and the right side were compared. The mean difference was 7.8 gram (left side larger then right side) and the standard deviation of the difference was 10.1 gram. That indicates that there may be a real anatomical difference between the two sides, since it is found in two completely independent ways. If that is indeed the case, the repeatability and the reproducibility calculated in the pre-trial may be estimated too large because of the anatomical difference. The butchers may therefore be better at cutting than indicated above. Further investigation is needed to give a full conclusion.

The classification equations (described later) are based on the sum of the two sides and a potential systematic difference between the sides is in that respect not a problem.

A systematic difference of the two sides may be of interest for the slaughterhouses and a further investigation may be relevant.

Cutting trials

Phase 1 cutting trial

To get a first impression on how well the vision equipment can predict weights and yields a cutting trial was made with the equipment in Vinderup (*phase 1 cutting trial*). 500 chickens raised in a special production at DJF, Foulum were slaughtered and measured by the vision equipment in Vinderup. The chickens were distributed on 10 weight groups (target live weight: 1040, 1349, 1596, 1853, 2115, 2380, 2643, 2988, 3239 and 3480 gram) and 4 feeding/parent groups (Low wheat / parent category 0, High wheat / parent category 0, Norm wheat / parent category +1 and Norm wheat parent category -1). The chickens were fed concept feed from DLG (Optima series) with low, norm or high addition of wheat. Appendix 1 shows the wheat programs. The parent groups represents the age of the mother hen when the egg is laid where +1 is 24-29 weeks, 0 is 30-45 weeks and -1 is 46-65 weeks. Equally distributed on weight and feeding groups 279 chickens were selected for reference cutting at DJF, Foulum. The aim of the special production and the selection of the 279 chickens were a large variation on carcass weight and breast fillet yield. Not all chickens could be identified regarding the sex, but 120 where identified as males, 137 as females and 22 could not be unidentified.

Figures 7, 8 and 9 show the distribution of carcass weight, total fillet weight (sum of both inner and outer fillets) and the total fillet yield.

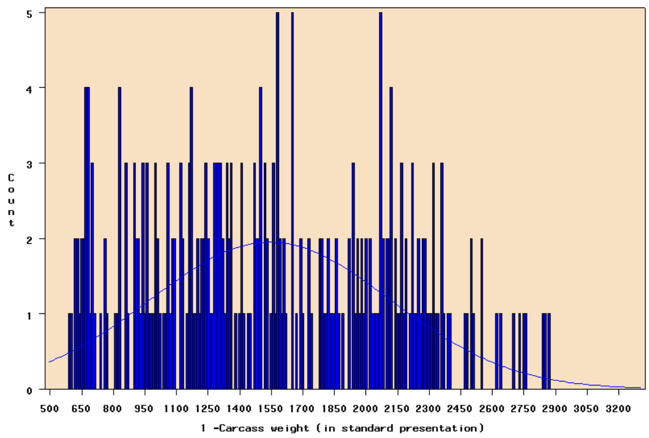


Figure 7. Phase 1 cutting trial. Variation in standard carcass weight in gram

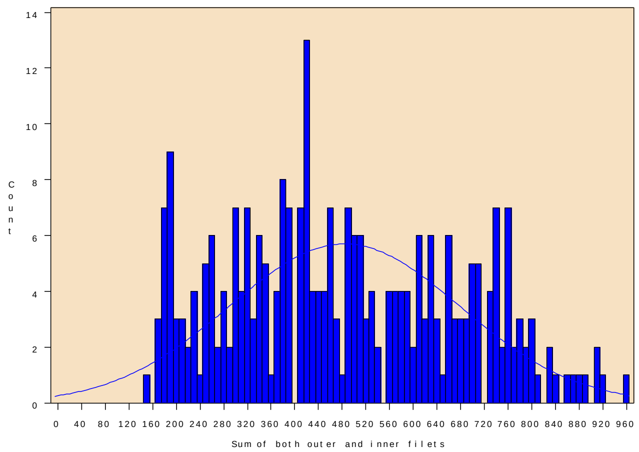


Figure 8. Phase 1 cutting trial. Distribution of total breast fillet in gram (sum of left and right side outer and inner fillet)

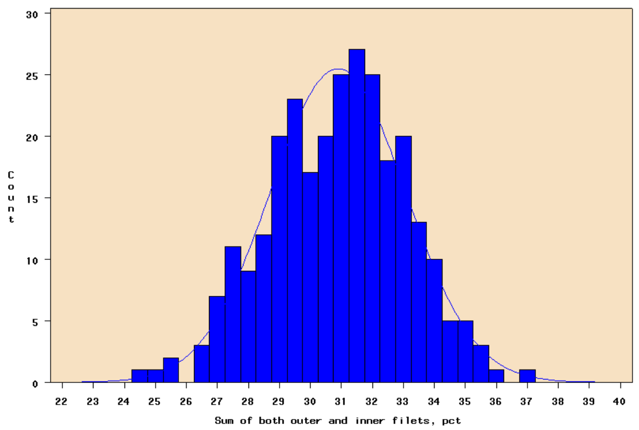


Figure 9. Phase 1 cutting trial. Distribution of total breast fillet yield % (sum of left and right side outer and inner fillet as percent of the standard carcass weight)

The mean, standard deviation, minimum and maximum values for carcass weight, total fillet weight and total fillet yield are shown in table 5.

Table 5. Phase 1 cutting trial. Carcass weight, total fillet weight and total fillet yield (N=279)

	Mean	Stand. dev.	Minimum	Maximum
Carcass weight (gram)	1544	571	588	2869
Total fillet weight (gram)	484	195	151	962
Total fillet yield (%)	30.9	2.2	24.6	37.1

The carcass weight ranges from 588 to 2869 gram, the total fillet weight from 151 to 962 gram and the total fillet yield from 24.6 to 37.1 %. That means that classification equations based on these data will be useable for chickens within the described ranges. Since there are few chickens in lower and higher ends of the ranges (figures 6-8), the equations may not be as accurate there.

Phase 2 cutting trial

In phase 2 of the project, the cutting trial was repeated (*phase 2 cutting trial*) in order to make an independent validation of the classification equations made in phase 1. The special production of chickens was made in the same way. This time the chickens were split between the slaughterhouses in Vinderup and Aars and a total of 247 chickens were selected for cutting (live weight group 1040 gram was left out because of only one chicken in this group in Vinderup). Figures 10, 11 and 12 show the distribution of carcass weight, total fillet weight and the total fillet yield in the phase 2 cutting trial.

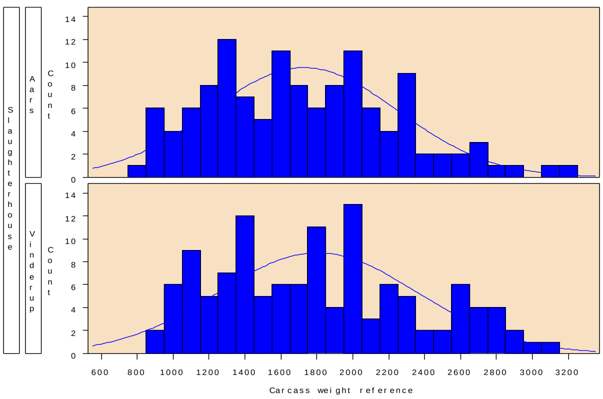


Figure 10. Phase 2 cutting trial. Variation in standard carcass weight in gram for the two slaughterhouses.

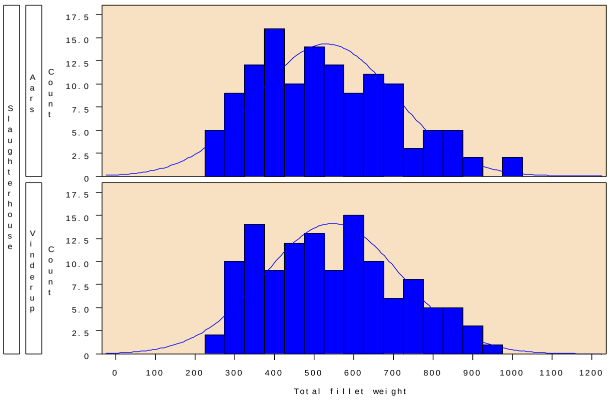


Figure 11. Phase 2 cutting trial. Distribution of total breast fillet in gram (sum of left and right side outer and inner fillet) for the two slaughterhouses.

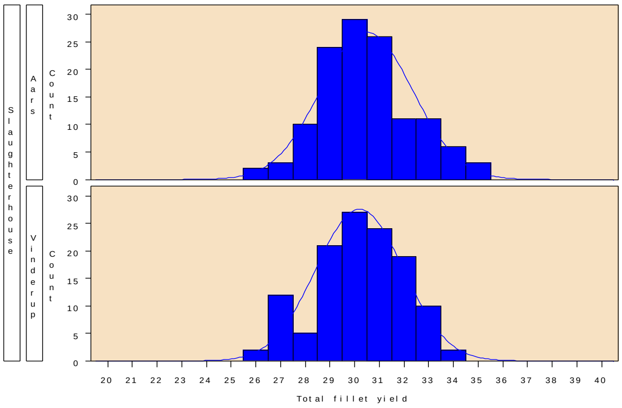


Figure 12. Phase 2 cutting trial. Distribution of total breast fillet yield in percent (sum of left and right side outer and inner fillet) for the two slaughterhouses.

The mean, standard deviation, minimum and maximum values for carcass weight, total fillet weight and total fillet yield for the two slaughterhouses are shown in table 6.

Table 6. Phase 2 cutting trial. Carcass weight, total fillet weight and total fillet yield for the two slaughterhouses (N=259)

Aars (n=136)	Mean	Stand. dev.	Minimum	Maximum
Carcass weight (gram)	1728	522	824	3193
Total fillet weight (gram)	530	174	240	1024
Total fillet yield (%)	30.5	1.9	26.3	35.4
Vinderup (n=123)				
Carcass weight (gram)	1805	554	882	3082
Total fillet weight (gram)	546	173	247	972
Total fillet yield (%)	30.2	1.8	25.6	34.0

The chickens are 2-300 gram heavier in the phase 2 trial than in the phase 1 trial. That is not considered to be a problem because the small chickens in general are too small for the slaughter process – they are very often damaged by the evisceration.

The total fillet weight is of cause also higher in the phase 2 trial. The mean of the total fillet yield is almost the same but the standard deviation and the range are a little smaller in the phase 2 trial.

Because the new special production of chickens were split evenly between the two equipments for all weight groups, the mean of the cutting references were expected to be the same for the two equipments and that was indeed the case: The mean reference carcass weight in Vinderup is 1805 gram and in Aars 1728 gram. The numeric difference of 77 gram is not statistically significant (p=0.3). For the chickens with known sex, the males weigh 198 gram more than the females on average (p=0.006); the difference is the same for the two slaughterhouses (no interaction). Corrected for the uneven distribution of females and males, the numeric difference in mean carcass weight between the slaughterhouses is 98 gram for the chickens with known sex (still not significant). At the first of the three days of slaughter the slaughter in Aars was delayed approx. three hours compared to the slaughter in Vinderup. This could mean that the chickens in Aars have lost more weight before slaughter and therefore weighed less. But the difference in carcass weight is seen on all three days of slaughter. The size of the difference cannot be compared between days of slaughter since the size of the chickens were not the same. The chickens were smaller on the first day of slaughter than on the second day but the difference is the same. That may indicate an effect of the delay of slaughter in Aars on the first day, but the difference between Aars and Vinderup (53 gram) is not significant (p=0.2). The difference does not become significant when including the live weight groups (no interaction, p=0.3). It was therefore decided that a correction in the weights registered for the first day of slaughter or in the specific weight groups was not relevant.

The mean reference fillet weight is 530 gram in Aars and 546 gram in Vinderup. The difference is not significant (p=0.5). For the chickens with known sex, the reference fillet weight is 513 gram for the female chickens and 564 gram for the male chickens (p=0.03). The mean reference fillet yield is 30.48 % in Aars and 30.20 % in Vinderup. The difference is not significant (p=0.2). For the chickens with known sex, the reference fillet yield is 30.65 % for the female chickens and 30.10 for the male chickens and the difference is significant (p=0.02).

Statistical methods for making equations

Classification equations were made by two different methods. In both cases the equations were made from 2 x 128 measurements – the *predictors* – based on image analysis of the two pictures taken by the front and the back view cameras. The results of the cutting trials were used as references.

The first method was based on stepwise linear regression where the four best predictors were selected minimising the standard error. This was done by E+V.

The second method was based on multivariable principal component regression PLS using Unscrambler version 9.2 (Camo Process AS, 2005). *Full cross validation* on the data was used. In short that means that the method calculates an equation on all chickens in the data minus one, checks the equation on the one left out, does that for all the chickens and finally delivers an equation as a "mean" of all the equations. The precision of the cross-validated equation is calculated as a "mean" of the precision of the individual equations. This was done by DMRI.

In the project cooperation agreement, it is stated that the classification equations developed in the project are to be confidential within the project. The individual predictors and the predictors included in the equations are therefore not described in detail in this report.

Version 1 equations

Linear regression classification equations were made for the weight and yield of the parts shown in table 7 and 8 with the phase 1 cutting trial data as reference. The columns show the mean and the standard deviation of the reference, the correlation between the predicted value (as calculated by the equation) and the reference, the standard error of the equations prediction, the standard error as percent of the reference mean and the standard error as percent of the reference standard deviation.

Table 7. Statistical results of *weight* equations (gram). Statistic: Stepwise linear regression including the four best predictors minimising the standard error

Parameter	Mean	Standard deviation	Correlation	Standard Error	StdE/Mean %	StdE/Std %
Carcass weight	1544,53	571,04	0,9964	48,77	3.16	8.54
Outer breast fillet	389,46	157,47	0,9882	24,28	6.23	15.42
Inner breast fillet	94,35	38,75	0,9809	7,58	8.04	19.57
Sum of outer and inner fillets	483,81	195,29	0,9904	27,22	5.63	13.94
Scraps from fillet	45,18	16,65	0,9421	5,62	12.45	33.77
Sum of outer and inner fillets with skin	528,99	210,78	0,9912	28,14	5.32	13.35
Wing 2-joints	139,36	47,79	0,9893	7,02	5.04	14.69
Wing tips	20,12	6,16	0,9629	1,67	8.32	27.17
Wing 3-joints	159,48	53,77	0,9890	8,03	5.03	14.93
Boneless thigh without skin and fat	210,98	82,00	0,9897	11,83	5.61	14.42
Thigh bone	33,58	11,74	0,9597	3,32	9.89	28.30
Skin and fat from thigh	43,67	18,52	0,9308	6,82	15.61	36.81
Thighs	288,23	109,86	0,9914	14,46	5.02	13.16
Boneless drumstick	137,41	52,09	0,9878	8,16	5.94	15.66
Drumstick bone	52,71	17,50	0,9548	5,24	9.94	29.94
Skin and fat from drumstick	18,94	7,17	0,9456	2,35	12.41	32.76
Drumsticks	209,05	75,31	0,9910	10,16	4.86	13.48

Table 8. Statistical results of *yield percent* equations. Statistic: Stepwise linear regression including the 4 best predictors minimising the standard error

Parameter	Mean	Standard deviation	Correlation	Standard Error	StdE/Mean %	StdE/Std %
Outer breast fillet	24,89	1,87	0,7892	1,16	4.65	61.86
Inner breast fillet	6,00	0,60	0,6849	0,44	7.33	73.39
Sum of outer and inner fillets	30,89	2,19	0,8157	1,27	4.13	58.26
Scraps from fillet	2,96	0,39	0,4763	0,35	11.66	88.57
Sum of outer and inner fillets with skin	33,85	2,14	0,8298	1,21	3.56	56.21
Wing 2-joints	9,13	0,50	0,7019	0,36	3.96	71.74
Wing tips	1,35	0,17	0,7930	0,10	7.54	61.36
Wing 3-joints	10,48	0,63	0,7592	0,41	3.96	65.56
Boneless thigh without skin and fat	13,56	0,73	0,6529	0,56	4.13	76.30
Thigh bone	2,22	0,27	0,6823	0,20	8.89	73.64
Skin and fat from thigh	2,82	0,51	0,4607	0,45	16.11	89.40
Thighs	18,60	0,86	0,5991	0,70	3.74	80.65
Boneless drumstick	8,88	0,57	0,6074	0,46	5.14	80.02
Drumstick bone	3,50	0,47	0,7413	0,32	9.07	67.61
Skin and fat from drumstick	1,24	0,17	0,4166	0,16	12.76	91.57
Drumsticks	13,62	0,80	0,7516	0,53	3.93	66.45

The standard error can be used to calculate the average precision of the equations as approximately ± 2 x standard error. For example the carcass weight, the average precision is ± 2 x 48.77 gram = 97.54 gram. For the weight of total breast fillet (sum of outer and inner fillets) the average precision is ± 2 x 27.22 gram = 54.44 gram and as yield percent of the carcass weight ± 2 x 1.27 % = 2.54 %.

Figure 13, 14 and 15 show plots of the predicted values versus the reference values for carcass weight, total fillet weight and total fillet yield.

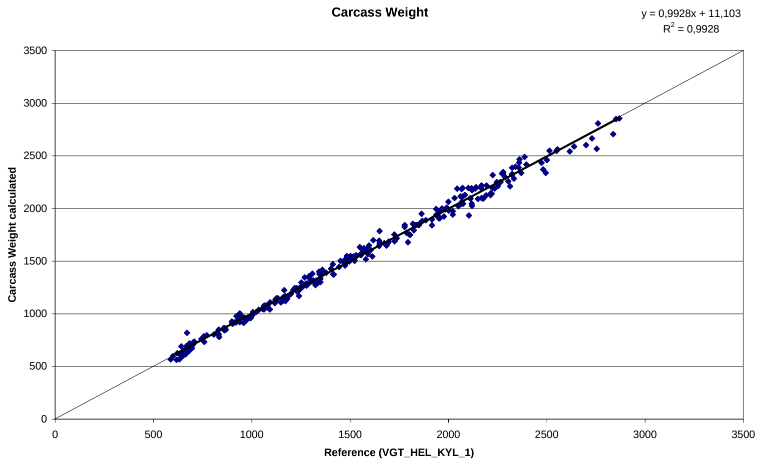


Figure 13. Carcass weight. Linear regression. Predicted versus reference.

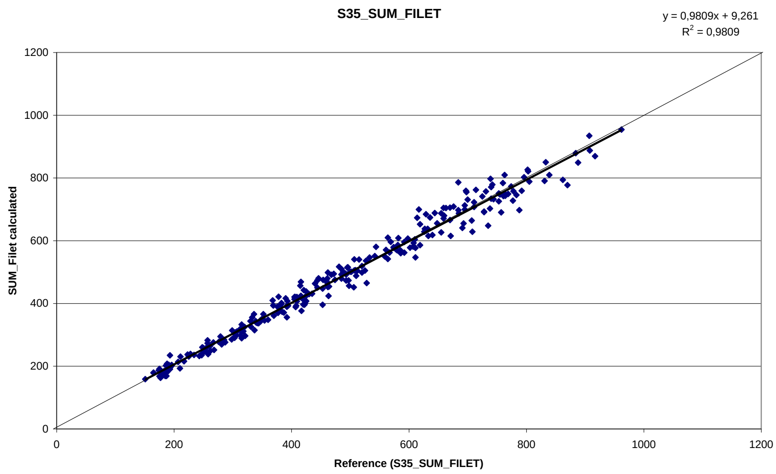


Figure 14. Weight of total breast fillet. Linear regression. Predicted versus reference.

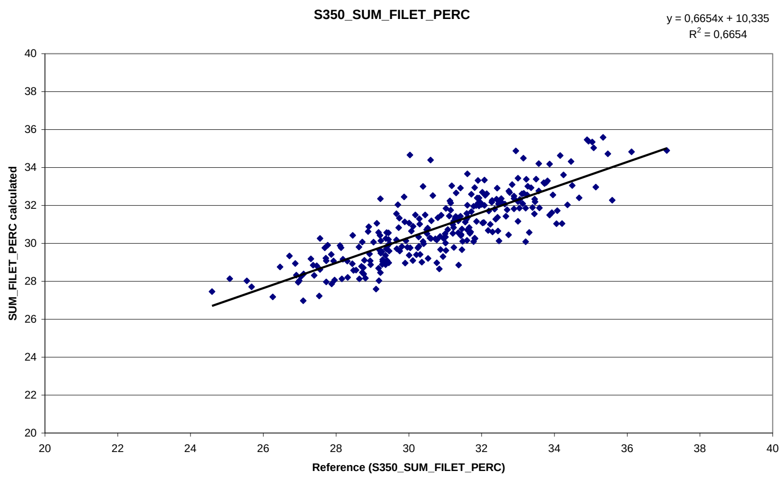


Figure 15. Yield percent of total breast fillet. Linear regression. Predicted versus reference.

Using stepwise linear regression on the vision predictors may have a weakness since many of the predictors are highly correlated and the standard error may be somewhat optimistic. The PLS method has therefore been used on the carcass weight and the weight and yield percent of the total breast fillet. In PLS, new predictors – *principal components* – are calculated from the original predictors. The first principal component is describing as much variation in the data as possible. Then the second principal component is calculated to describe as much of the rest of the variation as possible and so on. The principal components (= the new predictors) are totally independent. Figure 16 shows the result of a PLS analysis on the carcass weight.

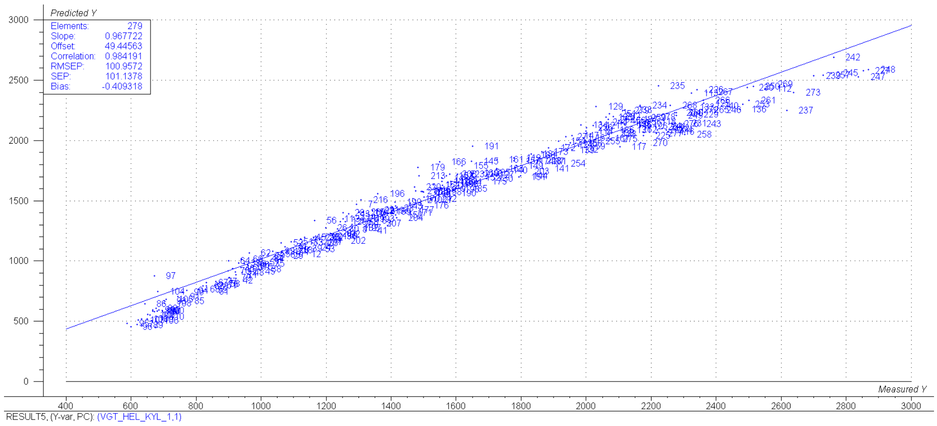


Figure 16. Carcass weight. PLS.

The plot shows the reference values (“Measured”) on the x-axis and the values predicted by the equation on the y-axis. The RMSEP of the equation is comparable to the standard error of the linear regression. In this case the RMSE is 101 gram and the average precision is therefore ± 2 x 101 gram = 202 gram. The resulting equation only needs the first principal component (PLS predictor) which is a good sign but note that the individual observations seem to lie on a slightly curved line. This indicates some non-linearity in the data and the equation may not be the best.

A third method *neural network analysis* still uses principal components but can handle non-linear data. Figure 17 shows the results of a neural network analysis on carcass weight. In this analysis, the equation is made on 75 % of the data (calibration set) and the equation is validated on the remaining 25 % of the data (test set). The RMSEP of the test set is a better estimate of the average precision in the “real world”. With this equation, the average precision of the predicted carcass weight is ± 2 x RMSEP = ± 2 x 59.5 gram = 119 gram. Looking at the plots, the observations seem to lie on a strait (not curved) line and the equation made in this way may be better than the equation made by the PLS analysis.

Test set (25% randomly selected). RMSEP=59.5g R = 0.994

Calibration set (75% randomly selected). RMSEC=47.4g, R =0.997.

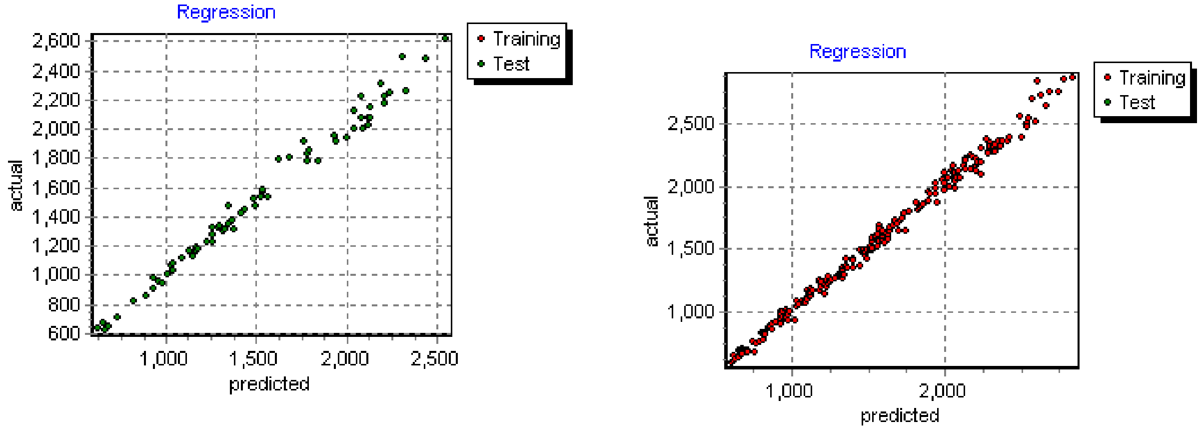


Figure 17. Carcass weight. Neural network on first 5 principal components.

Another way of “straightening the curve” for carcass weight using the PLS method was also tested. Consider this: We are using two-dimensional pictures to predict a three-dimensional weight, which does not sound linear. There the reference carcass weight was lifted to the power of 2/3 – making it “two-dimensional”. Then PLS was used as before. The result is shown in figure 18.

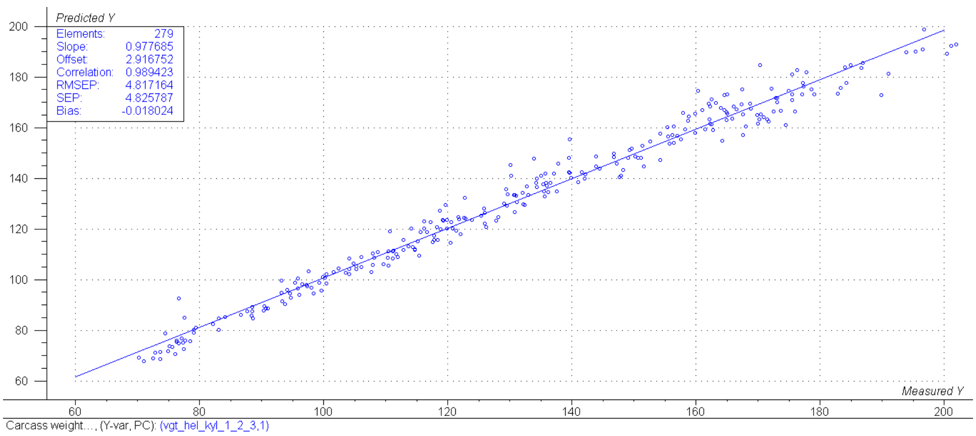


Figure 18. Carcass weight lifted to the power of 2/3. PLS.

This also “straightens the curve” to almost linear. The resulting equation predicting the carcass weight in the power of 2/3 was then calculated back to an equation predicting the actual carcass weight and the RMSEP was calculated to 88.08 gram.

Figure 19 shows the results of a PLS analysis on the weight of the total breast fillet.

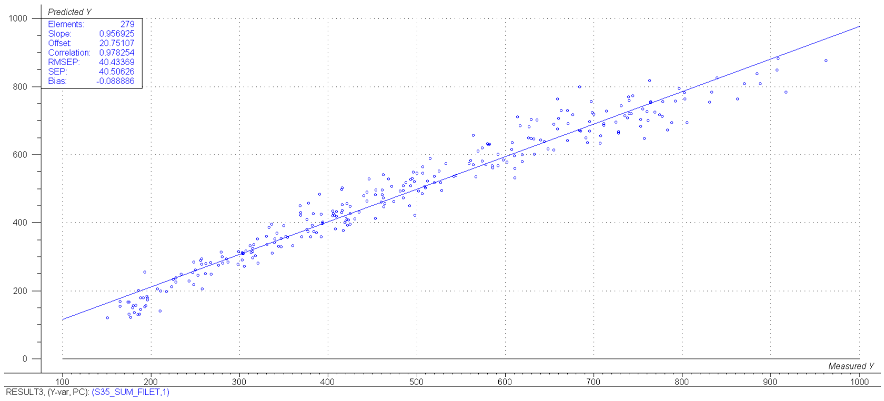


Figure 19. Total fillet weight. PLS.

The values seem to lie on an almost straight line indicating a usable equation although very low and very high values seem to be underestimated. The RMSEP is 40.4 gram which means that the fillet weight is predicted by a precision of ± 80.8 gram with 95 % certainty.

Figure 20 shows the results of a PLS analysis on the total breast fillet yield.

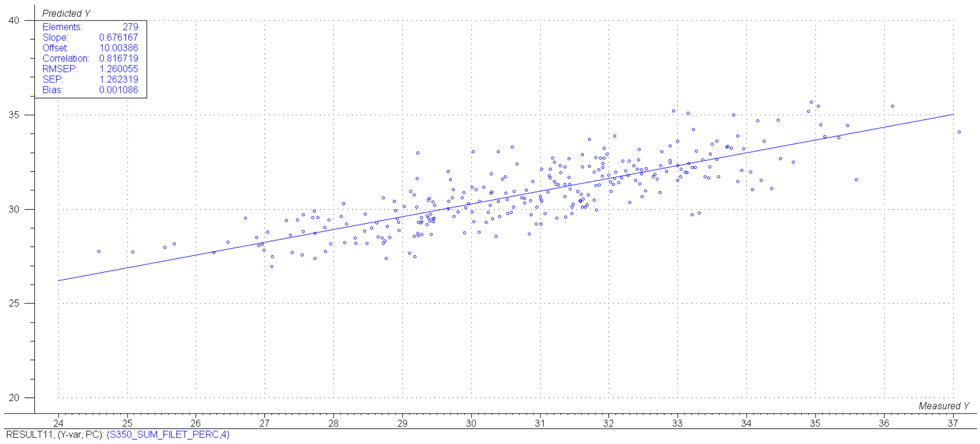


Figure 20. Total breast fillet yield PLS.

The RMSEP is 1.26 % and the average precision of the predicted yield percent is therefore ± 2.52 % with 95 % certainty.

The linear regression equations for carcass weight, total fillet weight and total fillet yield seems to be better than the PLS equations, which is surprising. The standard error of the linear regression and the RMSEP of the PLS are not totally comparable since they are calculated exactly the same:

$$Standard\ error(linear\ regression) = \sqrt{\frac{\sum_1^i (\hat{y}_i - y_i)^2}{n-k-1}}$$

$$RMSEP(PLS) = \sqrt{\frac{\sum_1^i (\hat{y}_i - y_i)^2}{n}}$$

where i = the chickens, $\hat{y}_i$ = the predicted value, y = the reference value, n = the number of chickens and k = the number of predictors in the equation.

That means that the RMSEP will be a little smaller than the standard error:

$$RMSEP = standard\ error\ x\ \sqrt{\frac{n-k-1}{n}}$$

With 279 chickens (n) and 4 predictors the standard error must be multiplied by 0.99 to get the RMSEP. Therefore, the standard error and the RMSEP are comparable.

Based on the promising results of the phase 1 classification equations made from linear regression and PLS, the steering group decided that the project should continue with phase 2 and 3.

Validation of version 1 equations

The 33 equations made by linear regression (table 7 and 8) and the 3 PLS equations (Figure 18, 19 and 20) were then implemented in the two vision equipments in Vinderup and Aars.

Split delivery from one producer

With the purpose of comparing the classification of the two vision equipments, chickens from one producer were split between Vinderup and Aars. The chickens came from 4 houses, were transported for the same time and were slaughtered at the same day. For the collection of the chickens each house was divided into a left and a right side and each side was divided into four sectors. The chickens in the eight sectors were sent to Vinderup and Aars respectively as illustrated in table 9.

Table 9. Split delivery from producer. The eight sectors of each house and where the chickens were send.

House	
Left	**Right**
Aars	Vinderup
Vinderup	Aars
Aars	Vinderup
Vinderup	Aars

In total 70,436 chickens were slaughtered and classified in Vinderup and 63,068 chickens in Aars. The total number of chickens was 133,504. Table 10 shows how many chickens from each house were sent to each equipment. Although it was not the purpose, there were delivered more chickens to Vinderup than to Aars for all four houses.

Table 10. Split delivery from producer. Number of chickens by equipment.

		Number
House		
2	**Aars**	15.660
	Vinderup	17.233
	Difference equipment	-1.573
3	**Aars**	15.701
	Vinderup	17.907
	Difference equipment	-2.206
4	**Aars**	15.885
	Vinderup	17.763
	Difference equipment	-1.878
5	**Aars**	15.822
	Vinderup	17.533
	Difference equipment	-1.711
All	**Aars**	63.068
	Vinderup	70.436
	Difference equipment	-7.368

Table 11 shows an overview of the classification of carcass weight, total fillet weight and total fillet yield calculated by the linear regression and the PLS equations for the two equipments.

Table 11. Split delivery from producer. Number, mean, standard deviation, minimum value and maximum value of carcass weight, total fillet weight and total fillet yield classification by equipment. (LR = linear regression equation, PLS = PLS equation).

		Standard Carcass Weight (g) LR	Standard Carcass Weight (g) PLS	Total breast fillet (g) LR	Total breast fillet (g) PLS	Yield total breast fillet (%) LR	Yield total breast fillet (%) PLS
Aars	**N**	63.068	63.068	63.068	63.068	63.068	63.068
	Mean	1.544,79	1.481,96	488,88	491,56	31,36	30,09
	Std	220,48	217,05	70,12	70,88	1,49	1,40
	Min	429,61	384,69	115,62	69,54	25,26	24,39
	Max	2.793,97	2.654,88	934,10	839,00	44,35	40,86
Vinderup	**N**	70.436	70.436	70.436	70.436	70.436	70.436
	Mean	1.568,66	1.572,54	487,09	500,88	30,78	29,63
	Std	227,98	237,07	72,26	73,93	1,44	1,39
	Min	319,67	329,55	34,95	10,37	23,82	21,83
	Max	3.486,94	3.016,59	1.102,67	1.035,08	46,18	39,44
Both	**N**	133.504	133.504	133.504	133.504	133.504	133.504
	Mean	1.557,39	1.529,75	487,93	496,48	31,06	29,85
	Std	224,78	232,27	71,26	72,66	1,49	1,42
	Min	319,67	329,55	34,95	10,37	23,82	21,83
	Max	3.486,94	3.016,59	1.102,67	1.035,08	46,18	40,86

Table 12 shows a comparison of the two equipments classification of the *carcass weight*. The table also compares the linear regression and the PLS equations.

Table 12. Split delivery from producer. Carcass weight. Mean standard by equipment, equation, and chicken house. (LR = linear regression equation, PLS = PLS equation).

		Standard Carcass Weight (g) LR	Standard Carcass Weight (g) PLS	Difference equation
House	Equipment			
2	Aars	1.445,85	1.381,64	64,21
	Vinderup	1.475,19	1.472,51	2,68
	Difference equipment	-29,34	-90,87	
3	Aars	1.585,95	1.525,84	60,11
	Vinderup	1.617,20	1.626,25	-9,05
	Difference equipment	-31,25	-100,41	
4	Aars	1.553,34	1.487,71	65,63
	Vinderup	1.567,56	1.571,05	-3,49
	Difference equipment	-14,22	-83,34	
5	Aars	1.593,29	1.531,94	61,35
	Vinderup	1.612,07	1.617,51	-5,44
	Difference equipment	-18,78	-85,57	
All	Aars	1.544,79	1.481,96	62,83
	Vinderup	1.568,66	1.572,54	-3,88
	Difference equipment	-23,87	-90,58	

The two equipments do not give the same mean carcass weight. For both equations and all four houses the equipment in Vinderup gives a higher carcass weight than Aars. With the linear regression equation the differences in carcass weight between the equipments are from 14 to 31 gram for the four houses. With the PLS equation the differences are from 83 to 100 gram. The average differences between the equipments are 24 and 91 gram respectively for the two equations. All the differences are highly significant ($p < 0.0001$): The differences between the two equipments are significant, the differences between the houses are significant and the differences between the equipments from house to house are not of the same size (the interaction between house and equipment is significant). But the important thing is that the Vinderup equipment gives higher carcass weight than Aars for all four houses. For all the individual sectors in the four houses, Vinderup has higher carcass weight than Aars for both equations as well ($p < 0.0001$).

The two equations do not give the same results. For all 8 combinations of house and equipment, the two equations give different results ($p < 0.0001$) but the 8 combinations do not all give the same difference. In Aars the linear regression equation gives 60 to 65 gram larger carcass weight than the PLS equation. In Vinderup the difference is smaller. For house 2 the linear regression equation gives 3 gram larger carcass weight than the PLS equation but for the other three houses the linear regression equation gives smaller carcass weight than the PLS equation (3 to

9 gram). The data cannot tell us which equation is the best since we do not have any reference in this trial. But note that the difference between the equations is bigger for Aars than for Vinderup. That may indicate that one of the equations is more robust than the other. Each house was divided into 3 sectors. If we look at the individual sectors, they show the same tendencies as the house they belong to (data not shown).

The data show a systematic difference between calculated carcass weights from the two equipments. There is all reason to believe that the two chicken samples delivered to Vinderup and Aars can be regarded as coming from the same population and they therefore should have the same average carcass weight.

Both equations were made on reference data from Vinderup (phase 1). The relatively small difference between the two equations for this plant may indicate that both equations work fairly well on the new chicken sample slaughtered in Vinderup. Assuming this, the equations do not work as well on the chickens slaughtered in Aars and the linear regression equation is the better of the two in Aars. This indicates that conditions in Aars are not the same as in Vinderup and that some of these conditions affect the equipments predictors included in the equations.

The difference between the two plants is larger for the PLS equation than for the linear regression equation. This is not surprising since the PLS equation includes many more predictors than the linear regression equation (always four) and the risk of including predictors that are influenced by the differences between the two slaughterhouses is bigger for the PLS equation, although both equations seem to include such predictors.

There seems to be a systematic difference in some of the predictors that are included in the carcass weight equations. The difference between the two equipments may be caused by one or more of the following conditions:

- Technical / mechanical differences between the two equipments.
- Environmental difference between the two plants such as steam which can affect the equipment.
- Differences in the slaughter processes up to the position of the equipments that the equipments / equations cannot compensate for.
- In theory any other difference from the catching process up to the position of the equipment. In this trial we have seen a different frequency of broken wings which indicates different handling. In Vinderup almost 5 % of the chickens had broken wings, in Aars 2.5 %. It is not know if this can have an effect on the prediction of carcass weight.

Table 13 shows a comparison of the two equipments classification of the *total fillet weight*. The table also compares the linear regression and the PLS equations.

Table 13. Split delivery from producer. Total fillet weight. Mean standard by equipment, equation, and chicken house. (LR = linear regression equation, PLS = PLS equation).

House number	Equipment	Total breast filet (g) LR	Total breast filet (g) PLS	Difference equation
2	Aars	459,78	460,42	-0,64
	Vinderup	458,80	470,10	-11,30
	Difference equipment	0,98	-9,68	
3	Aars	502,79	503,06	-0,27
	Vinderup	502,68	516,34	-13,66
	Difference equipment	0,11	-13,28	
4	Aars	488,25	493,79	-5,54
	Vinderup	485,14	500,61	-15,47
	Difference equipment	3,11	-6,82	
5	Aars	504,50	508,74	-4,24
	Vinderup	500,94	515,60	-14,66
	Difference equipment	3,56	-6,86	
All	Aars	488,88	491,56	-2,68
	Vinderup	487,09	500,88	-13,79
	Difference equipment	1,79	-9,32	

The results are not as clear and simple as for the carcass weight. Firstly, the two equations do not behave the same way. For the *linear regression equation*, Aars gives a small but statistically significant higher fillet weight than Vinderup in house 4 and 5 (3 gram, $p > 0.0001$), but in house 2 and 3 there is no significant difference between Aars and Vinderup. For the *PLS equation*, Vinderup gives significant higher fillet weight than Aars for all four houses (7 to 13 gram, $p < 0.0001$).

Looking at the individual sectors in the houses, the sectors in house 2 and 3 show a special pattern for the linear regression equation: In sector 1 Vinderup gives higher fillet weight than Aars whereas in sector 2 Aars gives the higher fillet weight than Vinderup and in sector 3 there is no significant difference. In house 4 and 5, Aars gives higher fillet weight than Vinderup, but in house 4 this is only significant for sector 1 and 3 but not for sector 2. In house 5 the whole difference is caused by a difference in sector 1 whereas sector 2 and 3 show no significant differences. We do not have an explanation for this pattern. For the PLS equation the house-differences are also seen in the individual sectors – Vinderup gives higher fillet weight than Aars. The only exception is sector 1 in house 5 where there is no significant difference (data not shown).

The results indicate that the PLS equation includes predictors which are influenced by differences in conditions in Aars and Vinderup. The linear regression equation may be more robust to these differences although it is difficult to explain the variation from house to house and sector to sector (see the previous argumentation for carcass weight).

Table 14 shows a comparison of the two equipments classification of the *total fillet yield*. The table also compares the linear regression and the PLS equations.

Table 14. Split delivery from producer. Total fillet yield. Mean standard by equipment, equation, and chicken house. (LR = linear regression equation, PLS = PLS equation).

		Yield total breast filet (%) LR	Yield total breast filet (%) PLS	Difference equation
House number	Equipment			
2	Aars	31,51	30,24	1,27
	Vinderup	30,86	29,73	1,13
	Difference equipment	0,65	0,51	
3	Aars	31,43	30,15	1,28
	Vinderup	30,80	29,66	1,14
	Difference equipment	0,63	0,49	
4	Aars	31,11	29,83	1,28
	Vinderup	30,68	29,52	1,16
	Difference equipment	0,43	0,31	
5	Aars	31,41	30,13	1,28
	Vinderup	30,80	29,61	1,19
	Difference equipment	0,61	0,52	
All	Aars	31,36	30,08	1,28
	Vinderup	30,78	29,63	1,15
	Difference equipment	0,58	0,45	

The two equations and the four houses show very similar results: Aars gives approximately 0.5 percent higher breast fillet yield than Vinderup. All the differences are highly significant ($p < 0.0001$). Looking at the individual sectors, all sectors for both equations show Aars approximately 0.5 percent higher breast yield than Vinderup (from 0.3 to 0.6 percent, $p < 0.0001$).

The results indicate that both equations include predictors that are influenced by differences in conditions in Aars and Vinderup (see the previous argumentation for carcass weight).

Classification of the remaining parts was not compared in this trial.

Based on the split delivery from the producer, it was concluded that based the phase 1 equations the equipment in Vinderup was calculating the *standard carcass weight* higher than the equipment in Aars. For the PLS equation the difference is larger than for the linear regression equation. The two equations did not include the same predictors but it looked like both equations included predictors that were influenced by differences in conditions in Aars and Vinderup.

For the *total fillet weight*, the two equations did not show the same pattern. The PLS equation gave higher fillet weight in Vinderup than in Aars. It looked like that equation included predictors that were influenced by differences in conditions in Aars and Vinderup. The linear regression equation did not give an unambiguous result. Differences depended on houses and sectors but in general they were smaller than the differences for the PLS equation. The linear regression equation looked more robust to the differences in conditions in Aars and Vinderup.

The equipment in Aars calculated the *total fillet yiel*d higher than the equipment in Vinderup. The difference was the same for the two equations. It looked like both equations included predictors that were influenced by differences in conditions in Aars and Vinderup.

Ideally there should be no significant differences of the classification means between the equipments. Part of that can be obtained by ensuring that the *equipments* are as alike technically and mechanically as possible. Technical / mechanical routine checks (calibration) of the equipments can ensure the "alikeness" over time. Another part of obtaining no significant difference between equipments is to make the conditions on the *slaughter plants* as alike as possible. If that is not enough it must be ensured that the equations do not include predictors that are affected by the differences in conditions (robustness). For example, differences in "unchangeable" conditions such as shackle width can be handled by not including predictors that are influenced by shackle width in the equations. This may make the equations less accurate but it is a matter of what is more important.

Guide bar and shackle width

There were two known differences between the two slaughterhouses during the split delivery.

In Vinderup, it was observed that the chickens in some cases were swinging towards and away from the cameras. This was considered to interfere significantly with the image analysis. In order to minimize the swinging of the chickens, a "guide bar" was installed in Vinderup but *after* the split delivery. In Aars, the guide bar was included when the second test equipment was installed there and it was therefore present during the split delivery. This difference may be part of the explanation for the described differences in classification between the slaughterhouses during the split delivery. The equations were based on data where the guide bar was not present. During the split delivery, it was still not present in Vinderup but it was present in Aars.

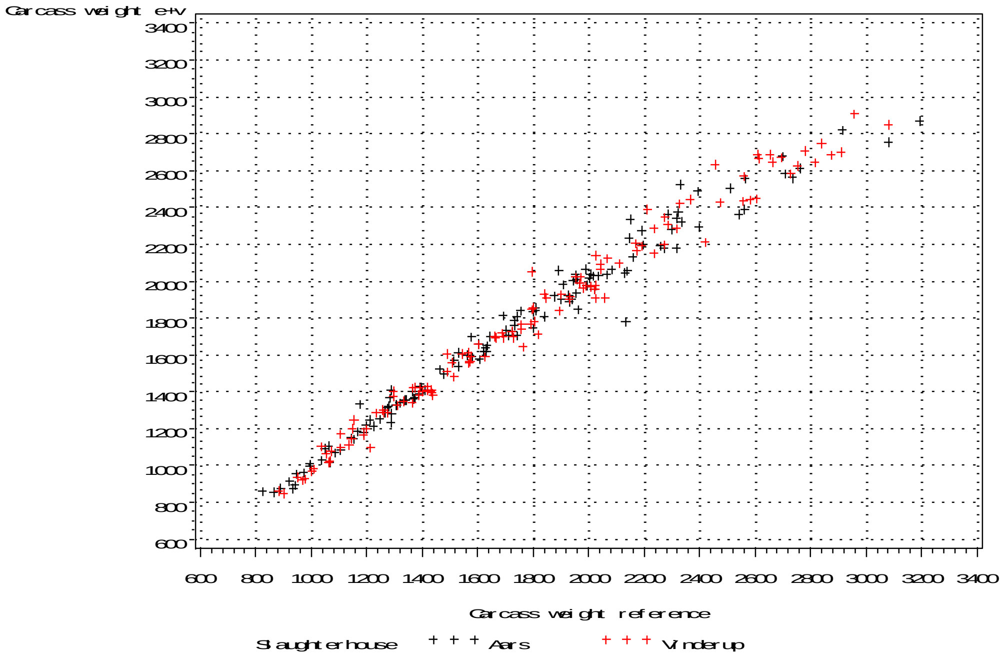
Furthermore, it was discovered that the shackle width of the two slaughterhouses are not the same. Some predictors are believed to be affected by the shackle width should therefore not be included in the classification equations which some of them were.

Compare to new references (validation)

The trial with split delivery from the producer did not include reference cutting of the chickens. That was done at the reference cutting of the special production of chickens in the phase 2 (described earlier). By that the classification results calculated by the version 1 equations were compared with new independent cutting references (validation). Ideally the classification equations should give the same results as the references, but that will never happen. We validate the precision of the equations by looking at the difference between the equation values and the reference values for all the chickens. If the mean of these differences is significantly different from 0 we have a systematic error – a *bias*. The standard deviation of the differences (the *residual standard deviation or RSD*) tells us how precise the classification is on average. The RSD can be used the same way as the standard error or the RMSEP: 2 x RSD is the precision with 95 % certainty.

Carcass weight

Figure 21 shows plots of the predicted values calculated by the equations versus the reference values for the two equations. Aars is indicated with black and Vinderup with red. The correlations are indicated below the figure. Figure 22a and b show the residuals (predicted – reference) versus the predicted values by slaughterhouse.



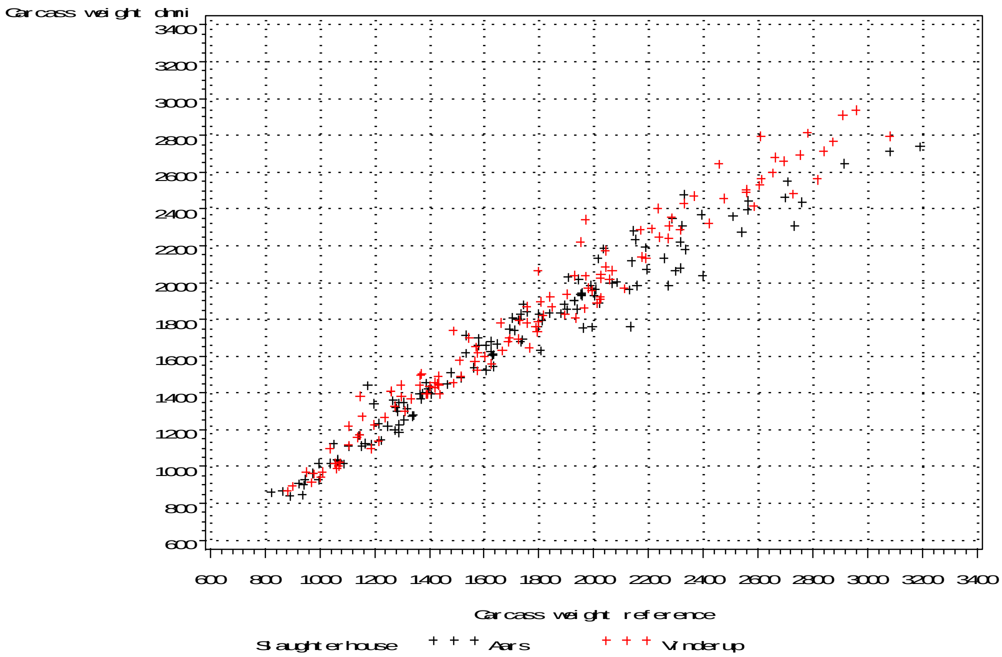
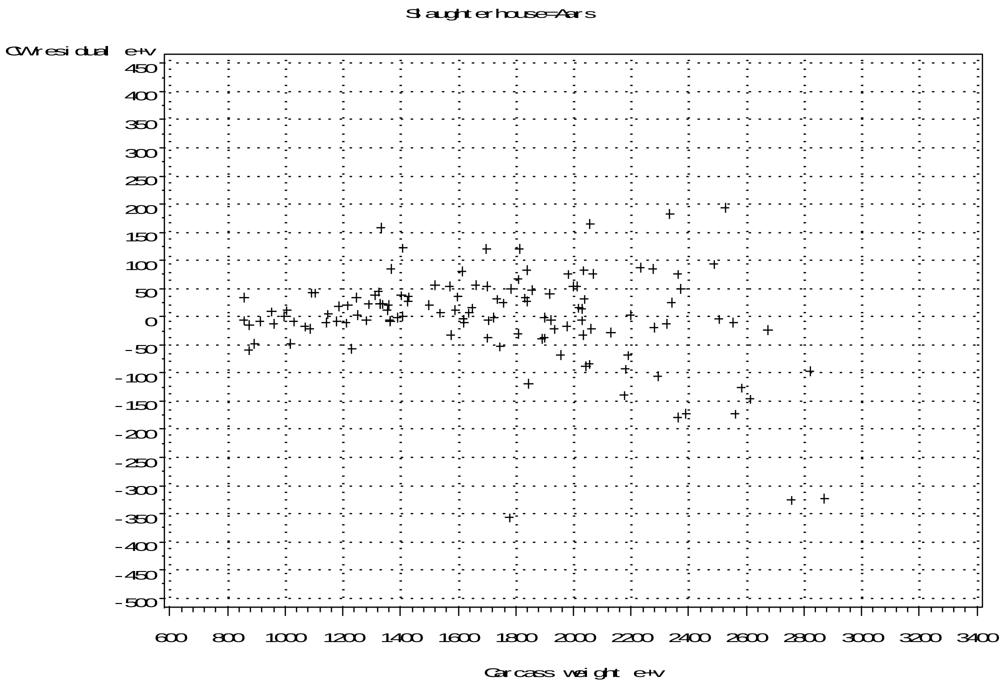


Figure 21. Carcass weight (gram). Predicted (y-axis) vs. reference (x-axis) values for linear regression (top) and PLS (bottom) equation. Slaughterhouses are indicated by colour.

The correlation between predicted and reference values are:

	Linear regression equation		PLS equation	
	Correlation	**p**	**Correlation**	**p**
Aars	0.98783	<0.0001	0.97463	<0.0001
Vinderup	0.99035	<0.0001	0.98275	<0.0001



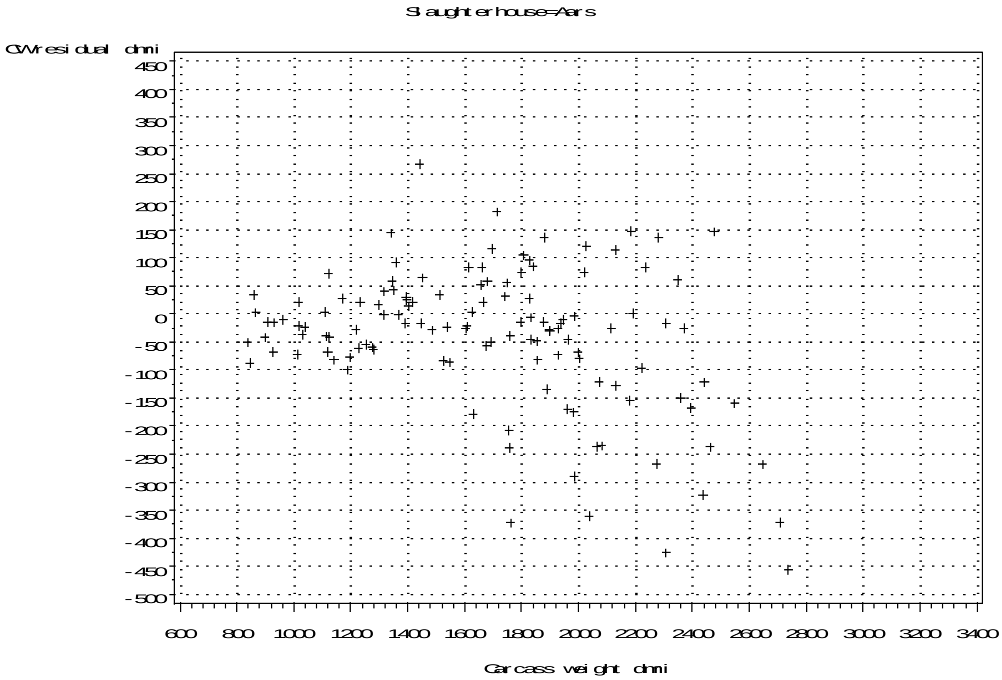
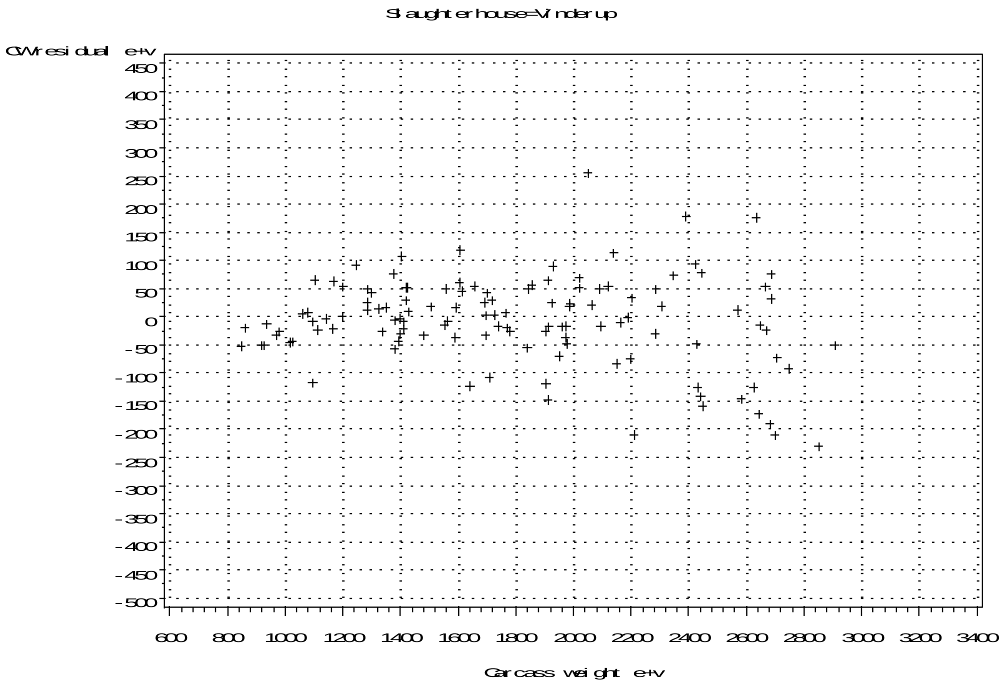


Figure 22a. Carcass weight (gram). Residual vs. predicted values for linear regression (top) and PLS (bottom) equation. Aars.



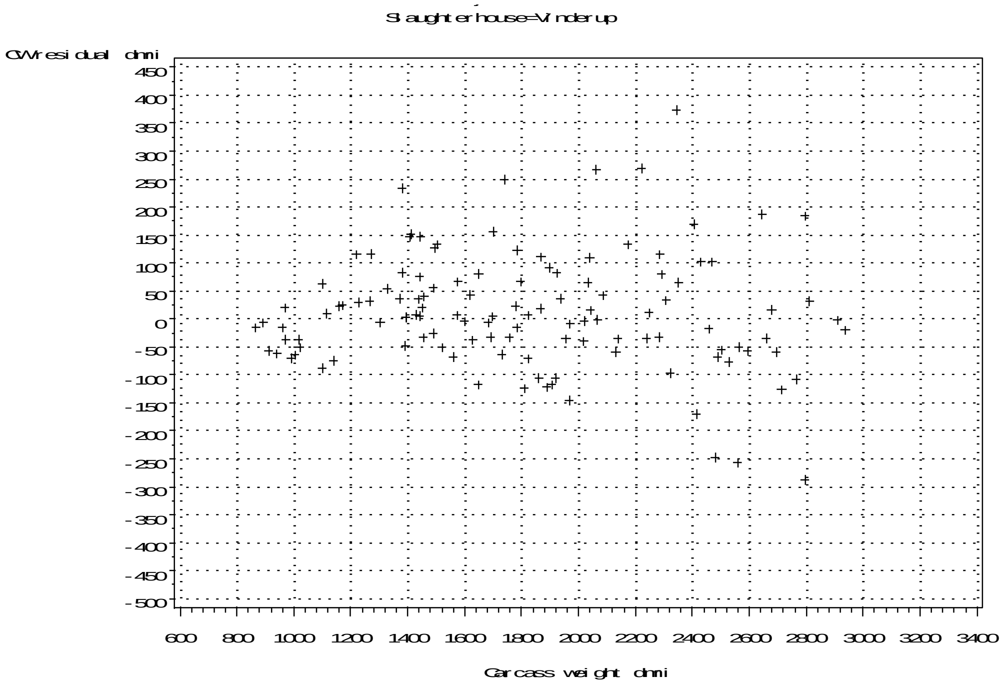


Figure 22b. Carcass weight (gram). Residual vs. predicted values for linear (top) and PLS (bottom) equation. Vinderup.

Both equations seem to be less accurate at high carcass weights and the DMRI equation seems to underestimate the carcass weight at high carcass weights in Aars.

Table 15 shows the reference weight compared with the residuals for the two equations. The reliability is a measure for how well the equation is (= (reference std)^2 / ((reference std)^2 + (residual std)^2)). It lies between 0 and 1 and a rule of thumb is that if it is over 0.8, the equation is good.

Table 15. Carcass weight (gram). Reference and residual (predicted - reference) of linear regression (LR) and PLS equation for Aars and Vinderup. Mean (*: significant, p = 0.0003), standard deviation and reliability.

		Reference carcass weight	CW residual LR	CW residual PLS
Aars	**N**	125	125	125
	Mean	1727.70	-1.22	-41.13*
	Std. dev.	522,42	83,82	124,6
	Reliability		0,97	0,95
Vinderup	**N**	122	122	122
	Mean	1804.55	-6.90	12.01
	Std	554,29	77,97	102,82
	Reliability		0,98	0,97
Both	**N**	247	247	247
	Mean	1765.66	-4.03	-14.88
	Std	538,68	80,87	117,19
	Reliability		0,98	0,95

The residual standard deviations are higher for the PLS equation than for the linear regression equation for both slaughterhouses, meaning that the PLS equation is not as precise as the linear regression equation. This can also be seen on the reliabilities but all reliabilities are over 0.9 which means that the equations are good.

The linear regression equation gives no significant biases. The PLS equation gives a significant bias of -41 gram on the Aars equipment meaning that the equipment underestimates the carcass weight by 41 gram on average. The PLS equation gives no significant bias on the Vinderup equipment. Biases indicate that either slaughterhouse conditions or vision equipment conditions (or both) are not the same as in Vinderup in January 2008 when data was collected for the development of the equations and that these conditions affect one or more predictors included in the equation. The reference material is produced in the same way and should not cause the biases. It looks like the PLS equation includes predictors that are affected by such conditions.

Table 16 shows how well the two equations classify the female and male chickens on the two equipments. Significant biases (t-test) are indicated with red.

Table 16. Carcass weight (gram). Bias (mean residual (predicted – reference)) and residual standard deviation (RSD) of linear regression and PLS equations by chicken sex and equipment.

	Linear regression equation				PLS equation			
	n	Bias	t-test p	RSD	n	Bias	t-test p	RSD
Female	105	4.53	0.5	63.48	105	-16.53	0.08	94.36
Aars	54	10.20	0.2	57.10	54	-34.09	0.007	91.85
Vinderup	51	-1.47	0.9	69.68	51	2.06	0.9	94.29
Male	119	-13.05	0.1	95.96	119	-10.88	0.4	138.97
Aars	53	-16.17	0.3	107.55	53	-50.85	0.02	158.69
Vinderup	66	-10.55	0.3	86.30	66	21.21	0.1	112.10

The PLS equation significantly underestimates (bias) the carcass weight of both female and male chickens in the Aars equipment. Otherwise the biases are not significant. Looking at the residual standard deviations, it seems that both equations work a little better for the females than for the males (smaller residual standard deviation). Furthermore, the linear regression equation is better than the PLS equation (smaller residual standard deviation) for both sexes.

18 chickens slaughtered in Aars had undetermined sex versus only 5 chickens slaughtered in Vinderup. This could indicate that the evisceration takes more out of the chicken in Aars than in Vinderup. Maybe that can explain a small part of the lower (although not significantly) carcass weight for the Aars equipment compared to the Vinderup equipment but since the weight is standardized this cannot explain the whole difference.

At the brainstorm in phase 0 the desired precision of the estimated carcass weight was 25-50 gram for sorting. None of the present equations can live up to that (2 x residual standard deviation). At best we have a precision of ±160 gram. Regarding payment to the farmers, the chicken industry has a big advantage compared to the pig and cattle industry because chickens are delivered and paid in large flocks. The errors in classification of the individual chickens will offset each other and the classification and payment of the flock will be very precise. Provided the flock is close to normally distributed, the classification precision of a flock (P(flock)) can be mathematically estimated by the formula:

$$P(flock) = \pm\frac{2 \text{ x RSD}}{\sqrt{\text{N}}}$$

Where RSD is the residual standard deviation and N is the number of animals in the flock.

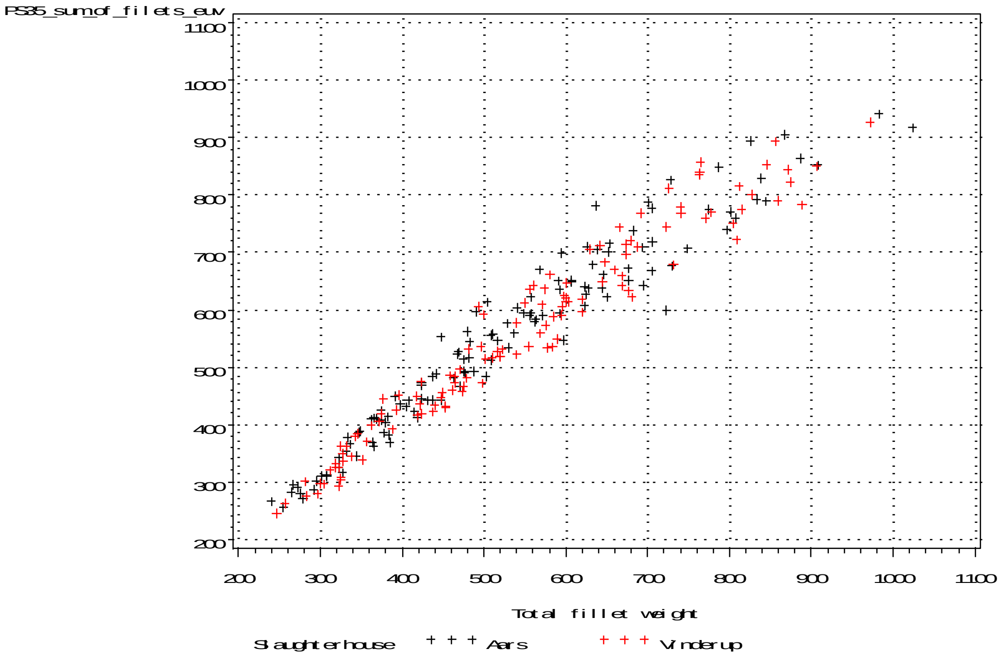
For example the precision of the estimated carcass weight of a flock of 30,000 chickens with a classification equation RSD = 160 gram is:

$$P(flock) = \pm \frac{2 \text{ x } 160}{\sqrt{30{,}000}} = \pm 1.8 \text{ gram}$$

The equations are a little more precise at low carcass weights and a little less precise at high carcass weights which are normal for this type of equations. The equations are a little more precise for female than for male chickens.

Weight of total breast fillet

Figure 23 shows plots of predicted versus reference fillet weight for the two equations. Below the figure the correlation between predicted and reference values are indicated.



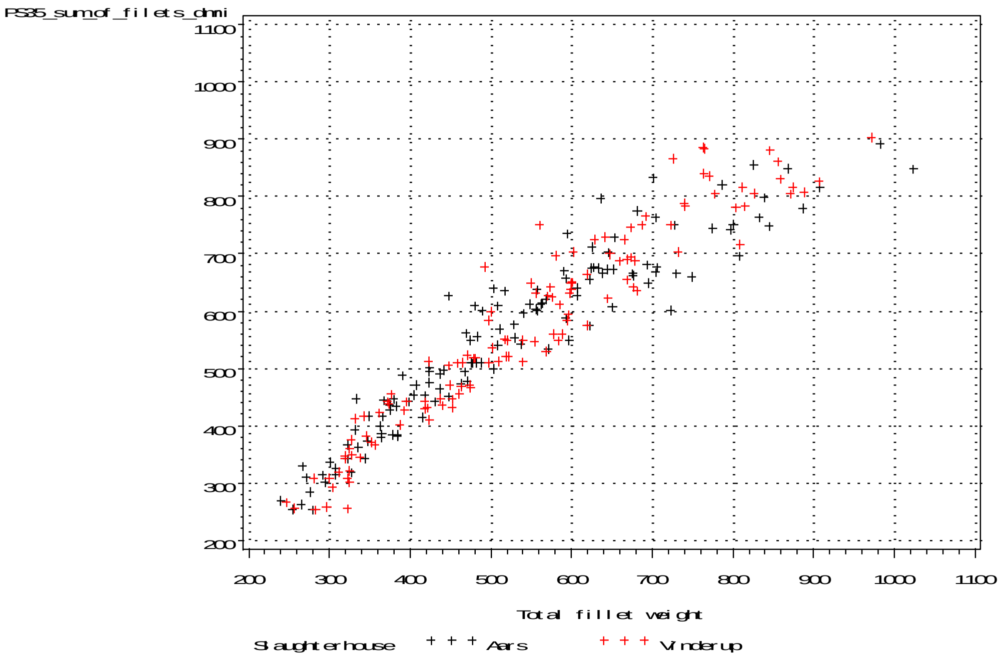


Figure 23. Total fillet weight. Predicted (y-axis) vs. reference (x-axis) values for E+V and DMRI equation. Slaughterhouses are indicated by colour.

The correlation between predicted and reference values are:

	Linear regression equation		PLS equation	
	Correlation	**p**	**Correlation**	**p**
Aars	0.96986	<0.0001	0.94290	<0.0001
Vinderup	0.97349	<0.0001	0.95713	<0.0001

The correlation between predicted and reference values are very high but both equations are less accurate at high fillet weights. Table 17 shows the reference fillet weight compared with the residuals for the two equations.

Table 17. Total fillet weight. Reference and residual (predicted - reference) of linear regression equation and PLS equation for Aars and Vinderup. Mean (*: significant, p = 0.003. **: significant, p < 0.0001), standard deviation and reliability.

		Reference fillet weight	TFW residual LR	TFW residual PLS
Aars	**N**	125	125	125
	Mean	529.78	21.02**	25.59**
	Std	174,09	42,42	58,51
	Reliability		0,9440	0,8985
Vinderup	**N**	122	122	122
	Mean	545.90	10.97*	23.70**
	Std	172,59	39,53	50,72
	Reliability		0,9502	0,9205
Both	**N**	247	247	247
	Mean	537.74	16.05	24.66
	Std	173,18	41,24	54,7
	Reliability		0,9463	0,9093

In both equipments both equations give significant biases. The equations overestimate the fillet weight by 11 to 24 gram on average. The biases indicate that either slaughterhouse conditions or vision equipment conditions (or both) are not the same in Vinderup and Aars as they were in Vinderup when data was collected for the development of the equations and that these changed conditions affect one or more predictors included in the equations.

If we look at how the reference fillet weight depends on the reference carcass weight then the fillet weight increases 306 gram per 1 kg increase in the carcass weight in Vinderup and 327 gram in Aars. That difference is significant (p=0.006). That may indicate some differences in the slaughter or chilling processes between the two slaughterhouses. There may even be difference in the processes between the phase 1 cutting trial and the phase 2 cutting in Vinderup to explain the bias in Vinderup.

Table 18 shows how well the two equations classify the female and male chickens on the two equipments. Significant biases (t-test) are indicated with red.

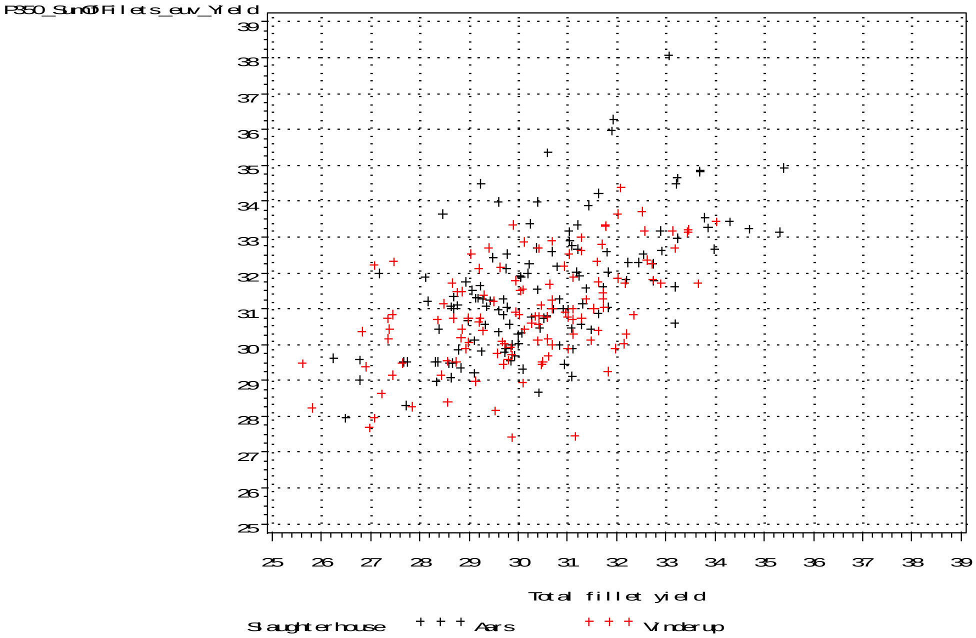
Table 18. Total fillet weight (gram). Bias (mean residual (predicted – reference)) and residual standard deviation (RSD) of linear regression and PLS equations by chicken sex and slaughterhouse.

	Linear regression equation				PLS equation			
	n	Bias	t-test p	RSD	n	Bias	t-test p	RSD
Female	105	20.96	<0.0001	36.16	105	27.68	<0.0001	50.37
Aars	54	25.70	<0.0001	34.60	54	29.35	0.0001	51.58
Vinderup	51	15.94	0.004	37.47	51	25.90	0.0005	49.51
Male	119	9.89	0.02	44.93	119	20.22	0.0003	59.63
Aars	53	12.85	0.06	48.48	53	18.11	0.05	67.09
Vinderup	66	7.52	0.2	42.08	66	21.91	0.0014	53.37

Both equations overestimate the fillet weight, except the E+V equation does not give a significant bias for the male chickens and the DMRI equation does not give a significant bias for the male chickens in Aars.

Yield of total breast fillet

Figure 24 shows plots of predicted versus reference fillet yield for the two equations. Below the figure the correlations between predicted and reference values are indicated.



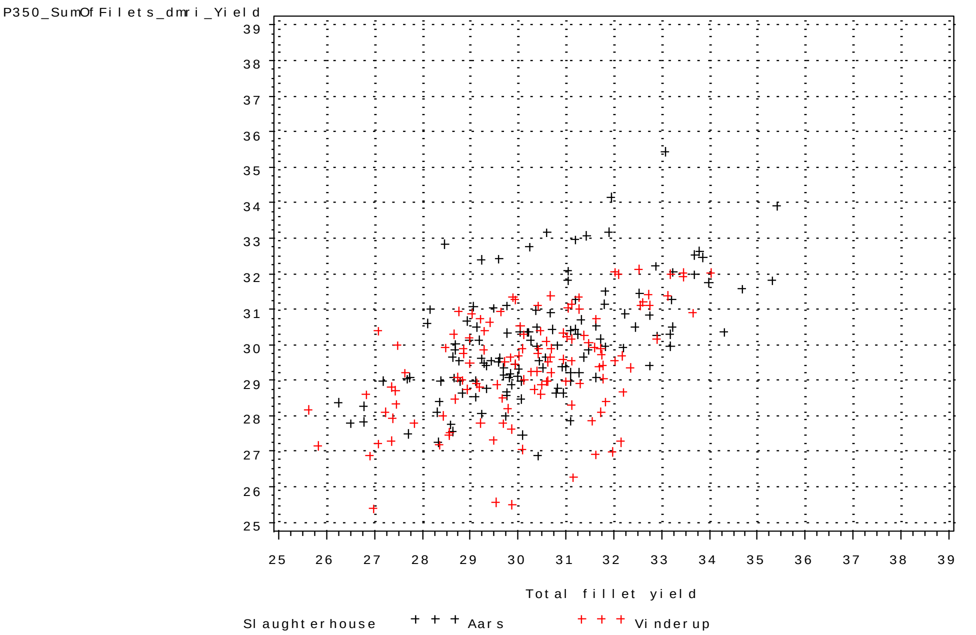


Figure 24. Total fillet yield (percent). Predicted (y-axis) vs. reference (x-axis) values for linear regression (top) and PLS (bottom) equation. Equipments are indicated by colour.

The correlation between predicted and reference values are:

	Linear regression equation		**PLS equation**	
	Correlation	**p**	**Correlation**	**p**
Aars	0.60287	<0.0001	0.56418	<0.0001
Vinderup	0.52263	<0.0001	0.48022	<0.0001

The fillet yield equations are not impressive. The correlations are 0.6 or lower. Table 19 shows the reference fillet yield compared with the residuals for the two equations.

Table 19. Total fillet yield (percent). Reference and residual (predicted - reference) of linear regression equation (LR) and PLS equation for the Aars equipment and the Vinderup equipment.
Mean (*: significant, p = 0.008. **: significant, p < 0.0001), standard deviation and reliability.

		Reference fillet yield	TFY residual LR	TFY residual PLS
Aars	**N**	125	125	125
	Mean	30.48	1.07**	-0.39*
	Std	1,86	1,63	1,62
	Reliability		0,5656	0,5686
Vinderup	**N**	122	122	122
	Mean	30.20	0.71**	-0.81**
	Std	1,77	1,6	1,68
	Reliability		0,5503	0,5261
Both	**N**	247	247	247
	Mean	30.34	0.89	-0.60
	Std	1,82	1,62	1,66
	Reliability		0,5579	0,5459

In both equipments both equations gives significant biases. On average the linear regression equation overestimates the fillet yield by 1.07 % in Aars and by 0.71 % in Vinderup. The PLS equation underestimates the fillet yield by 0.39 % in Aars and 0.81 % in Vinderup. The biases indicate that either slaughterhouse conditions or vision equipment conditions (or both) are not the same in Vinderup and Aars as they were in Vinderup when data was collected for the development of the equations and that these changed conditions affect one or more predictors included in the equations.

If we look at how the reference fillet yield depends on the reference carcass weight then the fillet yield increases 0.8 % per 1 kg increase in the carcass weight in Aars while the fillet yield does not change significantly by changing carcass weight in Vinderup. This difference is slightly significant (p=0.05). It is not surprising as we found larger increase in fillet weight by increasing carcass weight in Aars.

Table 20 shows how well the two equations classify the female and male chickens on the two equipments. Significant biases (t-test) are indicated with red.

Table 20. Total fillet yield (percent). Bias (mean residual (predicted – reference)) and residual standard deviation of linear regression and PLS equations by chicken sex and equipment.

	Linear regression equation				PLS equation			
	n	Bias	t-test p	Residual std	n	Bias	t-test p	Residual std
Female	105	0.98	<0.0001	1.67	105	-0.38	0,02	1.62
Aars	54	1.19	<0.0001	1.60	54	-0.21	0.3	1.55
Vinderup	51	0.76	0.003	1.73	51	-0.55	0.02	1.69
Male	119	0.77	<0.0001	1.57	119	-0.86	<0.0001	1.67
Aars	53	0.87	0.0002	1.60	53	-0.63	0.007	1.63
Vinderup	66	0.69	0.0006	1.56	66	-1.05	<0.0001	1.70

The E+V equation overestimate the fillet yield and the DMRI equation underestimates the fillet yield, except the DMRI equation does not give a significant bias for the female chickens in Aars.

Weight of other products

Linear regression equations for other products / parts of the chicken were developed in phase 1 and the equations have been used on the phase 2 validation data. The data have not been analyzed in detail but in appendix 2 you can see plots and some statistics for these equations.

Prediction of sex

One possible way to make better equations is to make different equations for the two sexes, males and females. In order to that we must be able to predict the sex. Based on trial 1 data, PCA prediction (classification) models are made and tested on both trial 1 data (results in table 21) and trial 2 data (results in table 22).

Table 21. Prediction (classification) of sex in trial 1 data based on PCA models made on trial 1 (number of chickens (percent)). Only chickens with known sex included.

	Classified as				
Reference	Correct sex	Both male and female	Wrong sex	No sex	Total
Males	5 (4 %)	113 (94 %)	1 (1 %)	1 (1 %)	120 (100 %)
Females	10 (7 %)	125 (91 %)	1 (1 %)	1 (1 %)	137 (100 %)
Total	15 (6 %)	238 (93 %)	2 (1 %)	2 (1 %)	257 (100 %)

Table 22. Prediction (classification) of sex in trial 2 data based on models made on trial 1 (number of chickens (percent)). Only chickens with known sex included.

	Classified as				
Reference	Correct sex	Both male and female	Wrong sex	No sex	Total
Males	16 (13 %)	95 (76 %)	1 (1 %)	13 (10 %)	125 (100 %)
Females	5 (5 %)	95 (88 %)	2 (2 %)	6 (6 %)	108 (100 %)
Total	21 (9 %)	190 (82 %)	3 (1 %)	18 (8 %)	233 (100 %)

The prediction of sex on the trial 2 data is the best validation of the “sex classification model”. It is clear that it is not possible to classify the sex correctly with the available predictors. Only 13 % of the male chickens and 5 % of the female chickens are predicted correctly. Most of the chickens will be predicted as both male and female (they fit in both the male and the female PCA model).

It is not useful to make different equations for the two sexes based on the predictors and the information presently available.

Conclusion

The split delivery from one producer showed considerable differences in the classification based on the version 1 equations between the two equipments. Furthermore, the validation of the equations on new cutting data showed in several cases significant difference between classification data and reference data.

One major cause was believed to be the guide bar (described earlier), which was present in both Vinderup and Aars during the cutting trial of phase 2 but not during the cutting trial of phase 1.

Therefore, the phase 1 cutting data were not the best for calculation of classification equations and it was decided to develop a version 2 of the equations based on the phase 2 cutting trial data where the guide bars were installed in both slaughter-houses. Furthermore predictors affected by shackle width should be excluded from the equations.

Version 2 equations

It was decided only to make new equations for the *carcass weight*, *the total breast fillet weight* and *the total breast fillet yield*.

Linear regression equations

Linear regression equations were made in the same way as for the version 1 equations this time based on phase 2 cutting trial data from both Aars and Vinderup and excluding predictors affected by shackle width.

Carcass weight

Figure 25 shows plots of the values predicted by the equation and the reference values for the Aars and the Vinderup equipment.

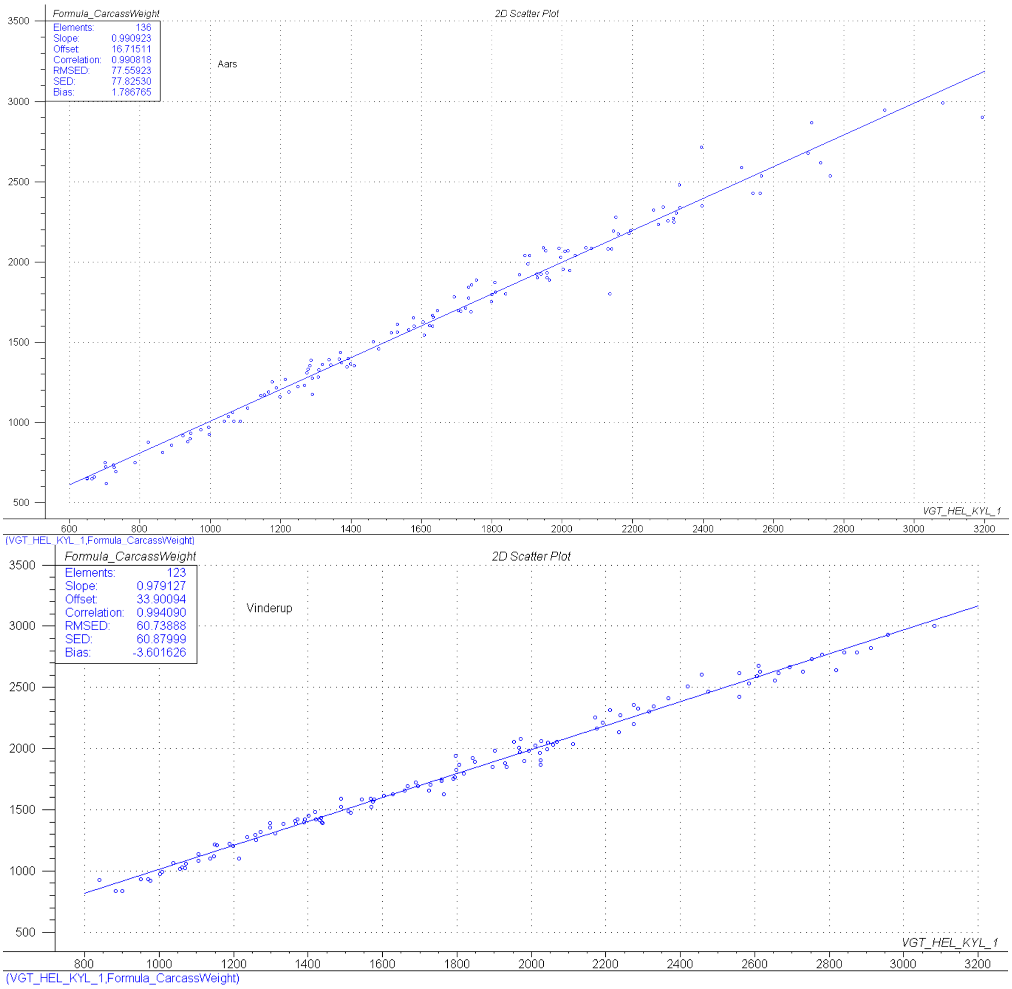


Figure 25. Carcass weight. Linear regression equation. Predicted (y-axis) vs. reference (x-axis) for the two equipments.

The statistics in the upper left corner of each plot shows a bias of 1.79 gram for the Aars equipment and -3.60 gram for the Vinderup equipment. (It was not tested if the biases are statistically significant). RMSED (root mean square error of deviations) can be compared to the RSD. For Aars RMSED is 77.56 gram and for Vinderup 60.74 gram. As before this corresponds to a precision of ± 155.12 gram with 95 % confidence for Aars and ± 121.48 gram for Vinderup.

The bias for the Aars equipment is very small and for the Vinderup equipment it is almost half of the bias with the version 1 equation. The RMSED's are a little smaller than for the version 1 equation. The version 2 equation is thus better than the version 1 equation. This is to be expected since the equation is tested on the same data as it is developed from but it looks like it was a good idea to install the guide bars and to exclude predictors affected by the shackle width.

The precision of the reference (the standard carcass weight) is not known but it is probably not more than a few grams. Theoretically there is therefore a potential for improvement, but in practice vision measurements may not have enough information for such an improvement.

The equation precision for female and male chickens is illustrated in figure 26.

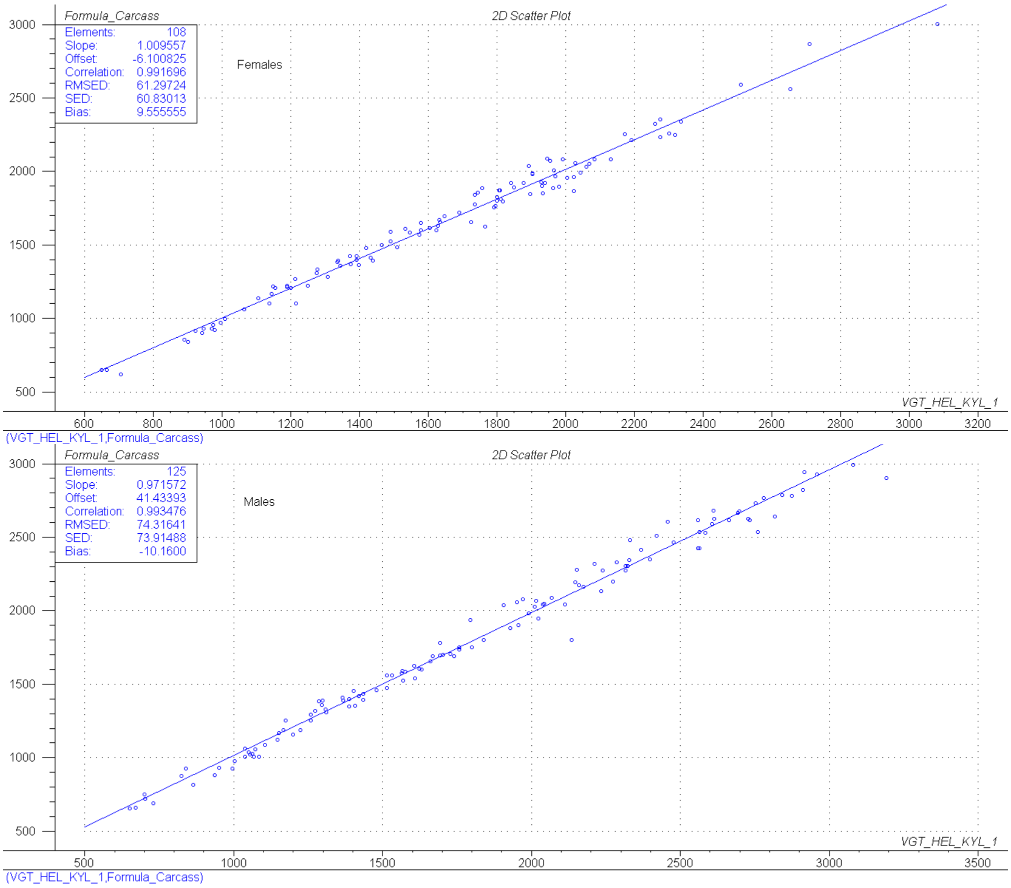


Figure 26. Carcass weight. Linear regression equation. Precision of female (top) and male (bottom) chickens. Predicted (y-axis) vs. reference (x-axis) for the two equipments.

The carcass weight of female chickens is classified with a systematic bias of +10 gram and the male chickens with a bias of -10 gram. Therefore, sex specific equations might be an improvement but it has not been possible to make reliable classification of the sex based on the vision equipment data (see below for further explanation). The RMSED is 61 gram for the females and 74 gram for the males – meaning that the females are classified a little more precise than the males.

Total fillet weight

Figure 27 shows plots of the values predicted by the equation and the reference values for the Aars and the Vinderup equipment.

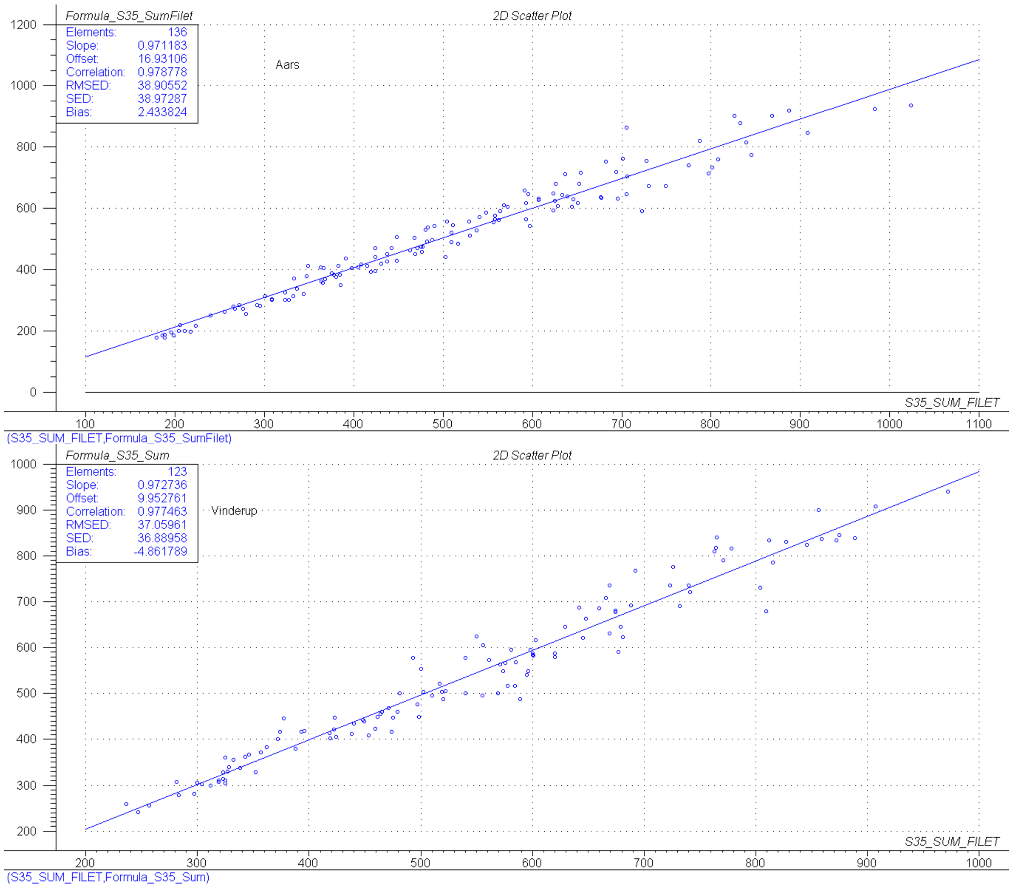


Figure 27. Total fillet weight. Linear regression equation. Predicted (y-axis) vs. reference (x-axis) for the two equipments.

The Aars equipment gives 2.43 gram in bias and the Vinderup equipment -4,86 gram. The RMSED is 38.91 gram for Aars and 37.06 for Vinderup. The biases are much smaller than for the version 1 equation and the precision (RMSED) is a little better. Compared to the precision of the reference (reproducibility = 8.33 gram) described earlier, there is still a theoretical potential for improvement of the prediction af the total fillet weight.

The equation precision for female and male chickens is illustrated in figure 28.

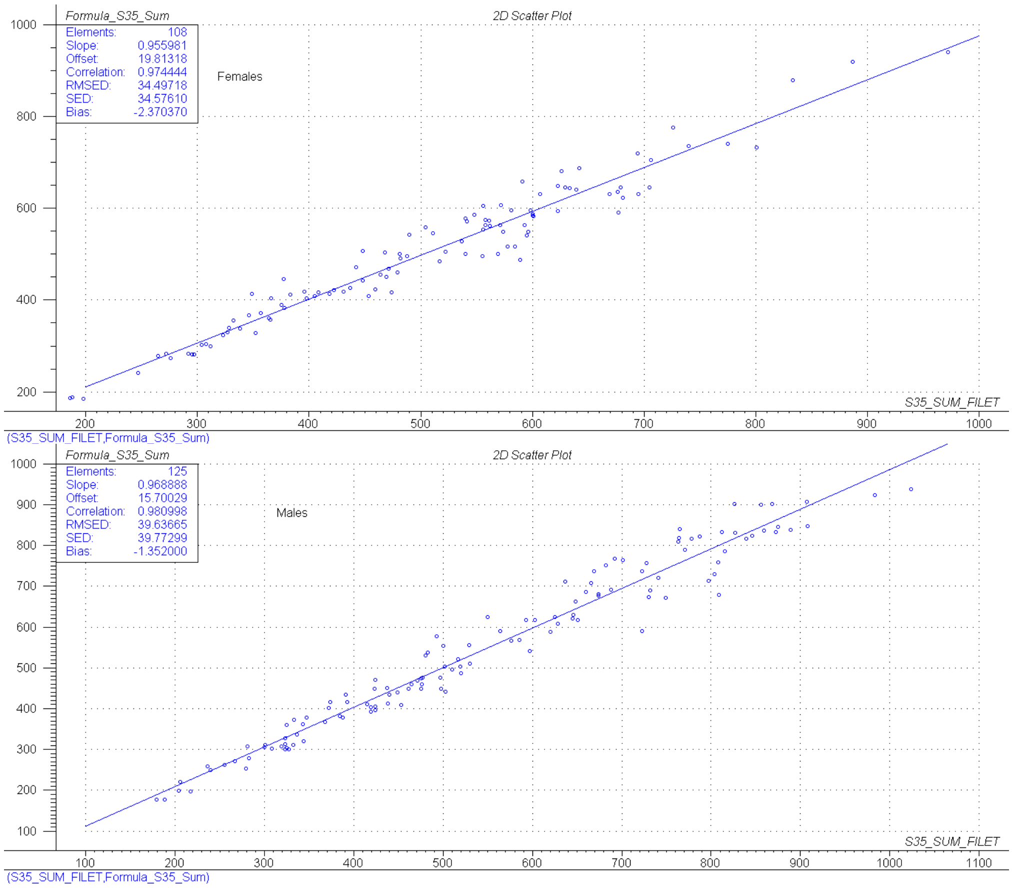


Figure 28. Total fillet weight. Linear regression equation. Precision of female (top) and male (bottom) chickens. Predicted (y-axis) vs. reference (x-axis) for the two equipments.

Both sexes are slightly underestimated (negativ biases) regarding total fillet weight. That can seem strange. Normally it would be expected that the biases would balance each other our but the explanation is that the chickens with undetermined sex (26 chickens) are overestimated and thus balance the underestimation of chickens with known sex. As described later, equations only based on the chickens with known sex will probably not be better. Furthermore, when the equations are to be used in future production, “chickens with unknown sex” will also have to be classified and that type of chickens should therefore be part of the reference data for the equations as it is here.

Total fillet yield

Figure 29 shows plots of the values predicted by the equation and the reference values for the Aars and the Vinderup equipment.

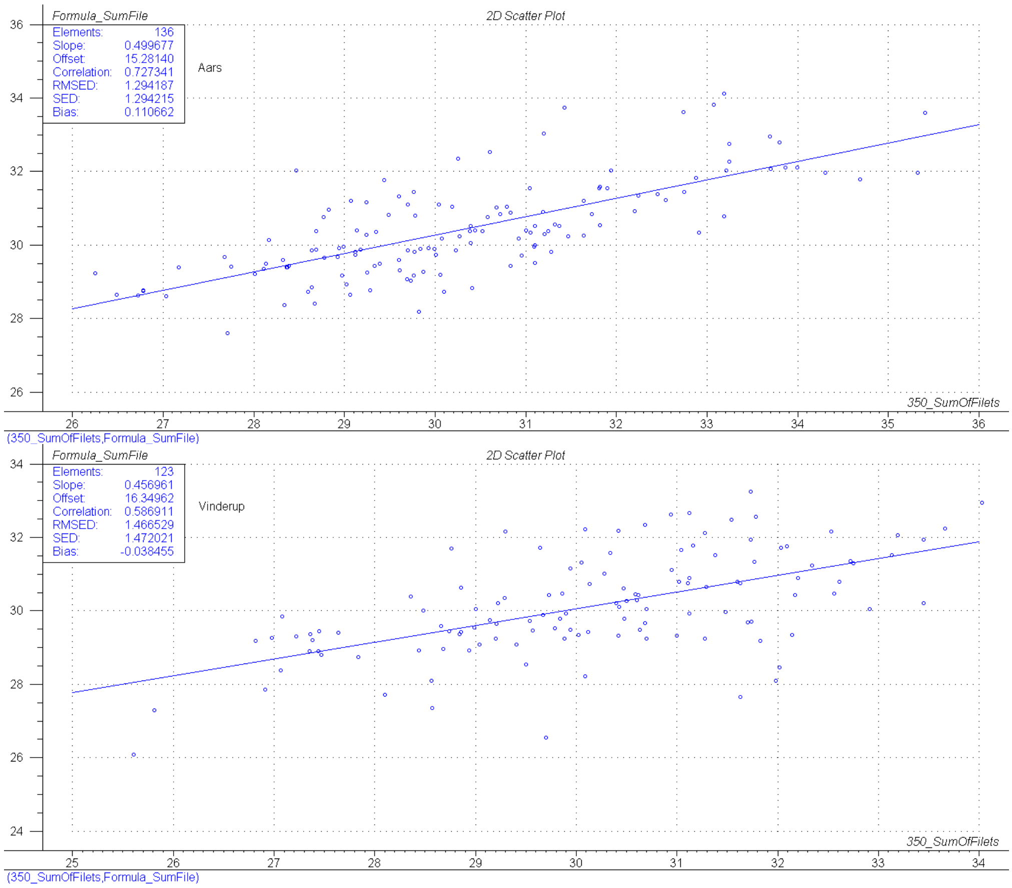


Figure 29. Total fillet yield. Linear regression equation. Predicted (y-axis) vs. reference (x-axis) for the two equipments.

The bias is 0.11 % for Aars and -0.04 % for Vinderup, which is much smaller than for the version 1 equation. The RMSED is also smaller (1.29 % for Aars and 1.47 % for Vinderup). This equation is thus much better than the first one. The error made by the vision equipment in predicting the reference (RMSEP) is actually smaller than the error made by the butchers in cutting of the reference (reproducibility = 1.93 %) as described earlier. Therefore the equation for the total fillet yield is probably as good as it can be.

The equation precision for female and male chickens is illustrated in figure 30.

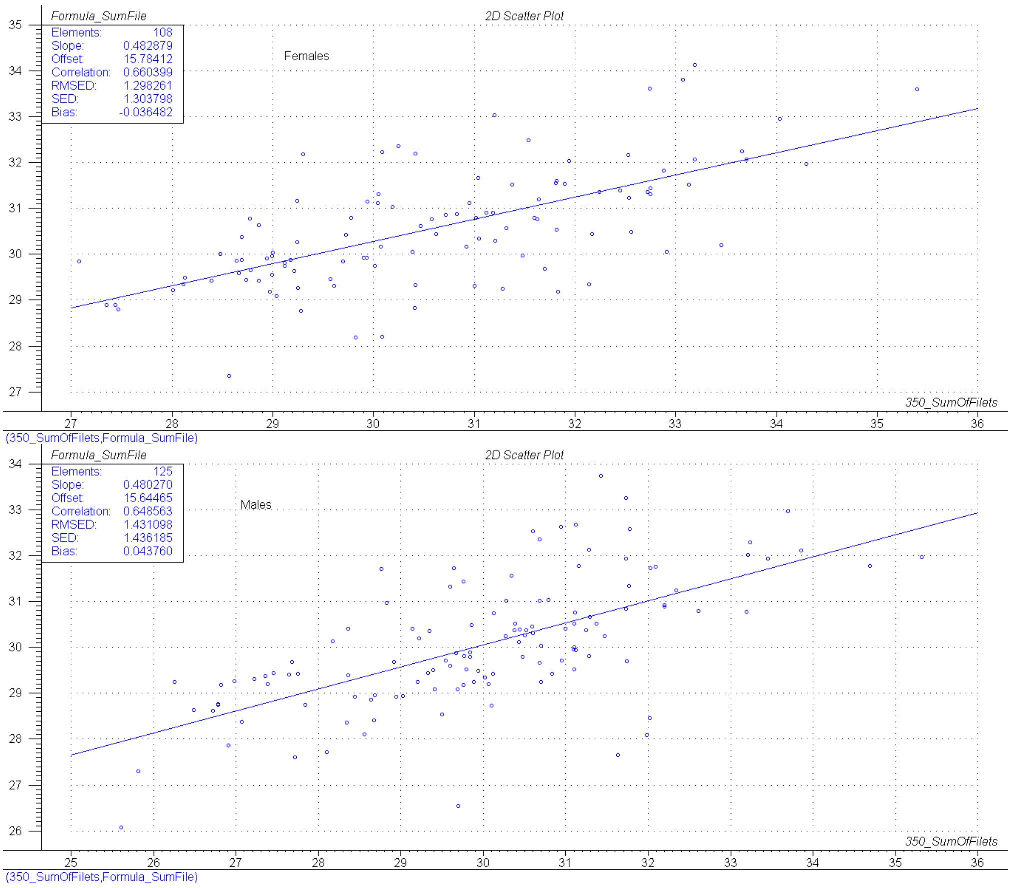


Figure 30. Total fillet yield. Linear regression equation. Precision of female (top) and male (bottom) chickens. Predicted (y-axis) vs. reference (x-axis) for the two equipments.

Biases for the two sexes are extremely small. RMSED are a little better for the females than for the males.

PLS equations

Using the same reference data as used for the linear regression equations and not including predictors affected by shackle width, multivariate PLS analysis was used to make equations for carcass weight, total breast fillet weight and total fillet yield.

Carcass weight

A number of different PLS equations have been tested. A PLS equation with all valid predictors gave a RMSEP of 126 gram. Using only predictors from the front view camera or the back view camera both gave a RMSEP of 139 gram. An approach where *interactions between predictors and squared predictors* were included looked promising. Unfortunately the available software could only handle interactions and squared variables of a maximum of 62 variables (predictors) and there are 214 valid predictors in the dataset. Equations made on different *subsets of interactions and squared variables* could bring the RMSEP as low as 87 gram. Still not as low as with the linear regression equation but it is recommended to further investigate if inclusion of interactions between predictors and squared predictors can make better equations for the carcass weight.

A PLS equation using the same four predictors as in the linear regression equation gives a RMSEP of 75.86 gram, which is a little *worse* than the linear regression equation (70.08 gram for both equipments). The biases for this equation are -2.36 gram for Aars and 4.73 gram for Vinderup (figure 31). Still small but not as good the linear regression equation. The RMSED are also a little larger than for the linear regression equation. It is a little strange that a multivariate principal component analysis like PLS cannot give at least as good an equation as a linear regression analysis. We have no explanation for this fact.

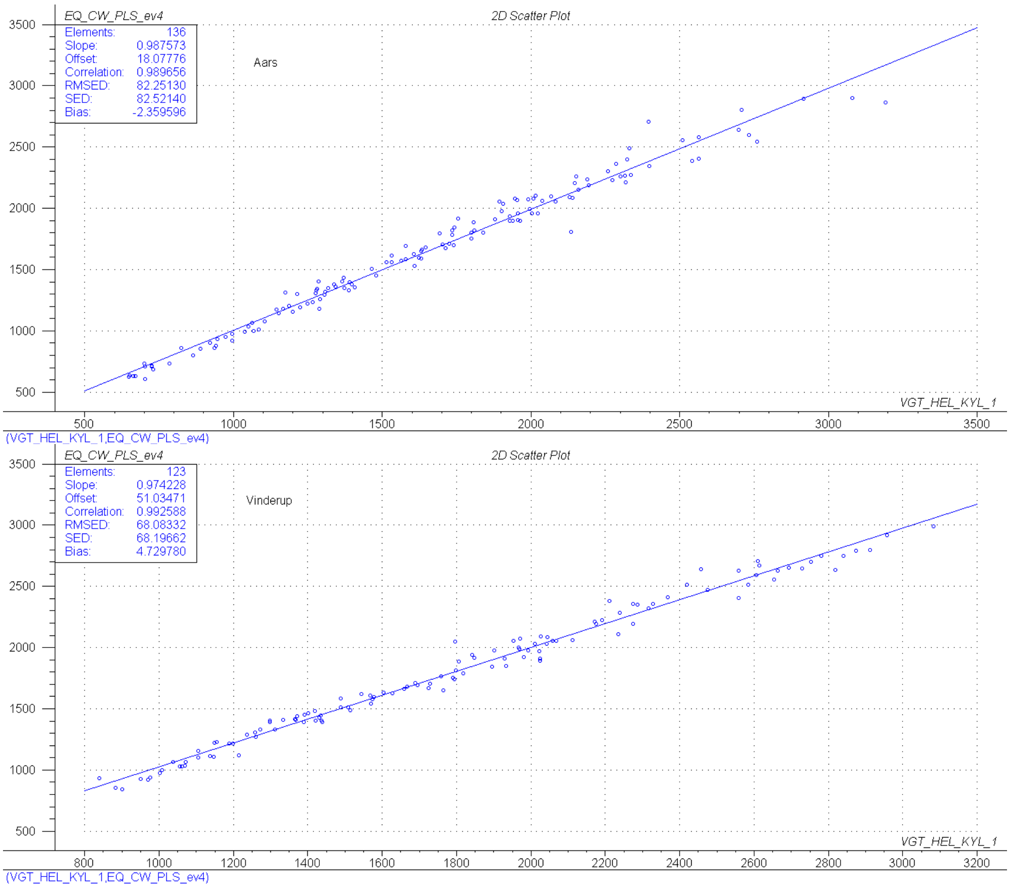


Figure 31. Carcass weight. PLS equation with the same four predictors as in the linear regression equation. Predicted (y-axis) vs. reference (x-axis) for the two equipments.

Total breast fillet weight

A PLS equation using all significant valid predictors gave a RMSEP of 49 gram, which is not as good as for the linear regression equation. Using subsets of predictor interactions and squared predictors did not improve RMSEP. The linear regression equation showed an overestimation of chickens with unknown sex. A PLS equation based only on the chickens with known sex still gave a RMSEP of 49 gram. Therefore and because also "chickens with unknown sex" must be classified, it does not make any sense to exclude chickens with unknown sex from the reference data.

Total breast fillet yield

A PLS equation using all significant valid predictors gave a RMSEP of 1.45 % which is not far from the precision of the linear regression equation. Including subsets of predictor interactions and squared predictors indicate RMSEP's as low as 1.42 %, but the present software cannot handle the size of the data and it is therefore not known how low RMSEP can get with this method. The possibilities for making better equations for total fillet yield by a more systematic testing of inclusion of predictor interactions and squared predictors is recommended to be investigated further.

Prediction of the sex of the chickens

As described above using equations common for female and male chickens may result in a bias for both sexes. Models for female and for male chickens using multivariate principal component analysis (PCA) were used to classify the chicken sex for the cuttings trial 2 data. Based on the models almost all chickens could be classified as both sexes. It does not look like inclusion of predictor interactions and squared predictors improves this classification.

Using PLS-DA (PLS Dicriminant Analysis) is another way of predicting the sex. Figure 32 shows the result of prediction of sex using PLS-DA on cuttings trial 2 data. A perfect prediction of sex would show total separation of males and females on the y-axis (predicted), which clearly is not the case. Any horizontal line attempting to separate the two sexes will result in a large proportion of wrongly predicted animals.

The conclusion is that the vision equipment data does not include any certain information about the sex of the chickens. Therefore it is not possible to use sex specific equations.

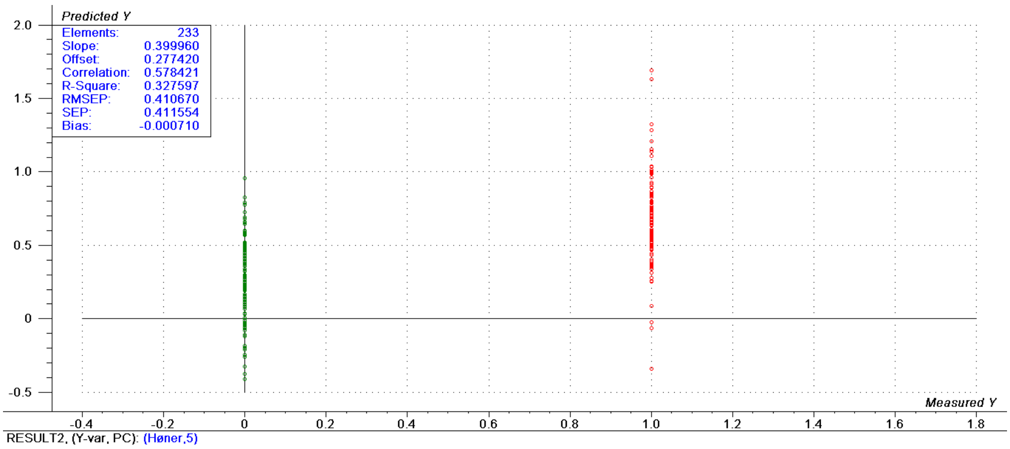


Figure 32. Prediction of sex using PLS-DA cuttings trial 2 data (green = males red = females)

The precision of the equations

When we consider if the equations are precise enough, it is important to remember what the equations will be used for. For *payment* to the producers the precision of classification of the individual chickens do not have to be very precise since large flocks of chickens are paid together and the individual random “errors” of the chickens will be balanced out. The precision of the classification mean of a flock (RSD_{flock}) of a given flock size (N) can be calculated (provided the flock is normally distributed regarding the classification) by:

$$RSD_{flock} = \frac{RSD_{chicken}}{\sqrt{N}}$$

If we consider for example a flock of 30,000 chickens the precision of the mean carcass weight, mean total fillet weight and total fillet yield can be calculated based on the RSD = RMSED described above and the precision with 95 % certainty being ±2×RSD.

For carcass weight with $RSD_{chicken}$=70 gram the precision of the flock mean will be:

$$Carcass\ weight RSD_{flock} = \frac{70}{\sqrt{30000}}\ gram = 0.404\ gram \ \Rightarrow$$
$$Carrcass\ weight\ precision_{flock} = \pm 2 \times 0.404\ gram = \pm 0.808\ gram$$

For total fillet weight with $RSD_{chicken}$=38 gram the precision of the flock mean will be:

$$Total\ fillet\ weight RSD_{flock} = \frac{38}{\sqrt{30000}}\ gram = 0.219\ gram$$
$$Total\ fillet\ weight\ precision_{flock} = \pm 2 \times 0.219\ gram = \pm 0.438\ gram$$

And for total fillet yield with $RSD_{chicken}$=1.38 % the precision of the flock mean will be:

$$Total\ fillet\ yield RSD_{flock} = \frac{1.38}{\sqrt{30000}}\ \% = 0.00797\ \%$$
$$Total\ fillet\ yield\ precision_{flock} = \pm 2 \times 0.00797\ \% = \pm 0.0159\ \%$$

Table 23 shows the precision of the flock means of classification for different flock sizes.

Table 23. Precision (95 % certainty) of the flock mean of carcass weight, total fillet weight and total fillet yield for different flock sizes

	Precision of flock mean classification					
	Carcass weight		Total fillet weight		Total fillet yield	
	(gram)	(percent of std)	(gram)	(percent of std)	(%)	(percent of std)
Estimated standard deviation	220	-	75	-	1,3	-
Flock size (N)						
30.000	0,808	0,37	0,439	0,59	0,01593	1,23
20.000	0,990	0,45	0,537	0,72	0,01952	1,50
10.000	1,400	0,64	0,760	1,01	0,02760	2,12
5.000	1,980	0,90	1,075	1,43	0,03903	3,00
4.000	2,214	1,01	1,202	1,60	0,04364	3,36
3.000	2,556	1,16	1,388	1,85	0,05039	3,88
2.000	3,130	1,42	1,699	2,27	0,06172	4,75
1.000	4,427	2,01	2,403	3,20	0,08728	6,71
900	4,667	2,12	2,533	3,38	0,09200	7,08
800	4,950	2,25	2,687	3,58	0,09758	7,51
700	5,292	2,41	2,873	3,83	0,10432	8,02
600	5,715	2,60	3,103	4,14	0,11268	8,67
500	6,261	2,85	3,399	4,53	0,12343	9,49
400	7,000	3,18	3,800	5,07	0,13800	10,62
300	8,083	3,67	4,388	5,85	0,15935	12,26
200	9,899	4,50	5,374	7,17	0,19516	15,01
100	14,000	6,36	7,600	10,13	0,27600	21,23
1	140,000	63,64	76,000	101,33	2,76000	212,31

The precision of the flock mean is of cause better when the flock is larger. When considering if a given precision is good enough for payment, the precision should be small compared to the variation (standard deviation) of the flock. The variation within flocks are not yet known but in the phase 2 data the standard deviation for the live weight group 2467 gram is 221 gram for the carcass weight, 79 gram for the fillet weight and 1.27 % for the fillet yield. For the live weight group 2730 the standard deviations are 219 gram, 69 gram and 1.30 % respectively. Therefore, let us assume that the standard deviations are 220 gram, 75 gram and 1.3 % respectively.

If we for example say that the precision should be smaller than 5 % of the variation, the flock size should be at least 200 chickens for the carcass weight, 500 for the fillet weight and 2,000 for the fillet yield. Therefore, if the payment are based on carcass weight and fillet yield, then the flock size should not be smaller than 2,000.

If the classification is to be used in *sorting of the individual chickens*, the precision is the 2 x $RSD_{chicken}$ (=RMSED). If we are sorting an individual flock, then a precision of ± 2 x 1.38 % = ± 2.76 % for the fillet yield is not good enough considering that this is 212 percent of the flock variation (1.3 %)! For the carcass weight the precision is 64 percent of the variation and for the fillet weight the precision is 101 percent of the flock variation. (See table 23 for "Flock size" = 1). In general, the equations are not considered to precise enough for sorting of individual chickens. On the other hand, if the classification is used to *sort whole flocks,* then the same considerations as for payment can be used.

Conclusion and recommendations

The version 2 linear regression equations including the best four predictors for carcass weight, total breast fillet weight and total breast fillet yield are so far the best equations available. The precision of these equations are considered to good enough for payment of large batches of chickens. For sorting of individual chickens the precision of the equations – especially the one for total fillet yield – are probably not be good enough to cause added value, but sorting of batches based on smaller or larger samples (the first number of chickens from the batches or flocks) may be accurate enough for added value.

Multivariate PLS equations may be an alternative if significant interactions and squared predictors are included. The available software could not handle the size of the data including all these effects but a new version of the software can handle the size of data. A preliminary analysis has showed some promise (data not shown).

Many of the predictors from the vision equipment are highly correlated and that may make the calculations in linear regression less reliable. Therefore, it is recommended to consider equations with combinations of predictors that are not too correlated. For example using only predictors representing distances (and not areas and volumes) or only areas etc. in multivariate analysis could be considered. Preliminary analyses of that kind have showed some promise (data not shown).

Finally it could also be considered to make further analysis of the vision images to develop *new predictors* that may be better to predict the classification parameters. One feature that has been mentioned is the heart-shape of the breast that may vary considerably and that may not be fully represented in the present predictors.

The number of chickens (247) and the distribution on reference slaughter weight and total fillet weight in the phase 2 cutting trial are sufficient as a base for development of the equations for classification of weights. Regarding the reference fillet yield more chickens in the low and high end of the scale would have been better in order to get a more precise equation, but as the carcass weight and the weight of total filet are highly correlated that can be difficult to obtain. More chickens in the reference data is of cause always better but the costs must also be considered. If classification of all the smaller parts of the chicken are considered less important, then future reference cuttings can include only carcass weight and total fillet weight and thereby save some cutting and registration costs.

Robustness of equations for weights and yields

Aim

The purpose of the robustness test is to determine whether variations in slaughter processes influence the measuring parameters (the predictors) for vision measurement (classification).

Introduction

A uniform and robust classification of chickens with vision assumes that the appearance of the carcass is not dependent on the prior slaughter process. The slaughter process is characterized by a number of factors which are slightly different both between slaughter lines and from day to day at the same slaughter line. It has not been possible to include all factors in this test. But three of the key factors are included:

- Electrical stimulation (type and time interval before classification)
- Plucking, i.e. setting of pressure on chicken
- Line speed of conveyor

Approach

Each factor is set at two levels, i.e. with/without electrical stimulation, high/low pressure by plucking and two line speeds. The effect of the factors on the classification is examined by comparing the classification of the two halves of a flock classified at one of the two levels of the factor. It is assumed that a flock can be divided into two equal halves. Each experiment consists of testing one factor at a time. Each experiment is conducted twice in the slaughterhouses in Vinderup and Aars, except one experiment of "pressure by plucking" in the Aars, which had to be interrupted because of too many slaughter errors resulting from the experiment. Lantmännen Danpo and Rose Poultry handled the data collection including choice of experimental flocks and setting the factor levels. While data analysis and reporting was handled by TI/DMRI.

Conclusion

Main result

Measurement of classification data, i.e. carcass weight and weight and yield of breast fillet, can be affected by the slaughter process to a greater or lesser degree. A factor may affect the calculation of carcass weight by up to approx. 30 grams, fillet weight by approx. 20 grams, and fillet yield by up to 0.3 %-points.

Experiments with pressure by plucking and changing line speed could be reproduced in Vinderup but not in Aars. While experiments with electrical stimulation gives an ambiguous result in both places. All factors affect the classification results.

Summing up it can be observed that process modifications of the same nature as in this experiment has influence on the classification. It is not possible to estimate an overall effect of the tested factors.

Partial results

The frequency of unclassified chickens is almost the same at the two slaughterhouses (approx. 2%). But the reason for lack of classification is not the same as determined by the distribution of error codes referring to the image analysis.

Data from the two cameras are recorded in a resulting data file, "slagteblad" and two "images files" with calculated predictor values. In a short time interval equal to 0.1% of the measurements are not consistent between the three data files, since classification data calculated online differ from offline calculations based on the predictors.

Comment

The test results give no opportunity to assess whether the differences that can be detected between the two slaughterhouses/equipments, provides various levels of classification for identical chickens.

It is recommended that parameters like "number of unclassified", the distribution of error codes and frequency of the image quality parameter "Plausibility" is part of a control system. Thereby greater experience with the cause of error codes and their interaction with the slaughter process can be achieved.

Discussion

Assumptions

The robustness test has shown that the classification results are affected by the slaughter process. In the robustness test, each factor is tested separately under the assumption that the other factors are maintained at "normal" level. The combination of factors is thus not known. But assuming that the effect of the factors are independent of each other, then the overall effect on carcass weight at worst will be in the range of 50-60 grams. This means that all slaughtered chickens can systematically be assessed 50-60 grams higher with one combination of factor settings, compared with another combination as illustrated in figure 33.

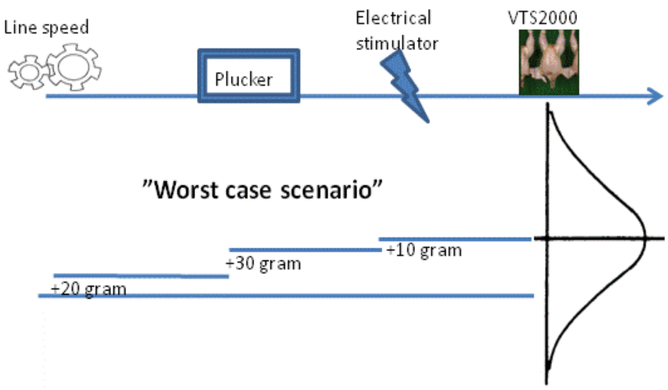


Figure 33. Illustration of measurement uncertainty in the determination of carcass weight composed of plausible systematic effects and random measurement error

Assuming that the setting of the slaughter process is changing from day to day, the systematic effect (bias) per day is regarded as a random daily variation, which is included in the uncertainty budget with variance = $bias^2$. Using the selected "worst case" impacts listed below totalling 60 grams, an estimate of the total measurement uncertainty is calculated by (60^2+70^2) gram = 92 gram.

"Reliability"

The variation of carcass weight in the population is in the order of 230 gram. The relationship between measurement error and the population variance "the reliability" can be calculated as 230^2 / $(230^2 + 92^2)$ = 86%. In other contexts, a measurement system with reliability larger than 80% is perceived as an acceptable measurement equipment. For comparison, a fully robust system. i.e. without day-to-day-variation gives an estimated reliability of 92 %. The corresponding calculations for fillet weight and fillet yield are shown in table 24.

	Day-to-day uncertainty	Measurement uncertainty	Combined uncertainty	Population standard deviation	Reliability	Reliability Full robustness
Slaughter weight	60 gram	70 gram	92 gram	230 gram	86%	92%
Fillet weight	20 gram	38 gram	43 gram	70 gram	73%	78%
Fillet yield	0.3 %	1.38 %	1.41 %	1.2 %	41%	43%

Table 24. Reliability

It is estimated that VTS2000 is sufficiently robust for measurement of carcass weight, while measurement of breast fillet weight and yield do not provide sufficiently robust predictions of individual measurements. Considering instead the mean of the individual measurements, the prediction uncertainty of the mean will be smaller than that of the individual measurement. For example, the mean breast yield of 100 measurements including the estimated robustness uncertainty will be determined with a standard deviation of 0.4% points (1.4% points on individual measurements). It will thus be possible to develop a payment system with regard to breast weight or yield based on flock means, which is sufficiently precise.

Classification of skin and wing damages

A system for finding skin and wing damages using the back and front images from the classification equipment has been developed and tested. Four parameters were included:

- Broken wings
- Bruises on breast and legs
- Skin damages
- Discoloration

The test gave the following results:

Defect classification test, SH Aars, 06.05.2010									Comparision Vision program and successive classification			
						Successive classification			Successive classification: Yes		Successive classification: Ye	
Trial / N	Defect	Specialist		Vision program (n=680)		based on images			Vision program: Yes		Vision program: No	
		Count	Percent	Count	Percent	Count	Percent		Count	Percent	Count	Percent
1 (flock 6)	Broken wings	35	5,15	42	6,18	52	7,65		37	71,15	15	28,85
680	Bruises (breast / legs)	4	0,59	3	0,44	14	2,06		3	21,43	11	78,57
	Skin damages		0,00	7	1,03	4	0,59		4	57,14	0	0,00
	Discoloration		0,00	0	0,00	5	0,74		0	0,00	5	100,00
				Vision program (n=680)								
2 (flock 7)	Broken wings	30	4,41	41	6,03	59	8,68		38	64,41	21	35,59
680	Bruises (breast / legs)	4	0,59	3	0,44	7	1,03		3	42,86	4	57,14
	Skin damages		0,00	4	0,59	3	0,44		3	75,00	0	0,00
	Discoloration		0,00	0	0,00	0	0,00		0	0,00	0	0,00

Defect classification test, SH Vinderup, 11.05.2010										Comparision Vision program and successive		
								Successive classification		Successive classification: Yes		Successive cl
Trial / N	Defect	Specialist 1 (Torben)		Specialist 2 (Brian)		Vision program		based on images		Vision program: Yes		Vision progra
		Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count	Percent	Count
1 (flock 6)	Broken wings	51	7,09	35	4,87	86	11,96	105	14,60	84	80,00	21
719	Bruises (breast / legs)	7	0,97	9	1,25	14	1,95	33	4,59	11	33,33	22
	Skin damages	10	1,39	10	1,39	12	1,67	12	1,67	10	83,33	2
	Discoloration	3	0,42	5	0,70	14	1,95	15	2,09	10	66,67	5
2 (flock 7)	Broken wings	67	9,14	60	8,19	80	10,91	110	15,01	77	70,00	33
733	Bruises (breast / legs)	21	2,86	12	1,64	18	2,46	42	5,73	15	35,71	27
	Skin damages	6	0,82	12	1,64	6	0,82	6	0,82	5	83,33	1
	Discoloration	0	0,00	8	1,09	16	2,18	13	1,77	12	75,00	1
3 (flock 8)	Broken wings	49	6,82	56	7,79	59	8,21	87	12,10	58	66,67	29
719	Bruises (breast / legs)	12	1,67	8	1,11	14	1,95	50	6,95	12	24,00	38
	Skin damages	3	0,42	6	0,83	9	1,25	6	0,83	6	66,67	0
	Discoloration	9	1,25	5	0,70	12	1,67	15	2,09	10	66,67	5

In Aars and Vinderup a test for the defect inspection has been done.
In Aars the normal manual defect inspection at the start of each flock has been carried out. Expert at Aars: We used for comparison the results of the official defect analysis. The analysis is carried out as follows: an Expert writes down all defects in a defined period (5 min = 680 carcasses) at the start of a flock. He is focused only to broken wings and great bruises on breast. Only wings broken in shoulder region (no broken wingtips) and clearly detectable bruises at the wings (not detected by the vision program when wings in normal position) are counted. Therefore the value “broken wings” is only limited comparable.

In Vinderup 3 test sets of about 700-720 chickens have been inspected by two inspectors.

All those carcasses have been analyzed online also by the VTS 2000.
Based on the stored pictures all carcasses have been classified again by us based on the specification from 2008-2009 (see columns ”successive classification” in the excel files). The image classification was executed by one person based on a defect-

feature-catalogue jointly worked out. It can be assumed a uniform evaluation method.

Furthermore we have compared the results of the vision program and image classification. We have defined 3 cases:

Case A: Accordance, vision program and image classification have detected the defect.
Case B: No accordance, image classification: defect, vision program: no defect
Case C: No accordance, image classification: no defect, vision program: defect

Please see attached excel file for the results.

The highest rate of defects was found by the image inspection. The lowest rate was found during the manual online inspection. We think that this is related to the fact, that for manual online inspection only the most seeable defects will be detected.

Manual classification of broken wings seems to be the most difficult part. Only 50% of the broken wings have been detected by the specialists. One explanation for this may be that some of the broken wings are behind the neighbour wing.

The vision system recognizes around 64-80% of broken wings. The difference between the vision program and image classification of broken wings is mostly based on the rigorous classification of broken wing tips as ”broken wing”. Because the wings of neighboured chicken are overlapped, it is difficult to detect broken wing tips.

Broken wingtips problem

a) Broken wings are not always detectable in image. It remains uncertain cases.

b) Vision program: The detection algorithm is based on a shape analysis of the wingtips. Well defined limits (length, width and direction) have to be set to distinguish between normal and broken wings. Generally this limitations are a little bit stronger (that means, we have less “broken wing” results) to avoid that too many normal wings are classified as “broken”. Inspection by eye is able to decide more complex.

c) Wing overlap problem: Areas on both sides of the neck oriented on the largest coordinate of the carcass axis as wingtip are examined by the vision program. But in reality it can occur that this is a wing of the neighboured carcass whereas the belonging, deeper positioned broken wingtip is not detected.

Bruises will be detected mostly on the breast by the manual inspection. Bruises on the legs will be detected on quite low rate by the manual classification.
The difference between the vision program and image classification of bruisesis mostly based on the rigorous classification of bruises on the legs.
For the image classification we found a relation bruises on breast / on legs 1 : 2.0 ... 2.5. For the vision program the relation value is 1 : 1...0.8

Bruises at breast are easier detectable by vision program because they are normally larger and more distinct. For bruising detection at the legs a spot size was fixed. Colour intensity and colour distribution are of influence. Fixed limitations are set for intensity and colour distribution. I am more cautious in order to avoid too much incorrect detection. Regular the spots don't have a continuous equal intensity. The appearance seems blurred this means the spot appears for the vision program smaller (parts seems to be out of intensity limitation). This results that some spots are out of the size limitation. The human eye is able to use larger ranges to come to decisions. Limitations can be increased. More bruises can be detected but the failure rate (no bruise, but as bruise detected) increases.

The discoloration values between the system and manual inspection differ highly. We think that the specification of a discoloration needs to be readjusted or discussed again.

The quantity of defects analysed except for “broken wings” is too small to be statistically significant.

Control of the classification

In order to ensure trust between producers and slaughterhouses regarding payment based on classification, it is recommended to establish a control system. Such a control system is established in Denmark for pigs, cattle and sheep. The control system for pigs, cattle and sheep is based on EU regulations and is managed by the independent unit “Klassificeringskontrollen” (the Classification Control).

Presently, there are no EU regulations regarding classification and payment of poultry. The Danish poultry industry can therefore decide if and how a control system shall work. In the following is given a proposal for a control system.

Proposal for control system

Rules

The rules for classification of broiler chickens extend to the following slaughterhouses:

- Chicken slaughterhouses that are members of “Det Danske Fjerkræråd” (Danish Poultry Council) and who slaughter more than xxxx chickens per week on a year average.
- Chicken slaughterhouses that are not members of “Det Danske Fjerkræråd” but via a contingent join the control system.

The aim is to define common rules for estimation of slaughter weight and total breast fillet yield (percent) which both are the base of payment to the producers. The individual slaughterhouse is required to inform the producer about the slaughter weight and the total breast fillet yield for each batch of chickens. The individual slaughterhouse decides how the carcass weight and the total breast fillet weight will be included in the payment. Furthermore, the individual slaughterhouse can decide to include other quality parameters in the payment.

The classification is based on the individual carcass weight and total breast fillet yield of the slaughtered chickens. The individual carcass weight must be estimated within a ± 200 gram per chicken with 95 % certainty. The individual total breast fillet yield must be estimated within ± 3 percent per chicken with 95 % certainty.

The average carcass weight by batch (more than 1,000 chickens per batch) will thereby be estimated within ± 6.3 gram with 95 % certainty and the average total breast fillet yield will be estimated within ± 0.1 percent with 95 % certainty. The average and standard deviation by batch of the carcass weight and the total breast fillet yield is the base for reporting to the producer.

If other parameters than carcass weight and total breast fillet yield are included in the payment, then they must also be reported to the producer.

Carcass weight is defined as a the slaughtered and eviscerated chicken with feet cut off in the joint and neck and neck skin cut off in a straight line across where the filet is attached to the shoulder. Total breast fillet yield is defined as the weight of the sum of left and right outer and inner breast fillets as percentage of the carcass weight as defined above.

A batch is defined as a payment unit agreed between producer and slaughterhouse, for example all chickens from a house delivered the same day.

Classification committee

The Classification Committee is appointed by "Det Danske Fjerkræråd". The committee includes two representatives for the producers and two representatives for the slaughterhouses. The tasks of the committee are:

- Prepare set of rules for classification of chickens.
- Prepare control instructions and guidance for weighing, classification and payment of chickens.
- Define demands for precision and calibration of automatic classification equipment.
- Deal with disputes and irregularities that cannot be handled by producer and slaughterhouse.
- Prepare a yearly report on the magnitude of the carried out control and the arrangements carried out as a consequence of the control.
- Prepare budgets and accounts for the costs linked to the tasks of the committee.

"Third party control"

With the aim of ensuring the trust between producers and slaughterhouses regarding payment, an overall control function, which has the supervision of measurement and administration, is established. The supervision includes:

1. Control of the slaughter process especially the process points that are expected to influence the classification. This includes a control of the presentation of the chickens at classification.
2. Control of procedure at daily calibration of classification equipment.
3. Control of traceability (correct registration of link between producer and chicken) and correct number of chickens by producer / delivery.
4. Control of the slaughterhouse self-policing.
5. Control of administration of classification i.e. that the measured data are correctly used in payment.

The "third party control" can be carried out by either "Klassificeringskontrollen for klassificering af svin, kvæg og får" (The Danish Classification Authority for pigs, cattle and sheep) or by a GTS institute e.g. Danish Technological Institute.

Self-policing system – daily control and supervision

The main aim of the self-policing system is to ensure correct and well functioning classification during the whole production process. The self-policing system includes:

- Daily calibration of classification equipment.
- Cleaning and other maintenance
- Data management
- Process control i.e. direct and indirect supervision of the slaughter and classification process.
- Potential updating of database with external access (third party control, service etc.).

Costs

The costs for management of the classification committee and thirds party control including one visit each quarter on each of four slaughterhouses (16 visits per year) will according to "Klassificeringskontrollen" be a little over 200,000 DKK / year. Further visits and work must be paid by the slaughterhouses separately. Details are to be negotiated.

Payment models

The principle

The idea is to let the payment of the chickens reflect the value of the chickens. A chicken can be used in several ways (several product mixes). It can be sold as a whole chicken or it can be cut up and sold as several individual products. Both the whole chicken and the individual products may have different values (price per kg) depending on the weight and quality. In many cases a given product can only be sold within given quantities. Therefore, the value of the individual chicken will normally depend on the characteristics of all the other chickens delivered to the slaughterhouse in a given period. The task of the slaughterhouse is to optimize the use of the given chicken population. Included in the optimization are also the production costs that are not the same for different product mixes. Obviously, it is more expensive to produce chickens cut up and deboned than it is to produce whole chickens.

Based on the calculation of the optimal use of the given chicken population, the values of selected classification parameters can be calculated. To be used in the payment, the value of a classification parameter will be an average for all chickens over a longer period regardless of the actual use.

The value of the classification parameters will most often not be linear. Using carcass weight as an example, the value of one extra gram carcass is not the same at 700, 1500, 2500 and 3000 gram. That being a reflection of the prices of the products at different weights. A whole chicken may for example have the maximum price (value per gram) at 1500-1800 gram and smaller prices outside this interval. The same may be the case for products like breast fillet, drumsticks etc.

The product prices and therefore the value of the classification parameters will vary over time. But the purpose of the payment system is not to reflect the exact value of the chickens at any given moment. It is an incentive for the producers to produce more valuable chickens to the benefit of both slaughterhouses and producers. Therefore, the selected classification parameters and their value in the payment system should not change every week. In order to give the producers the possibilities of long term planning, the value of for example carcass weight and total fillet yield should remain the same over longer periods. General fluctuations in the market prices may on the other hand be reflected by more frequent changes in the general level of the payment – using a *quotation*.

A model example

In the following the basic principles of a payment model based on the value of the chickens and the classification parameters “carcass weight” and “total breast fillet yield” is described as an example.

The model is based on the data from the phase 2 cutting trial including classification data and weight of all products. Other than that, the model is based on very simple data where there are only two product mixes (whole chicken and chicken cut in outer and inner breast fillets, wings, thighs, drumsticks, carcass shell and scraps). Product prises and production costs are set so that the level of payment corresponds to the present level. The use of the chickens is not optimized meaning that half of the chickens are used for each product mix – randomly selected. The value of each chicken is then an average of the value of each product mix. This may not make the model realistic in every way but the basic principles can be illustrated.

Using PLS analysis to predict the chicken value based on carcass weight and total fillet yield gives this model:

$Value_{chicken}$ = 0.01313 DKK/gram x carcass weight + 0.191 DKK/percent x fillet yield -19,312816 DKK

That means that if the carcass weight becomes 1 gram higher, then the value of the chicken becomes 0.01313 DKK higher. And if the fillet yield becomes 1 percent-unit higher, then the value of the chicken becomes 0.191 DKK higher. The constant (-19.312816 DKK) ensures the right level of the value.

Next step is to let the payment be the same as the calculated value of the chicken:

$Payment_{chicken}$ = 0.01313 DKK/gram x carcass weight + 0.191 DKK/percent x fillet yield -19,312816 DKK

A payment equation like this is probably not easy to understand and communicate between slaughterhouse and producer. Therefore, the payment equation is written in another way but still with the exact same content. We start with the payment for a "base-chicken" of 1800 gram carcass weight and fillet yield 30 percent:

$Payment_{base\text{-}chicken}$ = 0.01313 DKK/gram x 1800 + 0.191 DKK/percent x 30 -19,312816 DKK = **10.05 DKK**

The payment of any other chicken is then calculated as a supplement or a deduction for carcass weight different from 1800 gram and for fillet yield different from 30 percent. The supplement or deduction for carcass weight is 0.01313 DKK/gram difference from 1800 gram as indicated in the payment equation. The supplement or deduction for fillet yield is 0.191 DKK/percent. The supplement or deduction for carcass weight and for fillet yield is illustrated in figure 34.

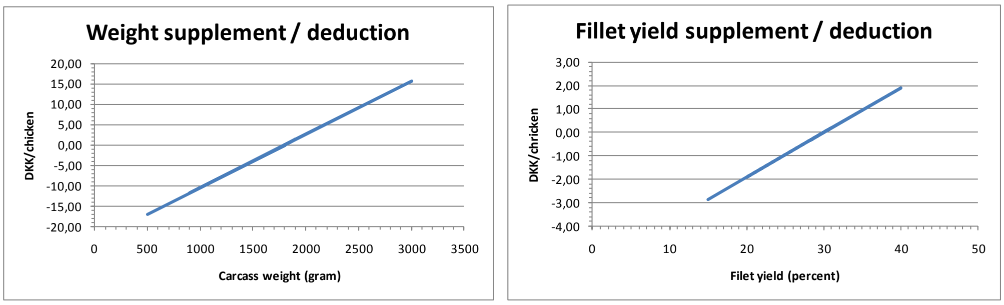


Figure 34. Payment model. Supplement or deduction for carcass weight and fillet yield.

The payment of the "base-chicken" (10.05 DKK) is the *quotation*, which can be changed regularly according to market prices. It can also be indicated per kg as (10.05 DKK / 1800 gram) 5.58 DKK/kg (rounded).

Choice of the "base-chicken" sends a signal to the producers that an 1800 gram chicken should have a fillet yield of 30 (a *norm* of 30 percent). But the fillet yield depends on the weight of the chicken and it could therefore be better to indicate a norm depending on the carcass weight. The relation between the “norm-fillet-percent” and carcass weight can be established in many ways. It is recommended to use a large sample of classification data (carcass weight and fillet yield) including representative producers and chickens. In this example the relation between the classification parameters fillet yield and carcass weight in the phase 2 cutting trial data is used, which gives this equation:

norm-fillet-yield = 29.00 + 0.000752 x carcass weight

The norm-fillet-yield as it depends on the carcass weight is illustrated in figure 35.

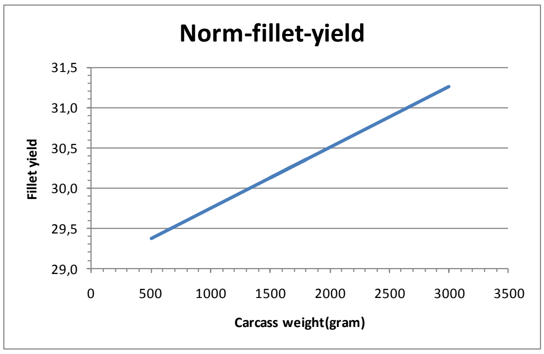


Figure 35. Payment model. Norm-fillet-yield.

The norm-fillet-yield is then used as base in the payment model and the “base-chicken” is now not only one chicken (with carcass weight 1800 gram), but any chicken with the norm-fillet-yield according to its carcass weight. The blue line in figure 36 represents the base-chickens and their payment is on the y-axis.

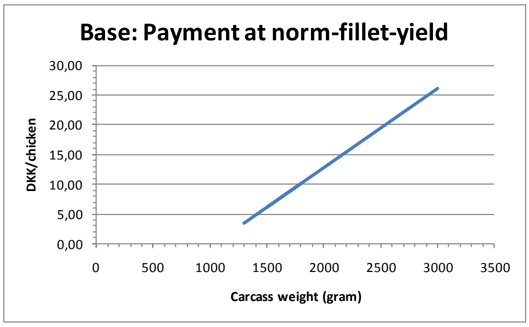


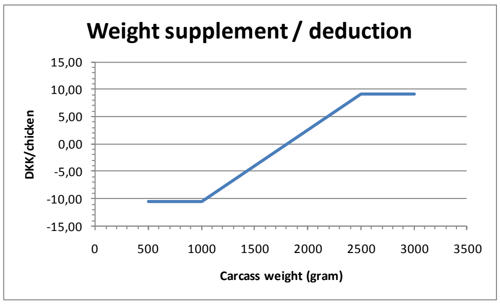
Figure 36. Payment model. Payment of “base-chickens” at norm-fillet-yield.

The relation between norm-fillet-percent and carcass weight may not be linear and the curves in figure 35 and 36 will then not be straight lines.

It is normal practice for the slaughterhouse to ask the individual producer to start the production and deliver the chickens to the slaughterhouse on specific dates. The slaughterhouse informs the producer on a “target weight”, which is the expected live weight of the chickens at delivery. For the given delivery, the slaughter weight at that “target weight” and the norm-fillet-percent at that slaughter weight is then defining the “base-chicken”.

In the pig sector the slaughterhouses communicate to the producers in “slaughter weight” (not “live weight”) regarding classification and payment since all payment is based on slaughter weight. The producers know how the slaughter weight corresponds to the live weight and can therefore deliver at the optimal slaughter weight. The advantage of this is that the slaughter weight is independent of feeding, watering etc. just before slaughter. For the same reason, the described model for payment of chickens is based on classification of slaughter weight and not live weight.

In the described payment model, it is not included that most products will have an optimum weight interval where the price has a maximum. That means that there will also be a carcass weight interval where the value of the chicken has a maximum. Therefore, the supplement / deduction for carcass weight will not be a straight line. In the same way we may not want a fillet yield over a certain point because it does not ad further value to the chicken. Finally we may want to have a maximum deduction for low carcass weight and low fillet yield. Then the supplement / deduction curves could there look as in figure 37.



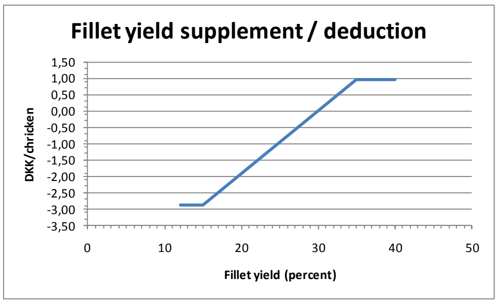


Figure 37. Payment model. Non-linear supplement or deduction for carcass weight and fillet yield.

The principles described above can be used to make a final payment model based on the classification parameters from the vision equipment. The following check-list can the be followed:

1. Description of the different uses (product mixes) of the chickens.
2. Description of the value of the chickens at different use. Costs and sales prices for the individual products.
3. Quality and weight demands for the individual products and how the demands are related to the classification. (Relations between weights and classification can be calculated from the phase 2 cutting trial data).
4. Sales share of the individual products.
5. Optimisation of the use of the raw material (the chickens) based on classification (maximizing the total value).
6. Calculation of the value of the classification parameters reflecting the value of the chickens and choice of parameters for the payment model.
7. Description of the connection between fillet percent and carcass weight (if they are chosen for the payment model). Based on a sample of classification data representing relevant types of producers, chicken sizes, chicken types, feedings

and seasons.

8. Calculation of the consequences of implementing the new payment system for relevant types of producers, chicken sizes, chicken types, feedings and seasons.
9. Description of payment model including figures, tables and explanations.
10. Establishing advisory procedures to the producers on how to obtain the optimal payment.
11. Presentation for the industry and the producers.

Possible payment parameters

Only parameters that the producer have full influence on, should be included in the payment. Carcass weight, fillet weight and fillet yield are examples of such parameters as long as the slaughter processes are not changed so much that the classification is affected (see the chapter on the robustness test). Examples of parameters that should not be included in the payment pH and driploss of the meat. The farmer has some influence in pH and driploss through choice of animals, feeding and handling, but transport and and slaughter processes have some influence and it would not be fair / acceptable to include such parameters in the payment. Some skin and wing damages can be included as long as there is a general acceptances that they are under the full control of the farmer.

In the above example, carcass weight and fillet yield is used as payment parameters. Other parameters can off cause be included. It will not make sense to include both fillet weight and fillet yield. As described earlier, the measurement of the fillet yield is not very precise for the individual chicken but as long as the payment is based on the mean of many chickens (a flock), the payment of the flock will be quite precise.

In phase 1 of the project, equations for many other parts were established. These equations are not validated in phase 2 and these parameters should therefor not be included in the payment.

Conclusion

As for any measuring systems, the precision of the vision classification equipment is not completely perfect. Therefore, the value estimation of each chicken is not perfect. But when evaluating a new payment model based on the vision classification, we have to compare to the present payment method. It is primarily based on weighing trucks with live chickens and subtracting the weight of truck and cages. With the proposed principle of a payment model based on classification of carcass weight and total breast fillet yield, there will be a much closer link between value of the chicken and the payment. The uncertainty of weight estimation based on truck weight is eliminated. Instead the payment is based on a standard carcass weight and more than just the weight of the chickens can be included in the payment. A producer that produces chickens with more of the valuable breast fillet can be rewarded.

Sorting

The purpose of sorting the chickens by selected classification parameters is to maximize the total value of a given chicken population (for example the production of one day or one week). That is done by calculating the optimal use of the individual chickens to different product mixes as described in **Payment models**.

In order to do that the relation between the classification parameters and the product weights (and quality if possible) must be known. For example how does the weight of the product “outer fillet” depend on the classification parameters “carcass weight” and “total fillet yield”? Product prises (including dependency on weight and quality) and production costs as described in **Payment models** must also be known. Furthermore, limitations of how much of a given product *can be sold* and how much *must be produced* according to orders must be known. Based on this information, it can be calculated which chickens should be used for which product mixes in order to maximize the total value.

The added value by optimizing the use of the chickens comes from:

- Better yields (some chickens are better suited for certain products)
- Better fulfilment of customer demands (deliver within more narrow bounds)

The basic preconditions for getting added value by sorting are:

a. Variation in the chicken population
b. More than one alternative use (product mix)
c. The chickens are valuable

Regarding a, the variation in carcass weight, total fillet weight and total fillet yield is quite large as indicated in table 25 where the classification statistics of one batch of approx. 28,000 chickens from one producer are shown.

Table 25. Variation in classification parameters for a randomly selected population of approx. 28,000 chickens.

	Carcass weight gram	Total fillet weight gram	Total fillet yield percent
Minimum	537	134	20.8
Maximum	3,015	793	35.8
Mean	1,440	423	29.6
Standard deviation	215	68	1.1

Regarding b, chickens are mainly produced as either whole chickens or cut in parts, but the whole chicken is produced in different sizes and the parts must have given weights in order to reach given package target weights. There is therefore a potential added value in an optimal use of the chickens.

Regarding c, it is of cause difficult to say if a given raw material is valuable. The "value thru-put" per hour on a pig respectively a chicken slaughterhouse is approx.:

- Pigs: 360 per hour x 1,000 DKK/pig = 360,000 DKK/hour
- Chickens: 10,000 per hour x 10 DKK/chicken = 100,000 DKK/hour

So based on the value alone, by comparing to the pig industry where sorting by classification has proven very valuable, there should be a potential for the chicken industry as well.

Further conditions for getting an added value by sorting are:

a. Precise measurements (classification)
b. Precise models for the relationship between classification and weight of products
c. Adequate traceability between classification and sorting
d. Adequate logistics

Regarding a and b, the more precise the better.

The precision of the classification of 70 gram for carcass weight, 38 gram for total fillet weight and 1.38 % for total fillet yield should be compared to the variation (standard deviation) in the population of chickens. Using the example illustrated in table 21 for one producer on one day, the precision is for carcass weight 33 % of the standard deviation, for total fillet weight 56 % and for total fillet yield 125 %, which is not impressive. The calculation is of cause not completely fair since the variation in the whole chicken population over for example a year must be expected to be much larger than for one single batch. Therefore, the evaluation of the potential value of sorting by classification should be made when classification data from many producers over a longer time are available.

The possibilities in using classification in sorting have been discussed with Rose Poultry and Lantmännen Danpo. DMRI has the experience of using optimizing software in order to maximize the value of pigs by sorting. The project has produced data that can be used to make models for the relationship between classification and weight of products (phase 2 cutting trial). Rose Poultry and Lantmännen Danpo have the information of product limitations, prices and costs and orders. Adequate traceability and logistics in order to handle sorting individual chickens based on classification is not yet available. Sorting of whole batches based on the batch mean classification or the mean classification of a sample from the batch may be possible in the present situation.

Implementation plan

Purpose and background for checklist

A checklist is established in order to have the best chance for a success full introduction with a new classification system based on vision measurements on the individual bird delivered for slaughter. The checklist is partly inspired on experience from previous introductions and changes of classification and payment systems in the beef and pork industry. The checklist is given as a recommendation and as a proposed model only. Since few specific legal requirements exist with respect to poultry classification and payment it will be mainly a commercial decision to which extent the individual recommendations should be followed, partially used or omitted.

Contract on delivery of vision systems and introduction of daily use in the industry

New and old equipment

The visions systems used in the project may be taken over by the slaughterhouses. For those equipments it is important to ensure that their quality is at the same level and identical to new systems delivered. This includes update of all software, hardware and documentation and manuals.

As part of ordering new systems a demand specification should be agreed with the supplier, this should include several aspects like:

- Capacity
- Guaranteed Stability of system
- User interface for monitoring of daily use
- Report and data interface with the slaughter data network and potential external bodies to receive data
- Data and image storage
- Service requirements and organization of service
- Warranty

User procedure

It is required that the necessary internal organization at the slaughterhouse is established for monitoring daily use of the new vision system for payment. It is the experience that this organization must be very clear in specifying tasks and responsibilities in order to establish quality measurements as a basis for payment. It is a difficult but necessary transition from working with project equipment to work with equipment that is the major determinant og producer payment. Use of process control charts and log books electronic or on paper for documenting the use of the system.

The slaughter plant will achieve reliable results from the measuring equipment by applying frequent control and checks as suggested below:

Daily procedures: according to manual for the equipment and eg. conditions agreed with 3.rd body control party checks of equipment including: visual, electronic test reports and test calibration of steel bird is performed, control of conditions and cleaning of lamps and camera, and logging of checks performed.

Weekly checks: in addition to the more technical daily evaluation it may be usefull to compare week average results to identify trends/drift at an early stage with a moving average.

Quarterly: The slaughter should evaluate performance and equipment over the last quarter e.g. in a dialogue with a third party control. The evaluation may be adjusted in frequency depending experienced variation.

Annually: Lamps and camera should be serviced every year or at least every xx months by the supplier or another technical service party trained in this. These may typically agreed within a service contract and could include exchange durable parts.

Incidental checks: Within the development project it is planned to test how change of process may affect or not the results from the measuring equipment. It is important to know if changes in procedures or equipment systematically will influence results. Eg. does change in parameters like carcass presentation for measurement, gambrels, stunning, electrical stimulation, scolding, plucking and slaughter line than may have an influence on results that should be corrected for. For parameters that in the project test are shown sensitive to measuring results, extra care and action is needed if a plant makes process changes after installation and approval of equipment. Generally however with any process change it is recommended to evaluate if actions should be taken to verify influence on measuring results. With respect to the poultry delivered larger changes in size, weight, dimensions, genetics and feeding that may push the system and used prediction models beyond their limitation shall also be monitored, and the need for a recalibration of the models may be needed over longer time intervals 3 -5 -10 years depending on rate of change in the production of birds.

3.rd party control

Presently the only instruments used or partially used for establishing payment of broilers is the truck weighbridge, and internal systems for counting numbers of birds in a batch and internal weighing systems on the conveyor.

With a new vision measuring system a estimated batch standard carcass weight, and breast meat yield may become a part of the future payment model. In order to achieve sufficient trust in this for both the producers and the meat plants, it is highly recommended in addition to internal procedures (own control) and monitoring of equipment, to outsource a frequent control from a external 3.rd party to warrant that the measuring systems is working correctly as a basis for payment.

Within the project a model for 3.rd party control of the vision systems and handling of data for producer payment is given (Larsen & Olsen, ref). In this model both technical checks of equipment use of data for payment is frequently audited. Eg. it will be ensured that the equipment used is running to specification and that the slaughter plant staff is monitoring and servicing equipment according to agreed standards. The 3.rd party control may be conducted fully by e.g. http://www.klassificeringskontrollen.dk/ or in cooperation another technical competent body with experience in monitoring/certifying equipment.

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Appendix 1. Wheat programs for chickens in phase 1 reference cutting trial

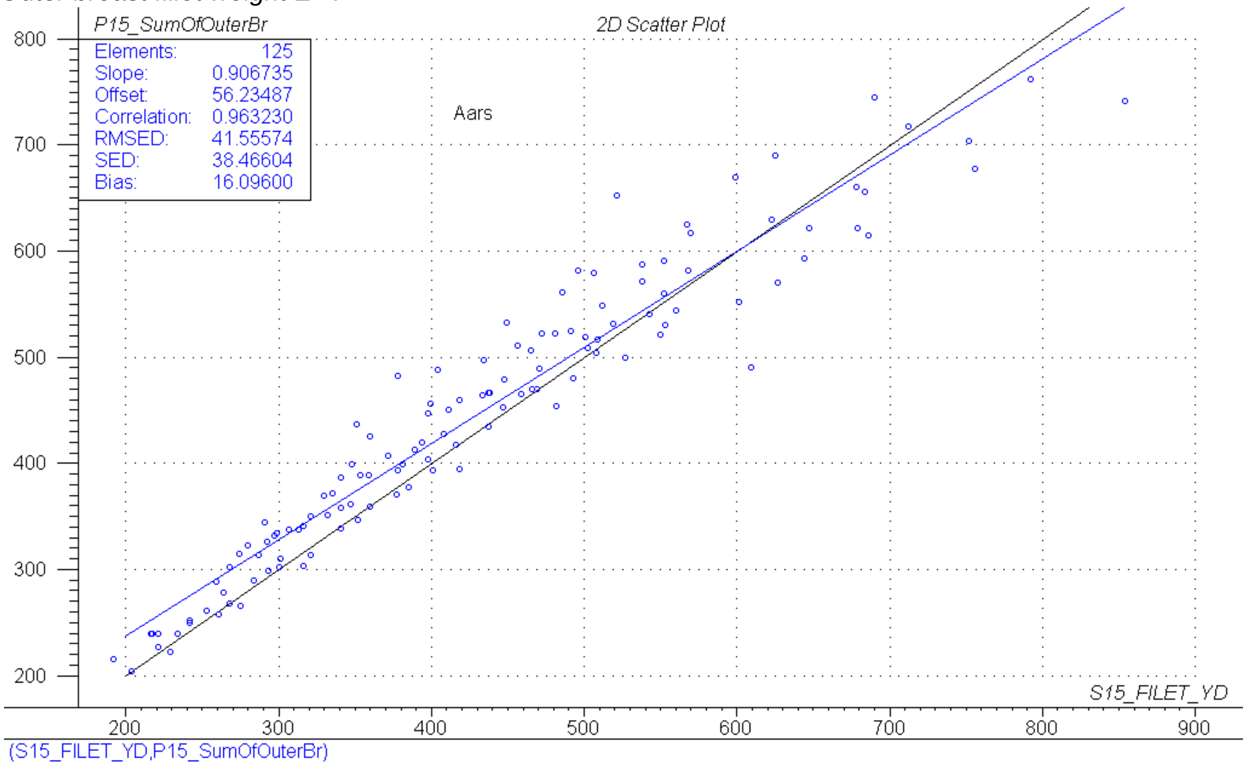
Percent wheat for low, norm and high group

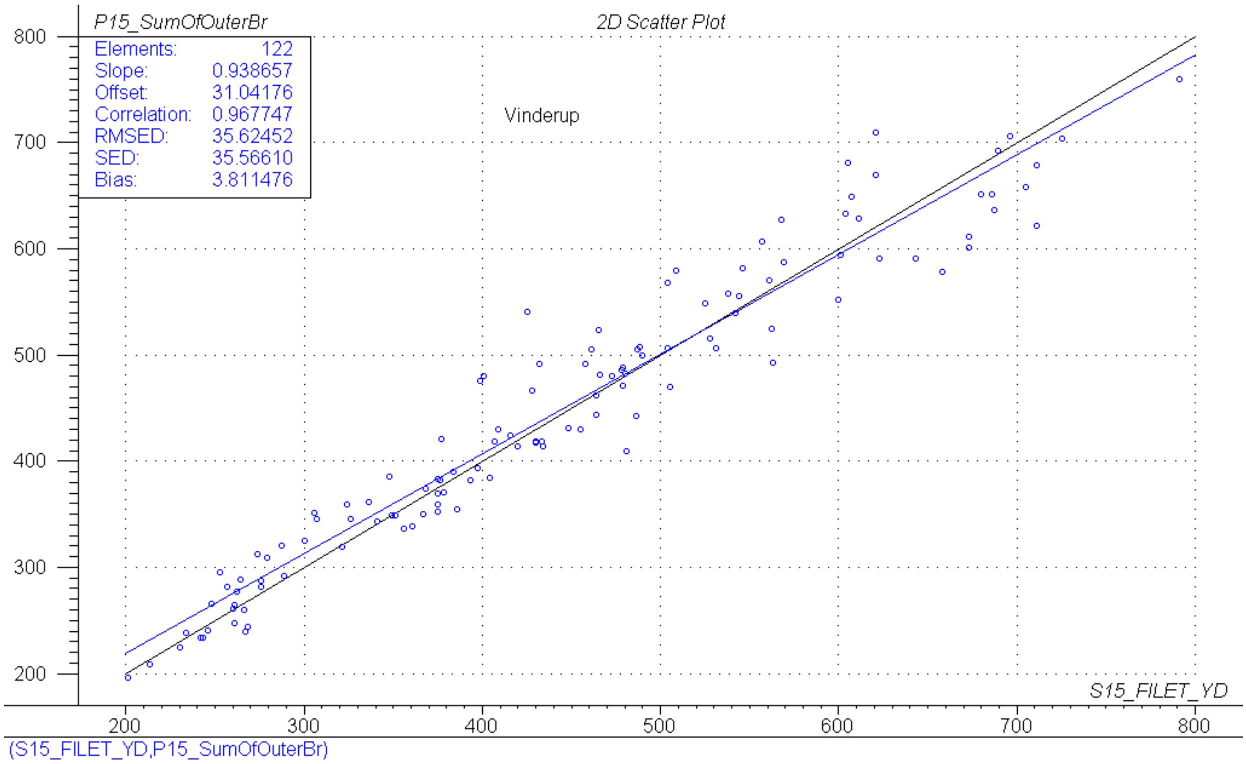
Day	Low	Norm	High
0	0	0	0
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0
9	0	0	0
10	4	6	8
11	5	7	9
12	6	8	10
13	7	9	11
14	8	10	12
15	7	11	15
16	8	12	16
17	9	13	17
18	10	14	18
19	11	15	19
20	12	16	20
21	13	17	21
22	12	18	24
23	13	19	25
24	14	20	26
25	15	21	27
26	16	22	28
27	17	23	29
28	18	24	30
29	19	25	31
30	20	26	32
31	21	27	33
32	22	28	34
33	23	29	35
34	24	30	36
35	26	32	38
36	26	32	38
37	26	32	38
38	28	34	40
39	28	34	40
40	28	34	40
41	30	36	42
42	30	36	42
43	30	36	42
44	32	38	44
45	32	38	44
46	32	38	44
47	34	40	46
48	34	40	46
49	34	40	46
50	34	40	46
51	34	40	46
52	34	40	46
53	34	40	46
54	34	40	46

Appendix 2. Equations for other parts

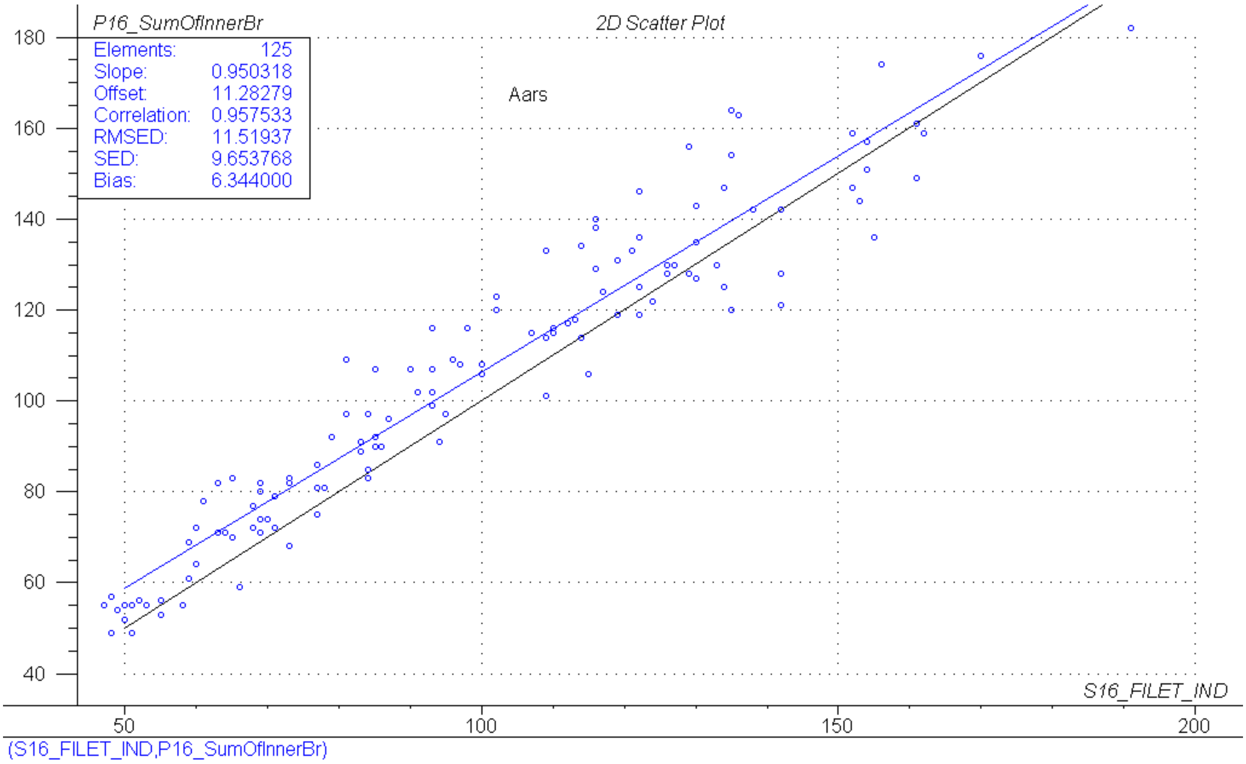
Linear regression equations for weight of other parts based on phase 1 data. Reference is on the horizontal (x) axis and predicted on the vertical (y) axis.

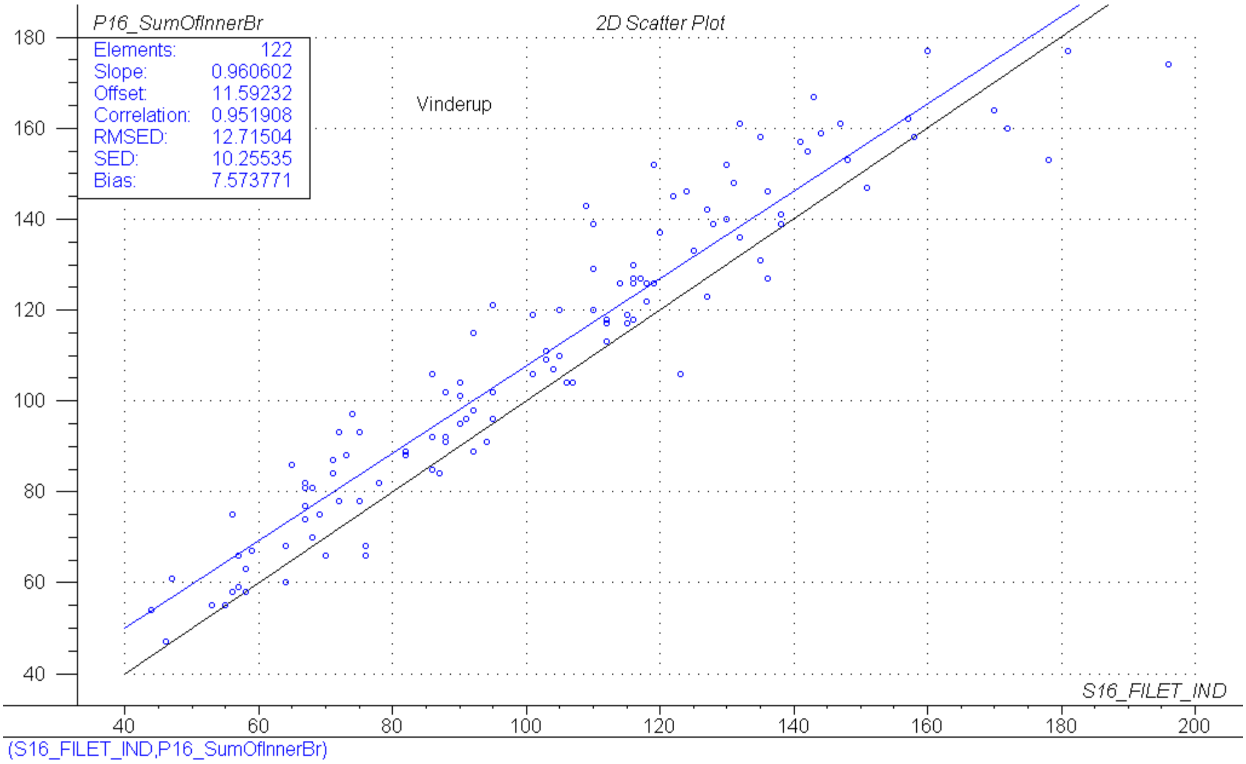
Outer breast fillet weight E+V



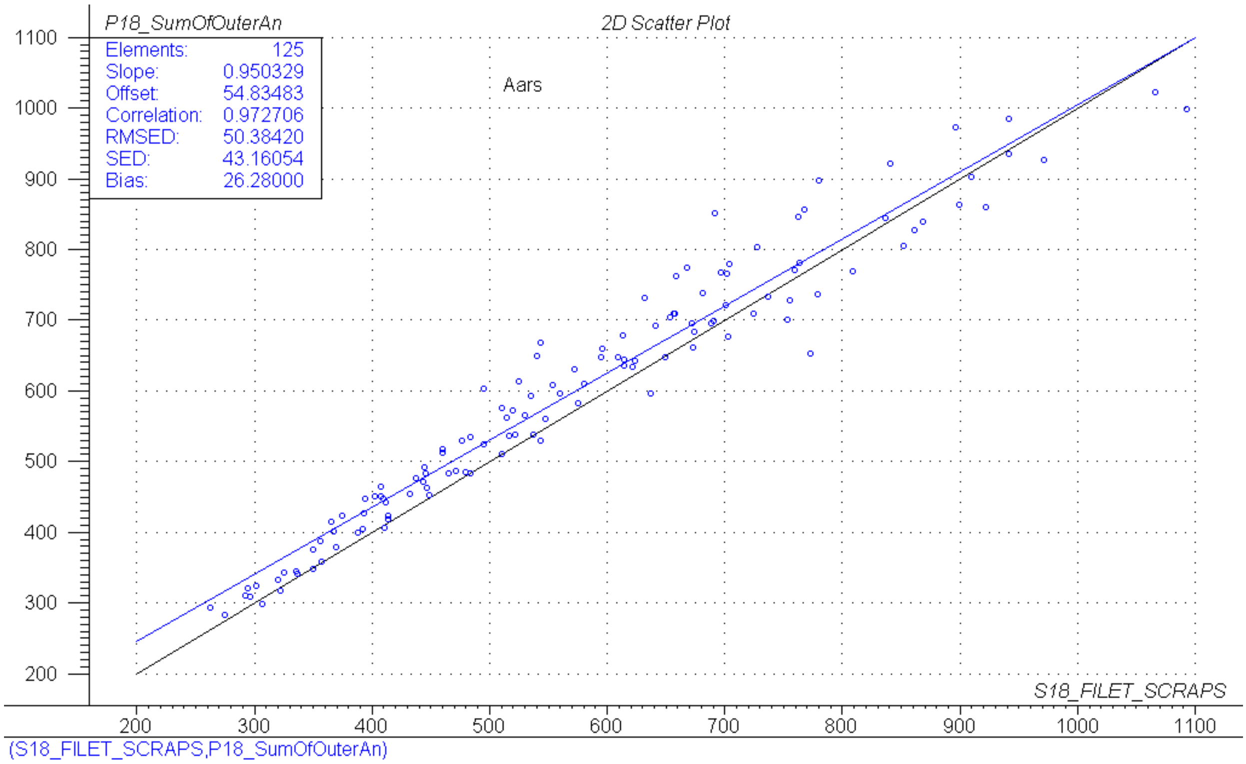


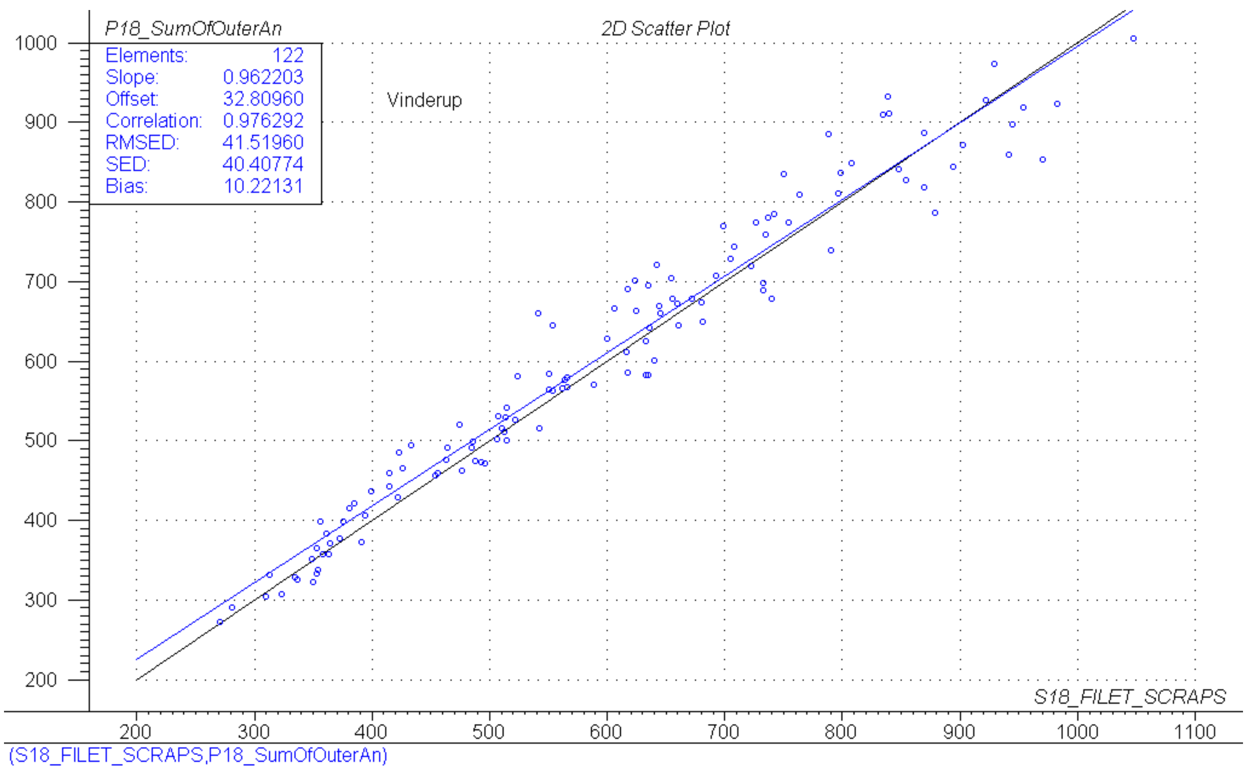
Inner breast fillet weight E+V



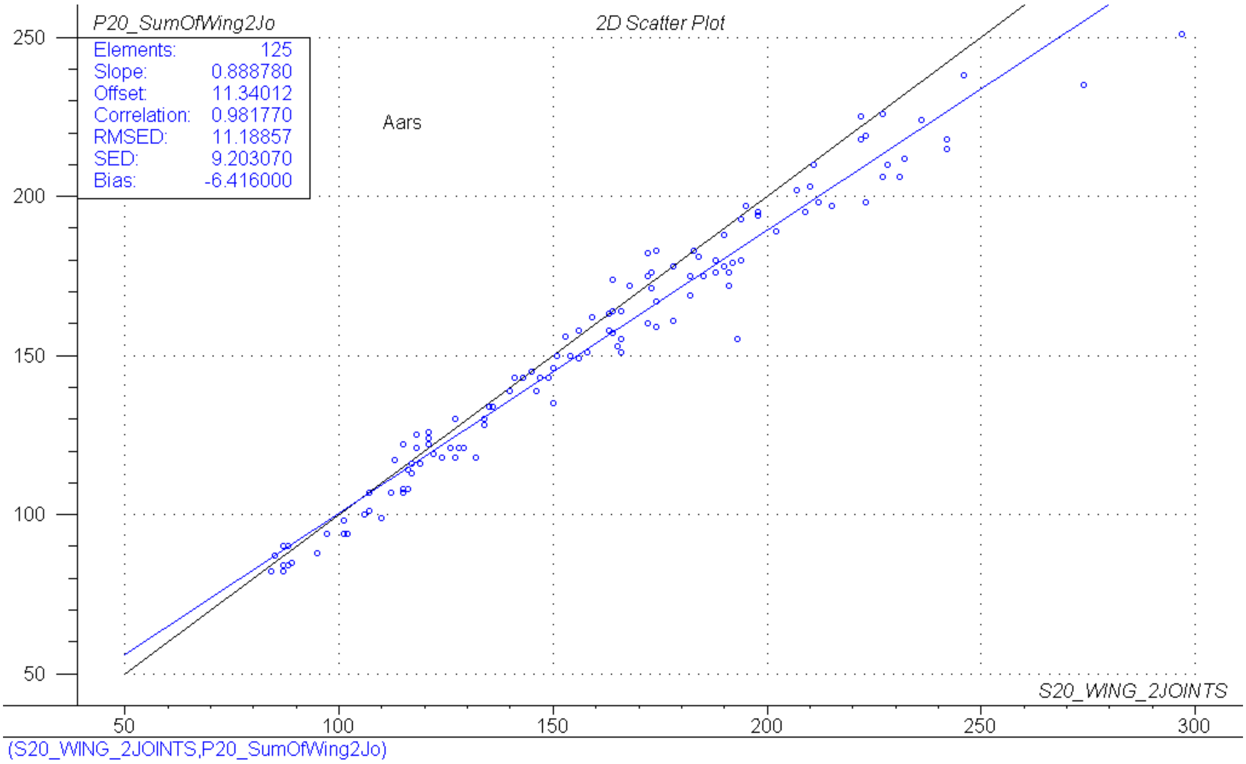


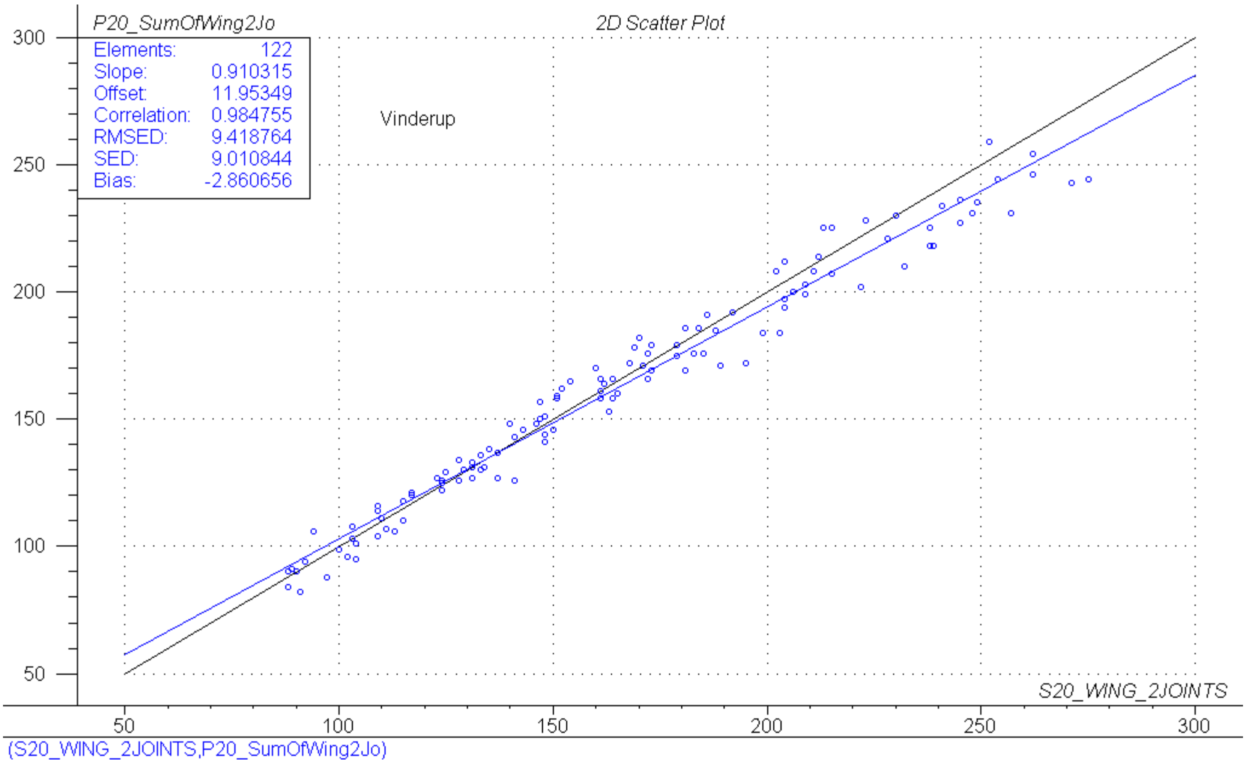
Sum of outer and inner fillet with skin weight E+V



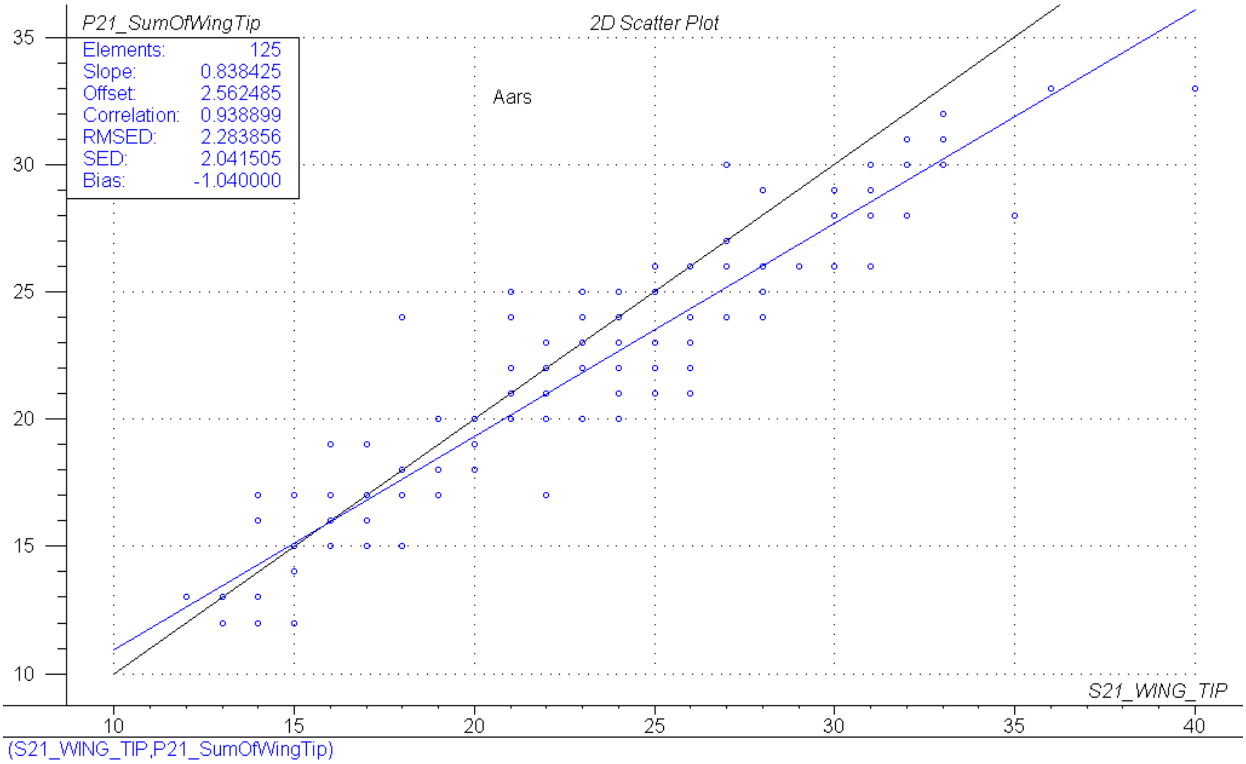


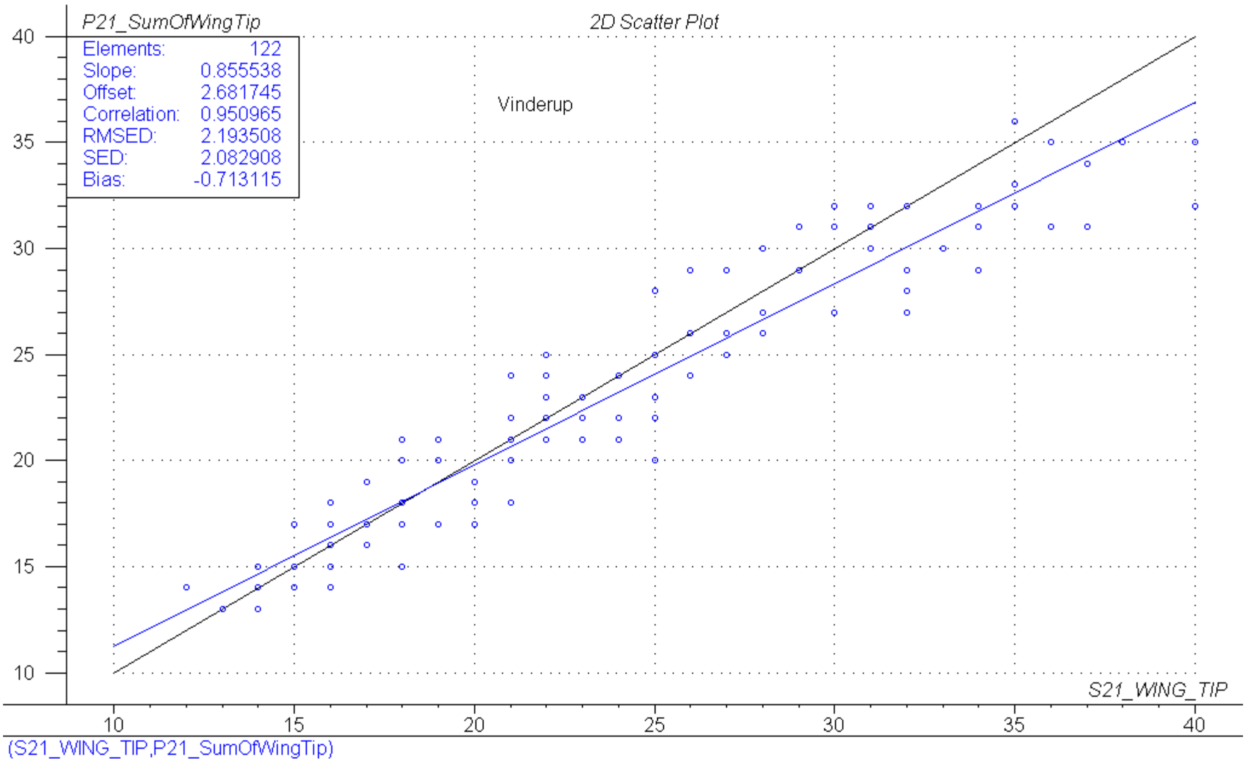
Wing 2-joint weight E+V



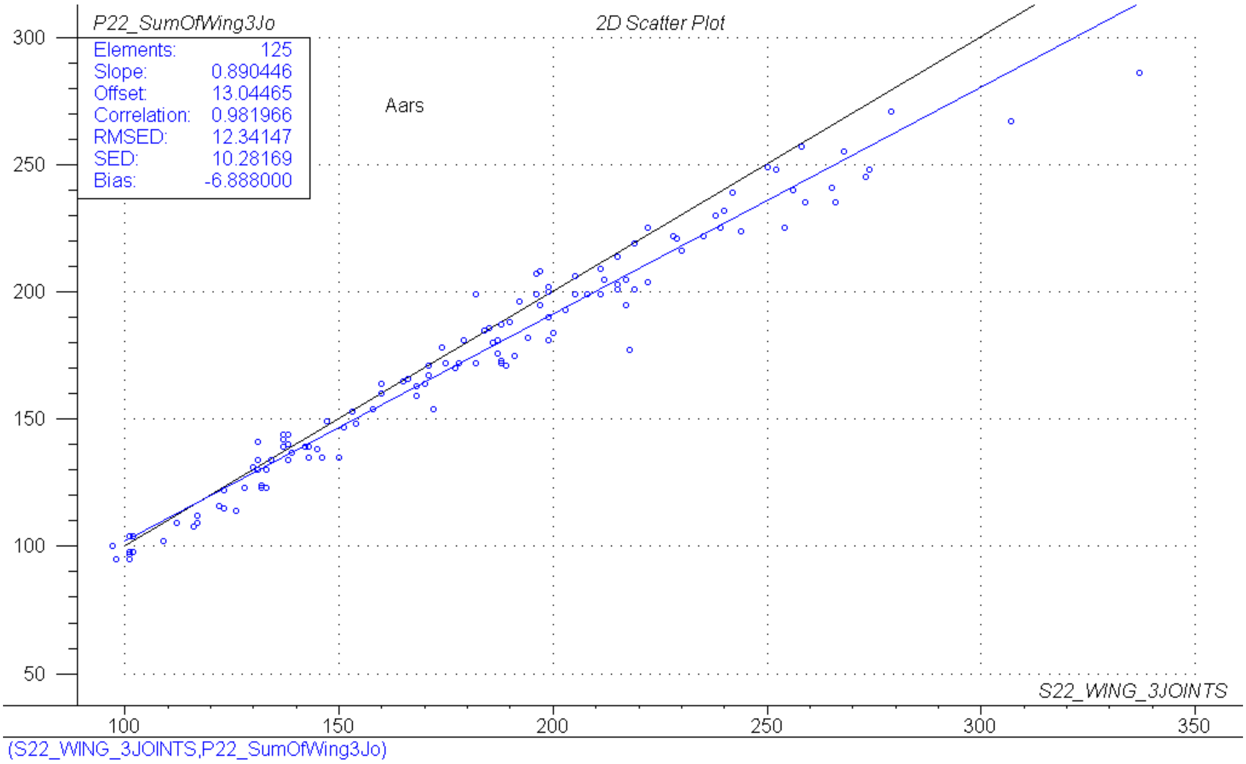


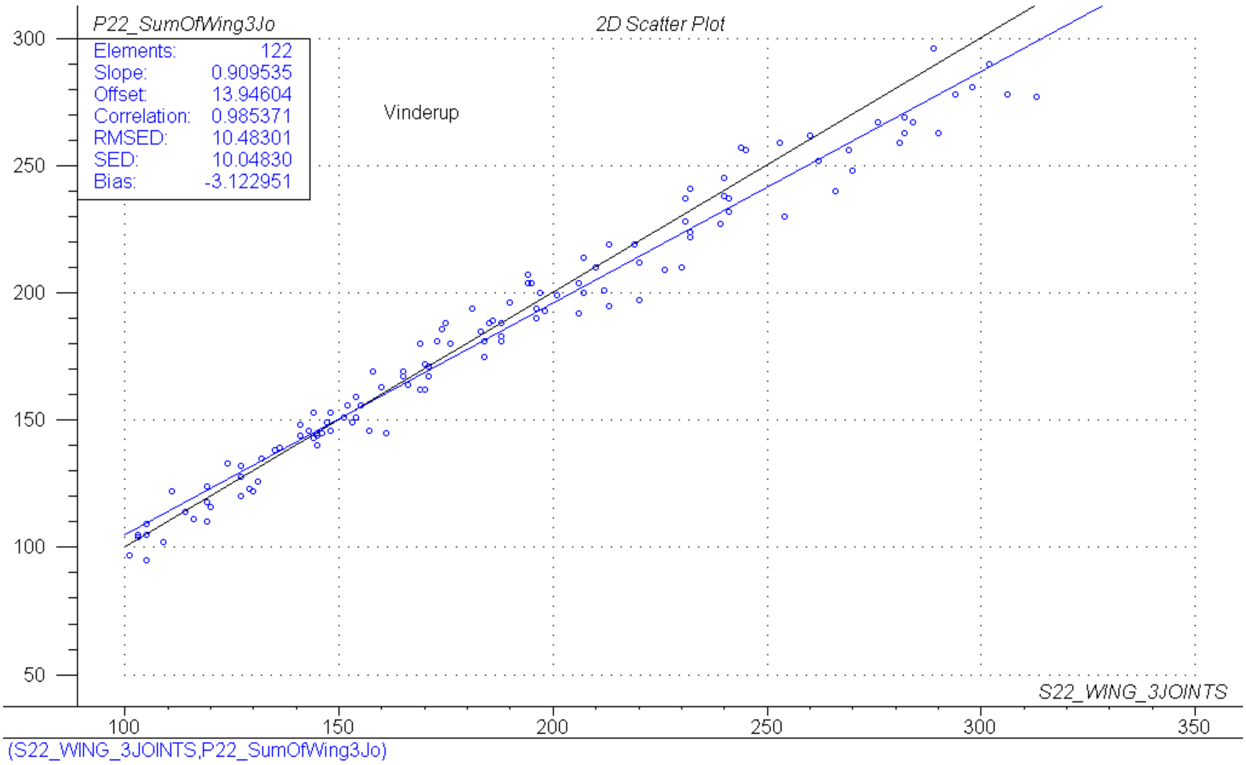
Wing tips weight E+V



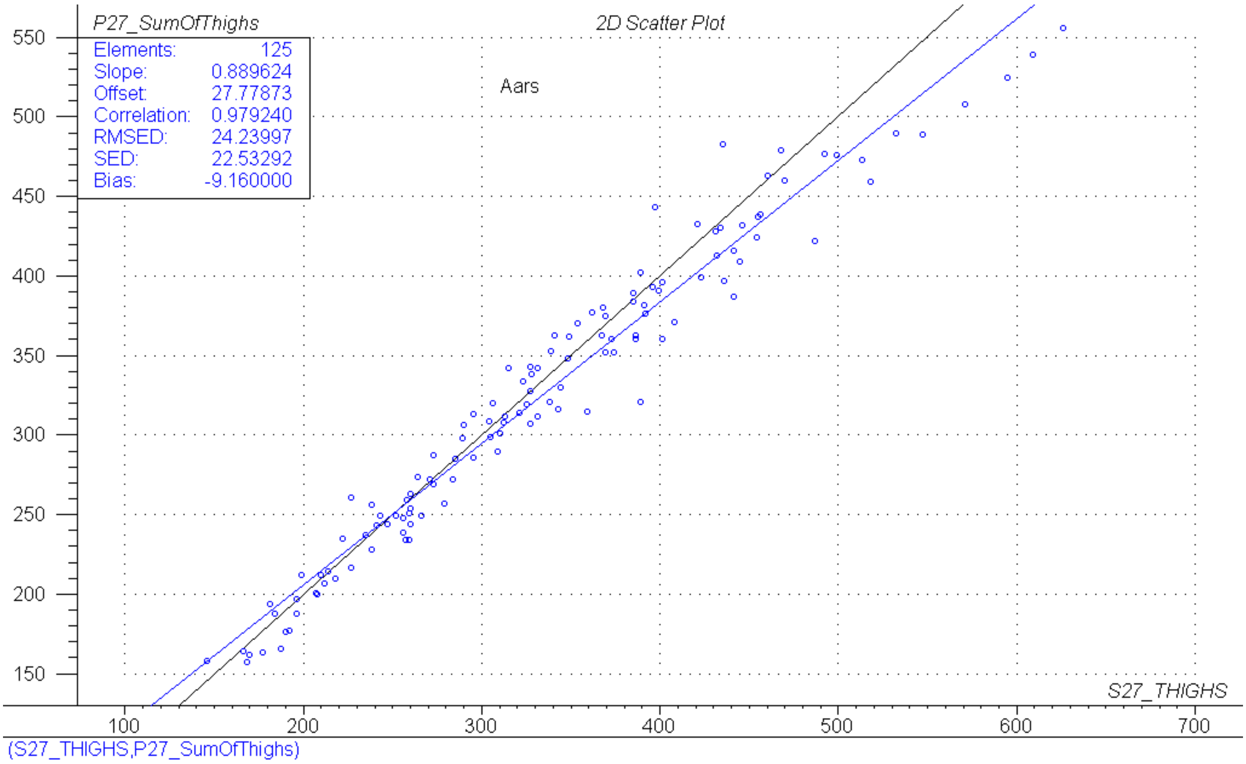


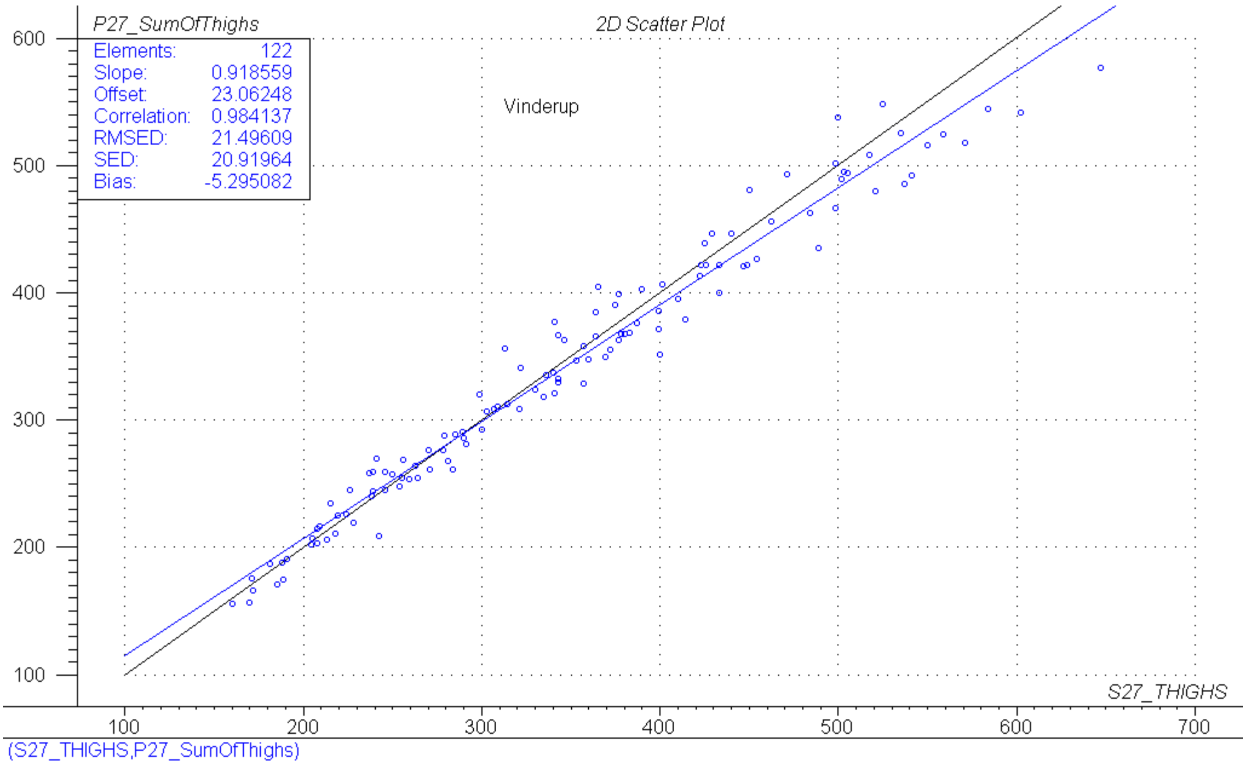
Wing 3-joint weight E+V



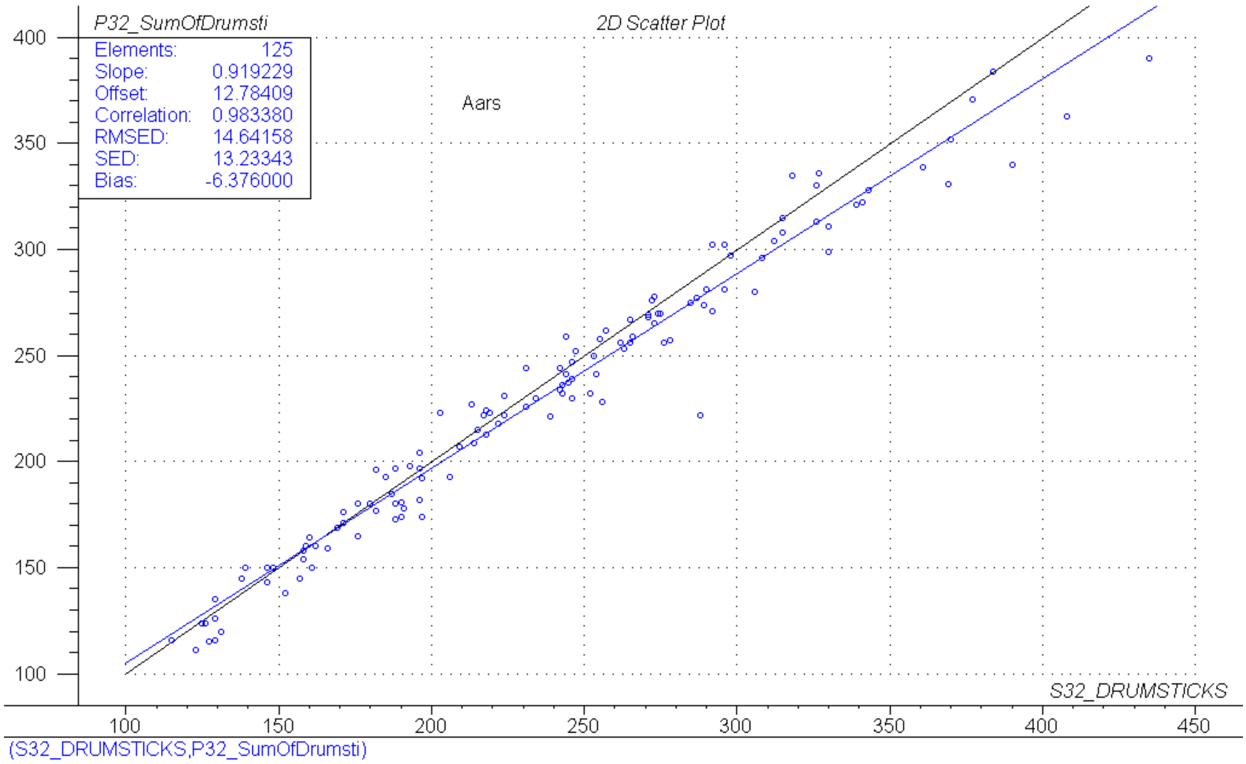


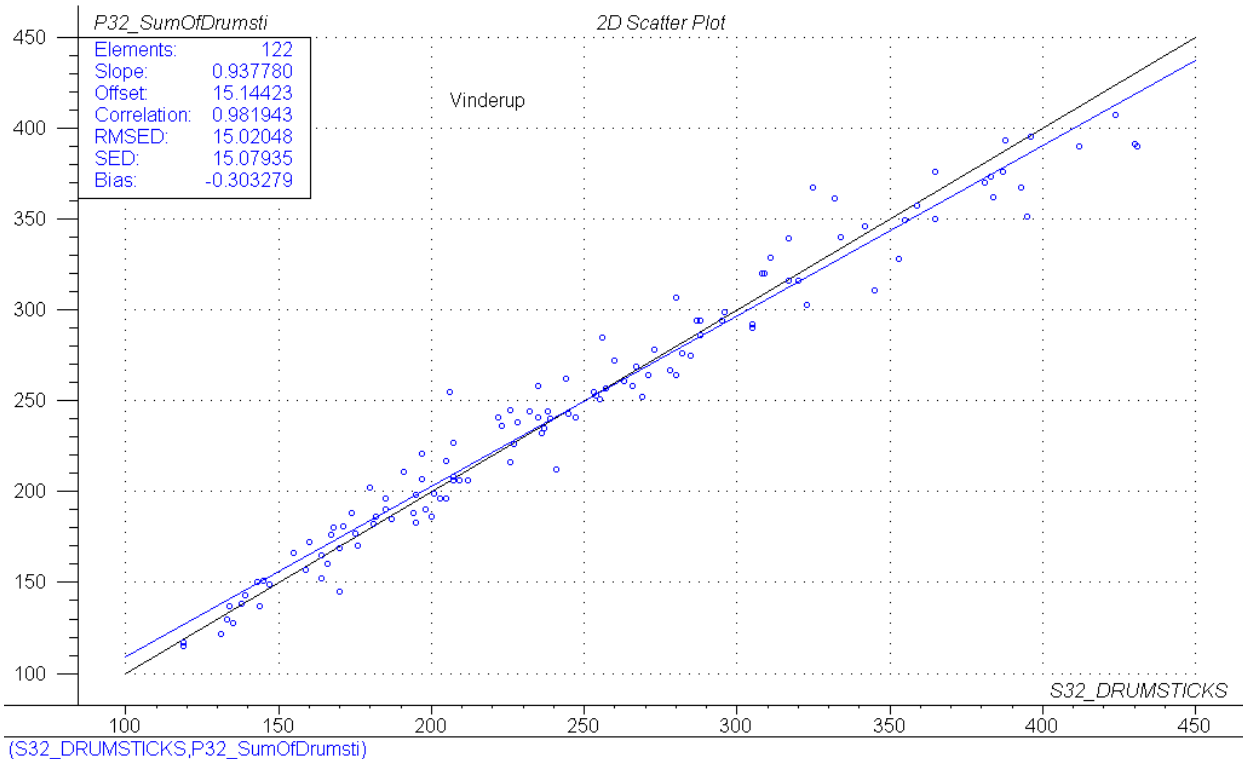
Thigh weight E+V



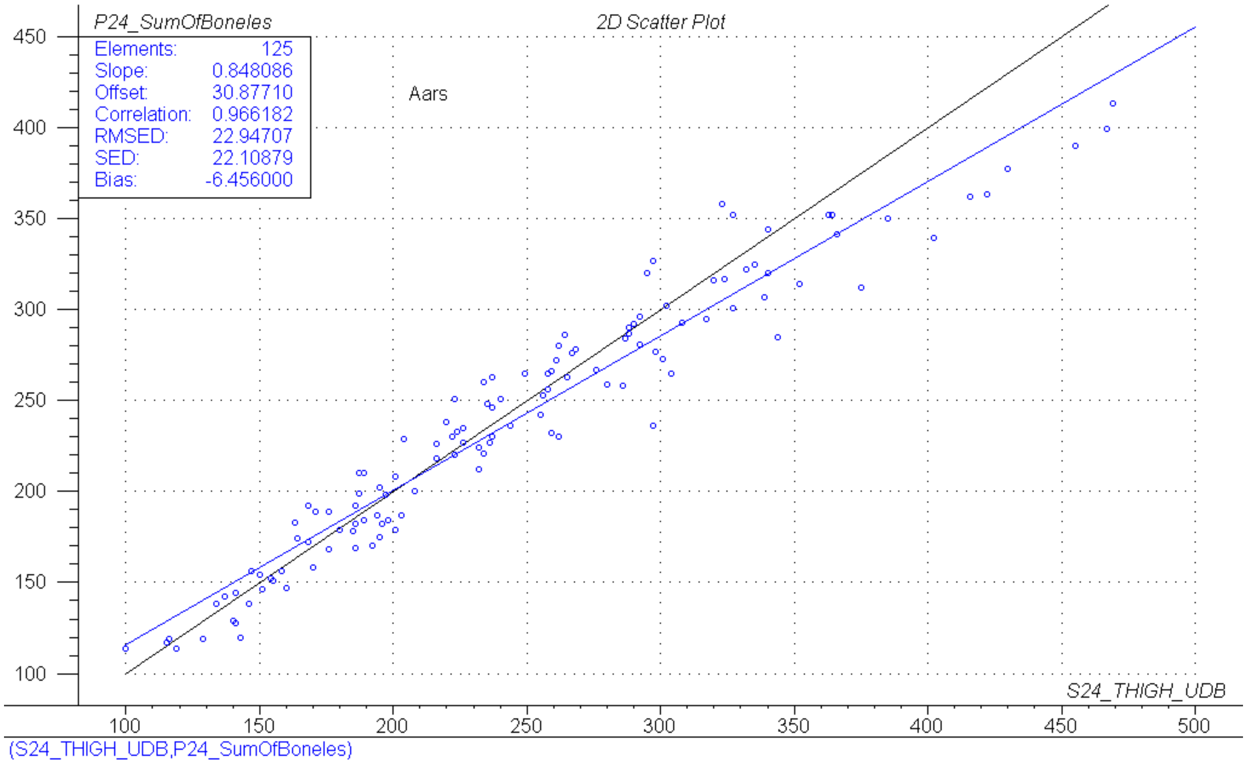


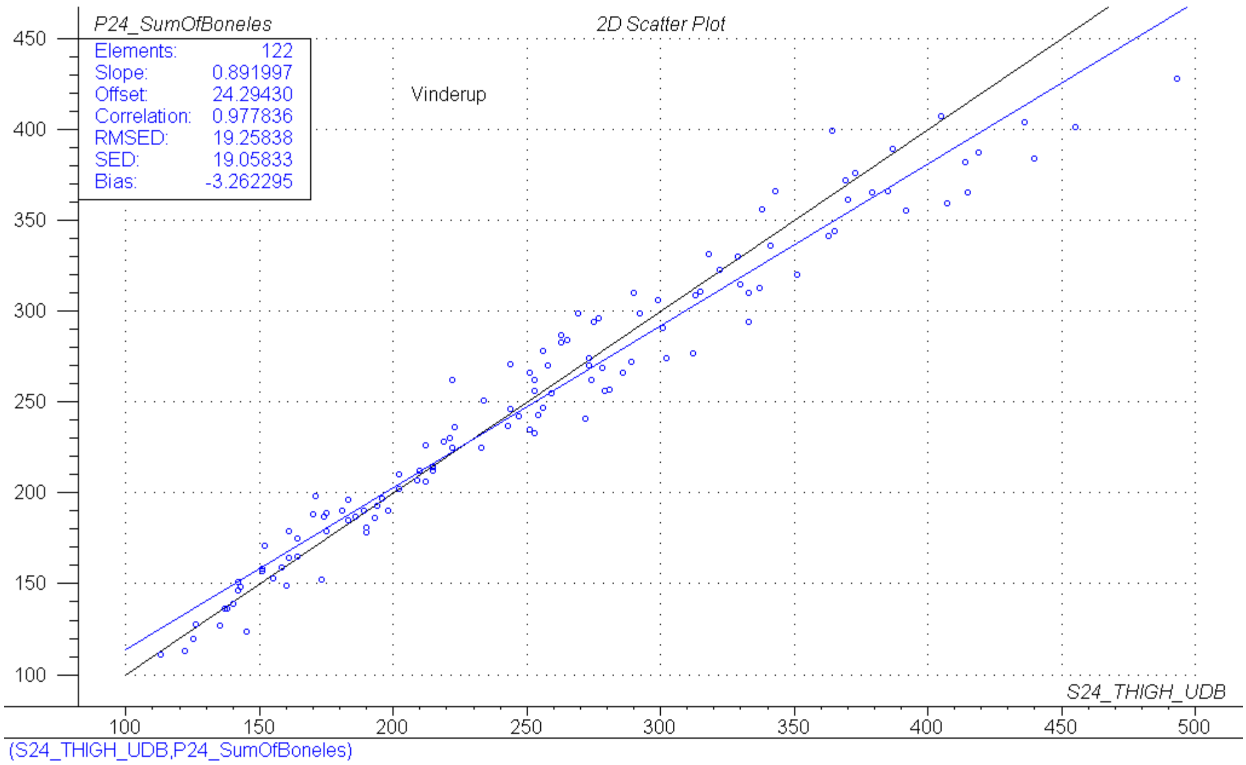
Drumstick weight E+V



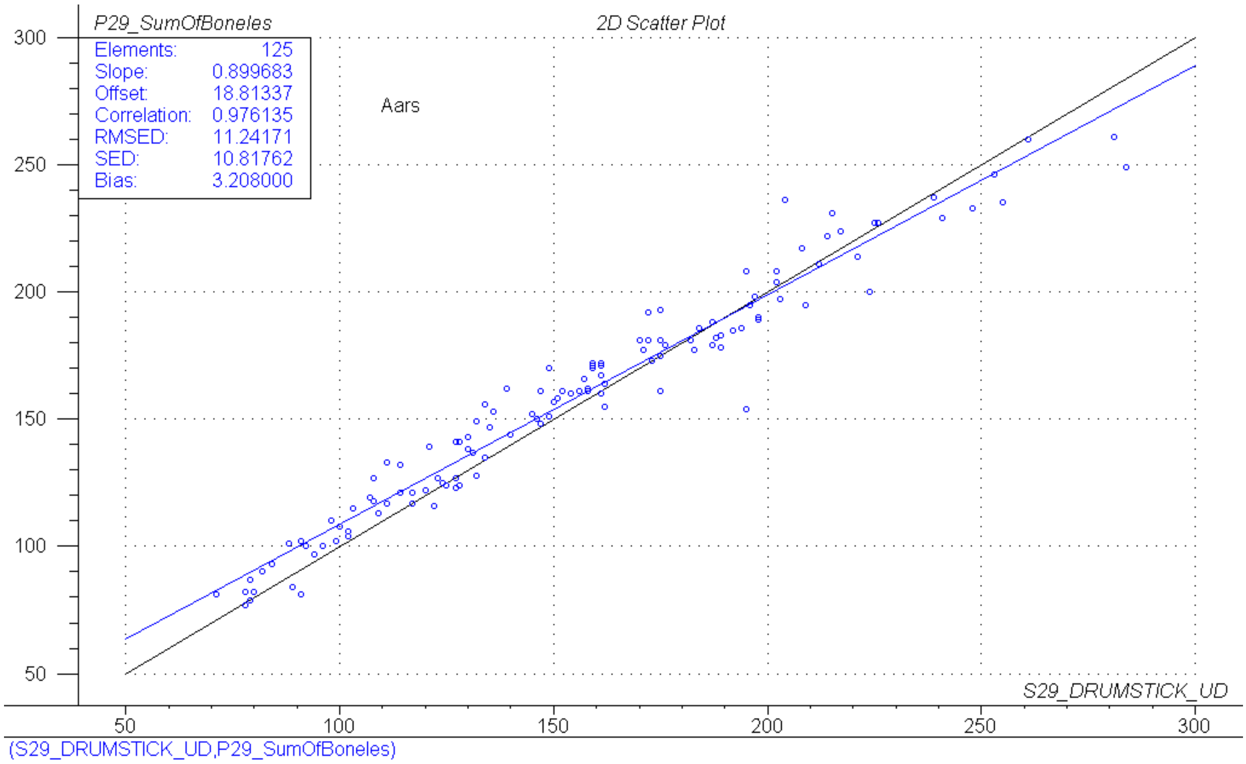


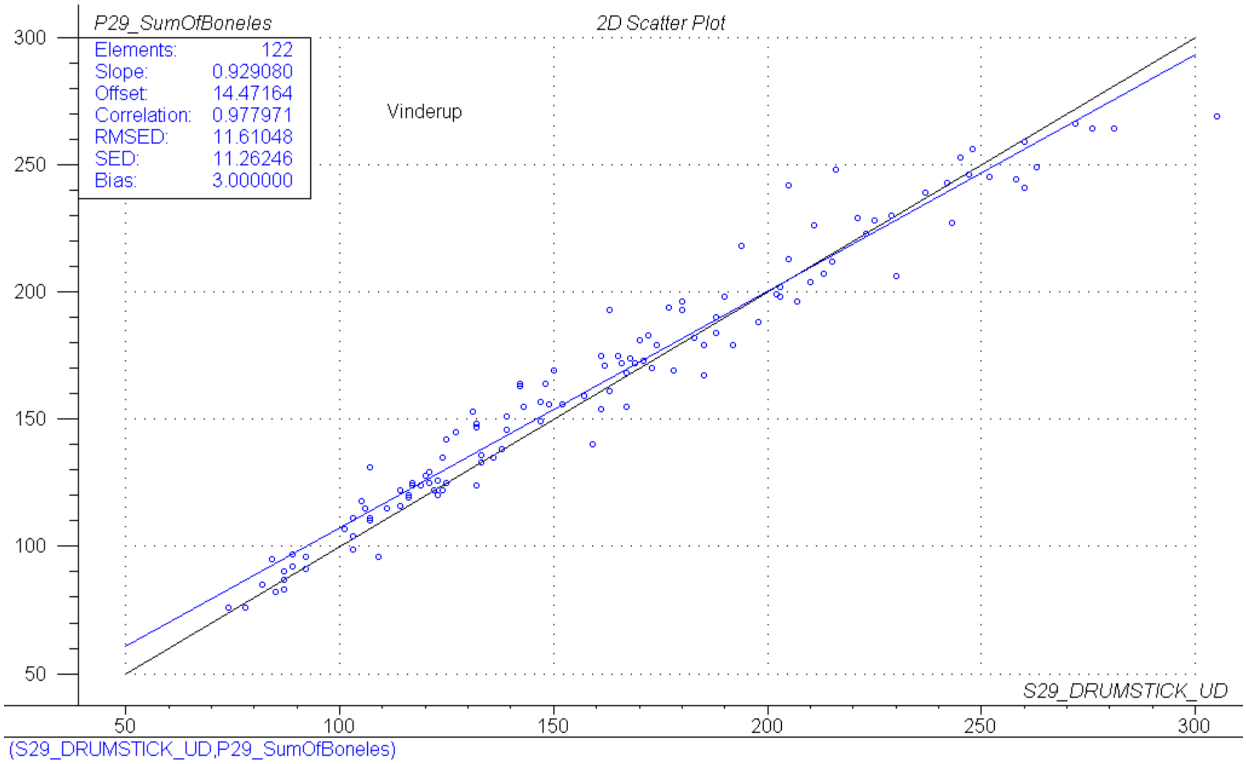
Boneless thigh without skin and fat weight E+V



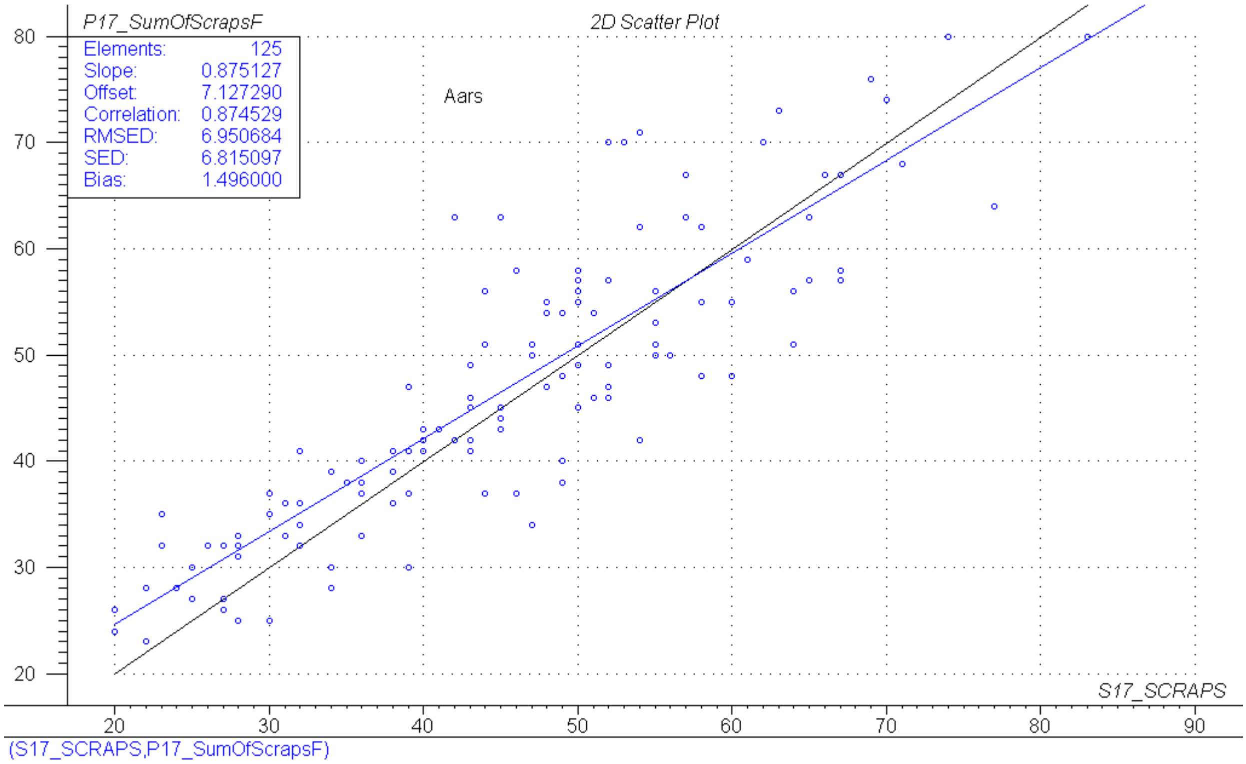


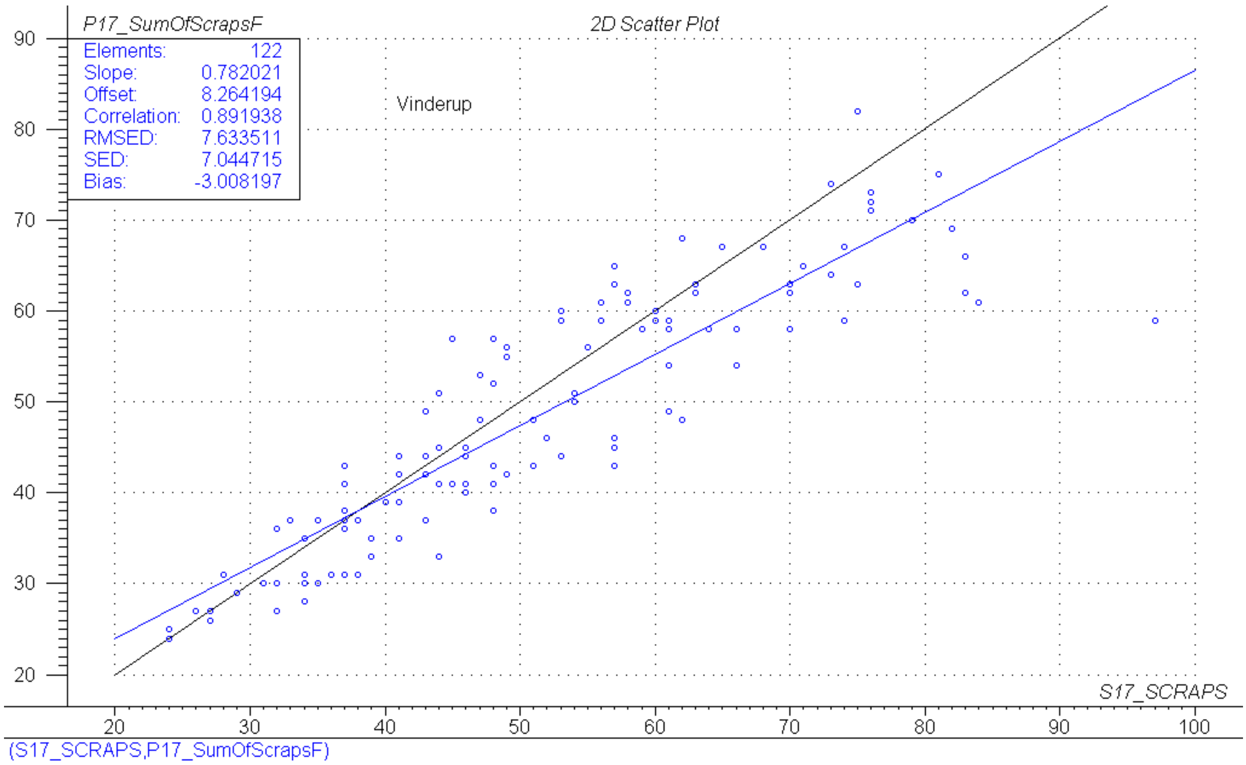
Boneless drumstick without skin and fat weight E+V



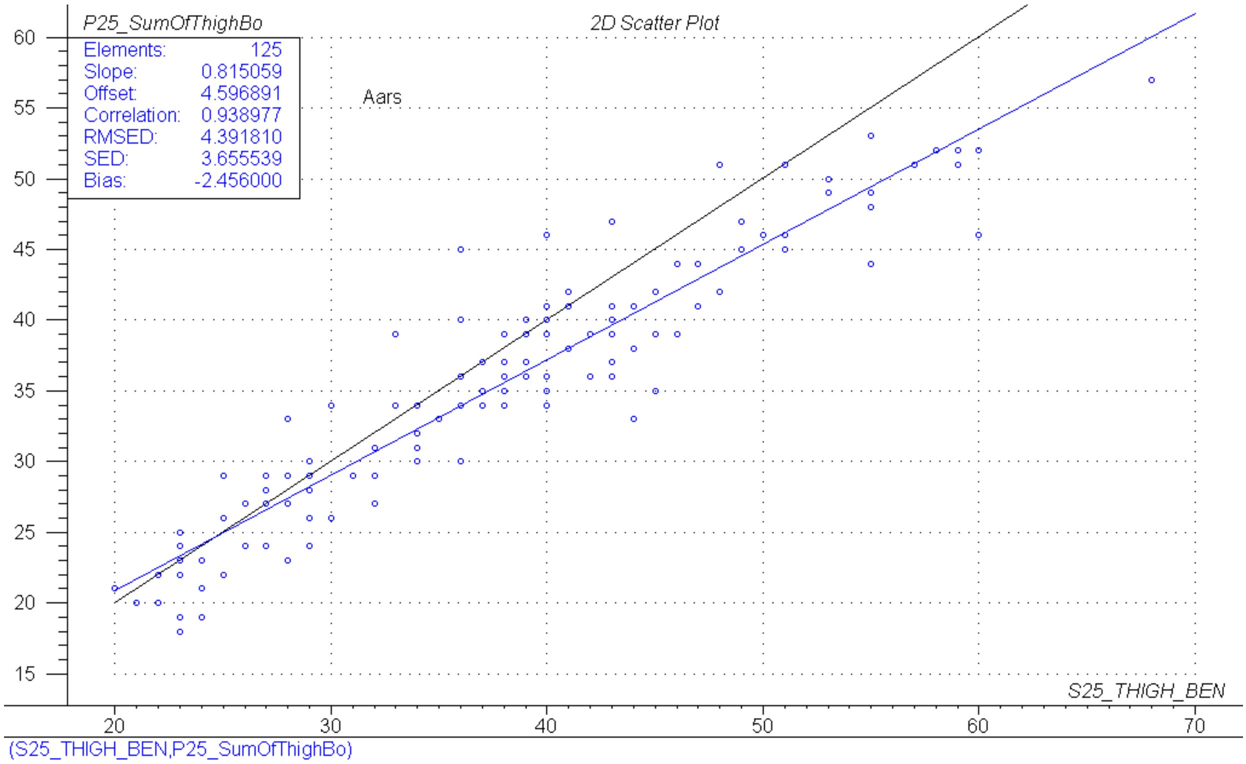


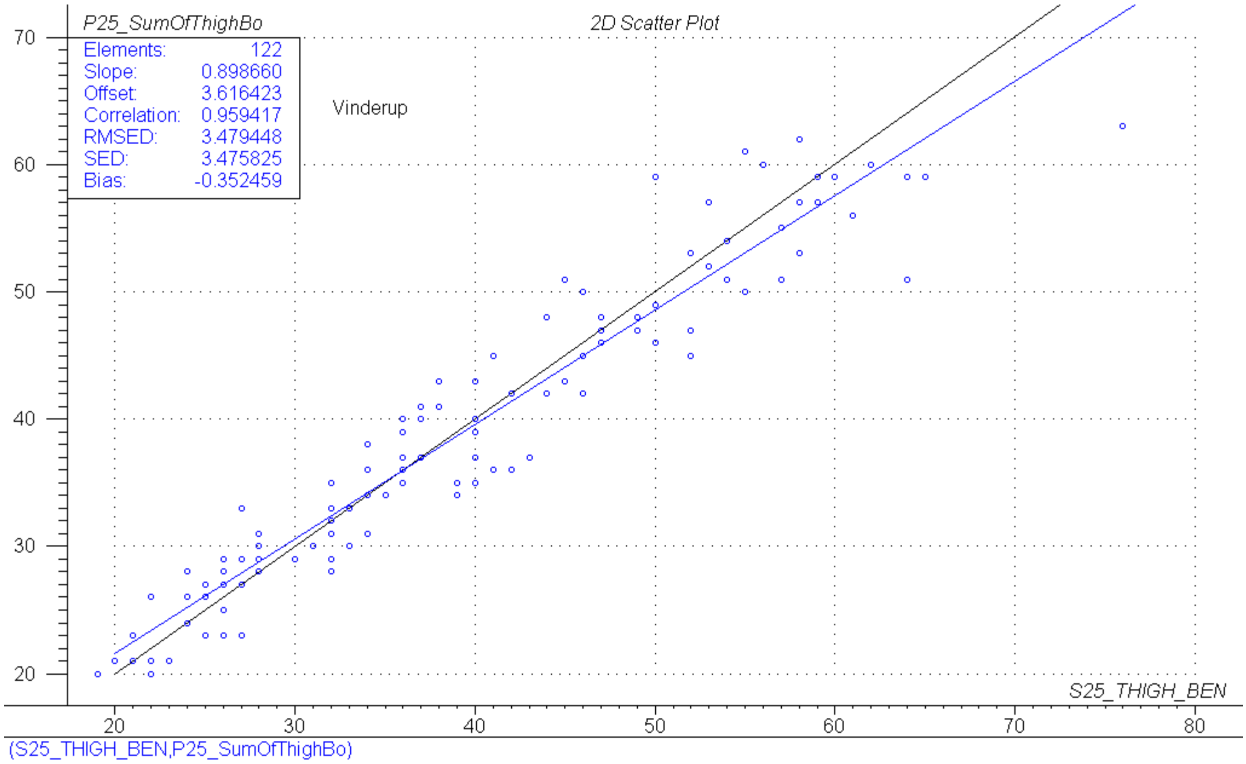
Scraps from fillet weight E+V



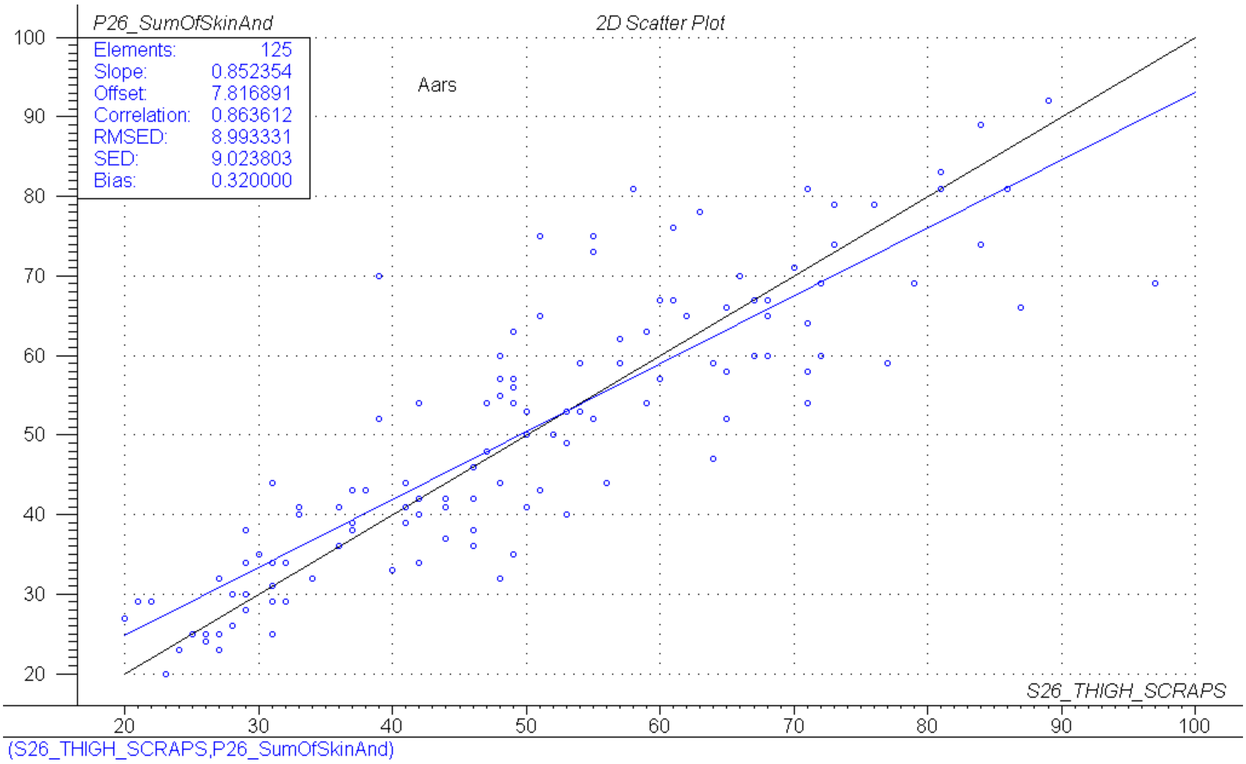


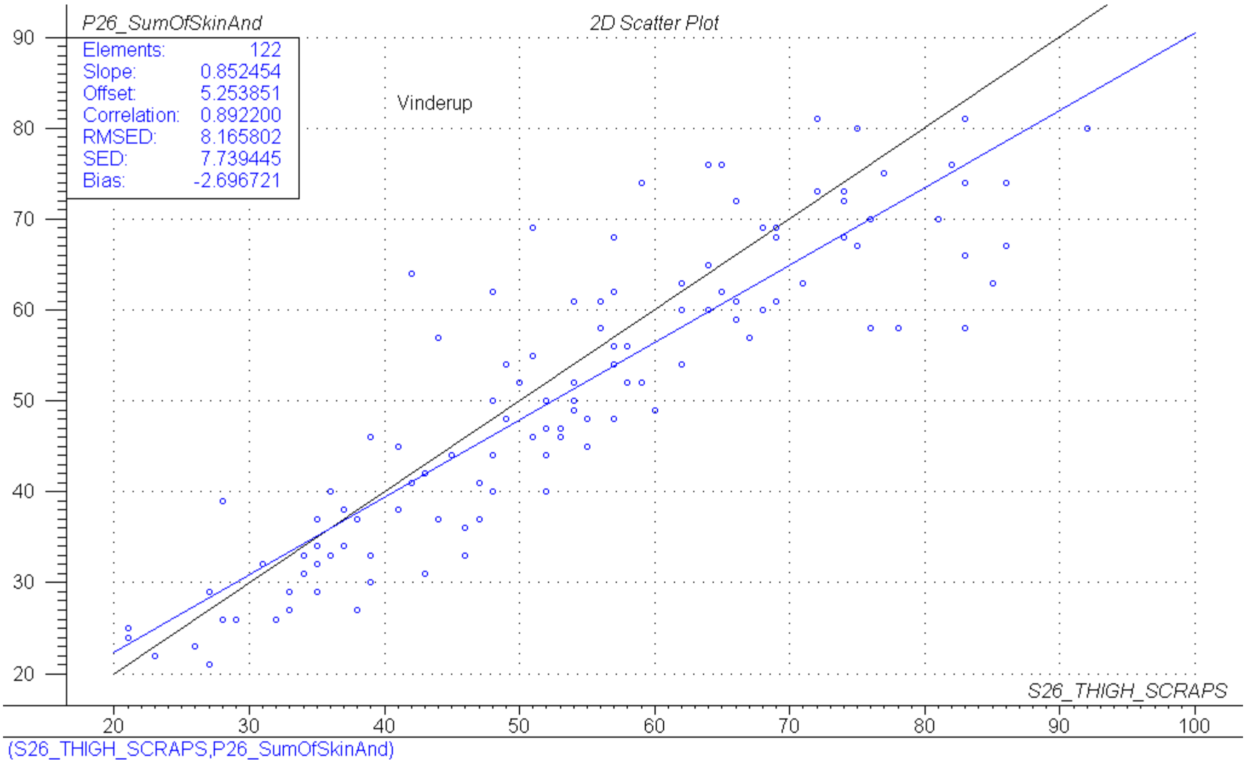
Thigh bone weight E+V



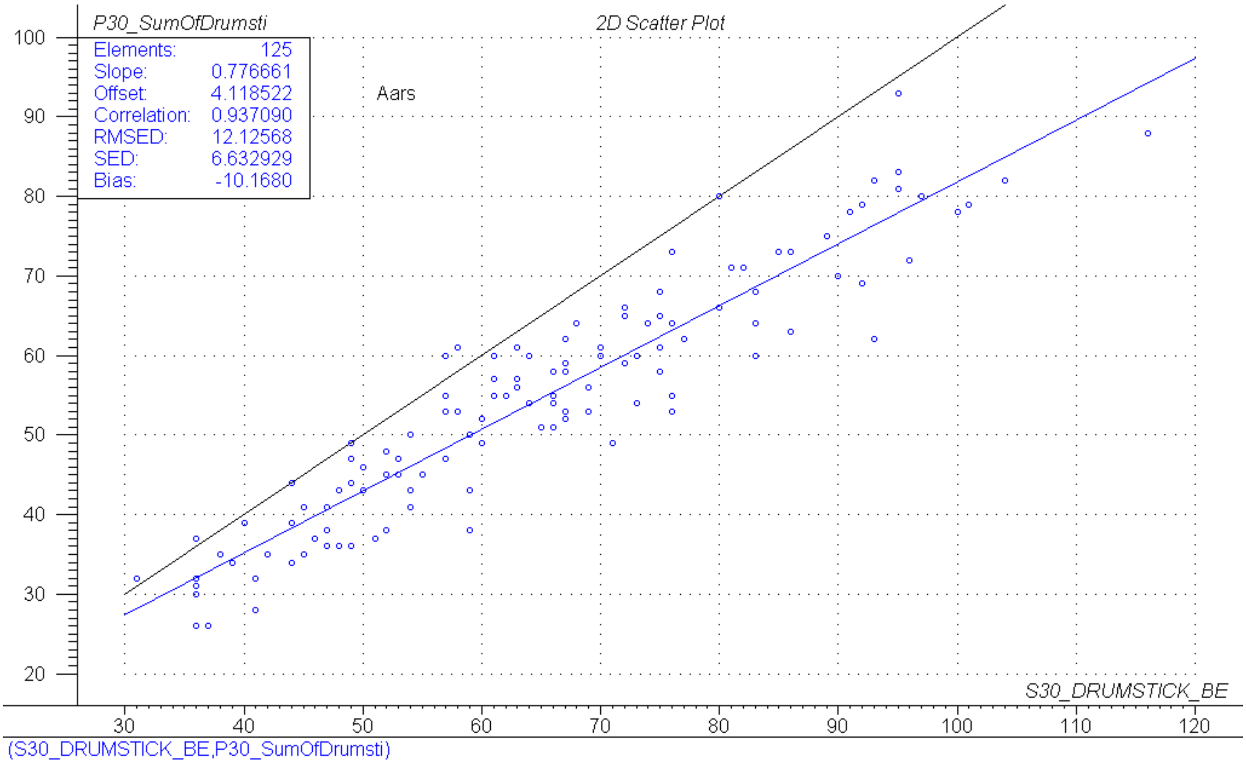


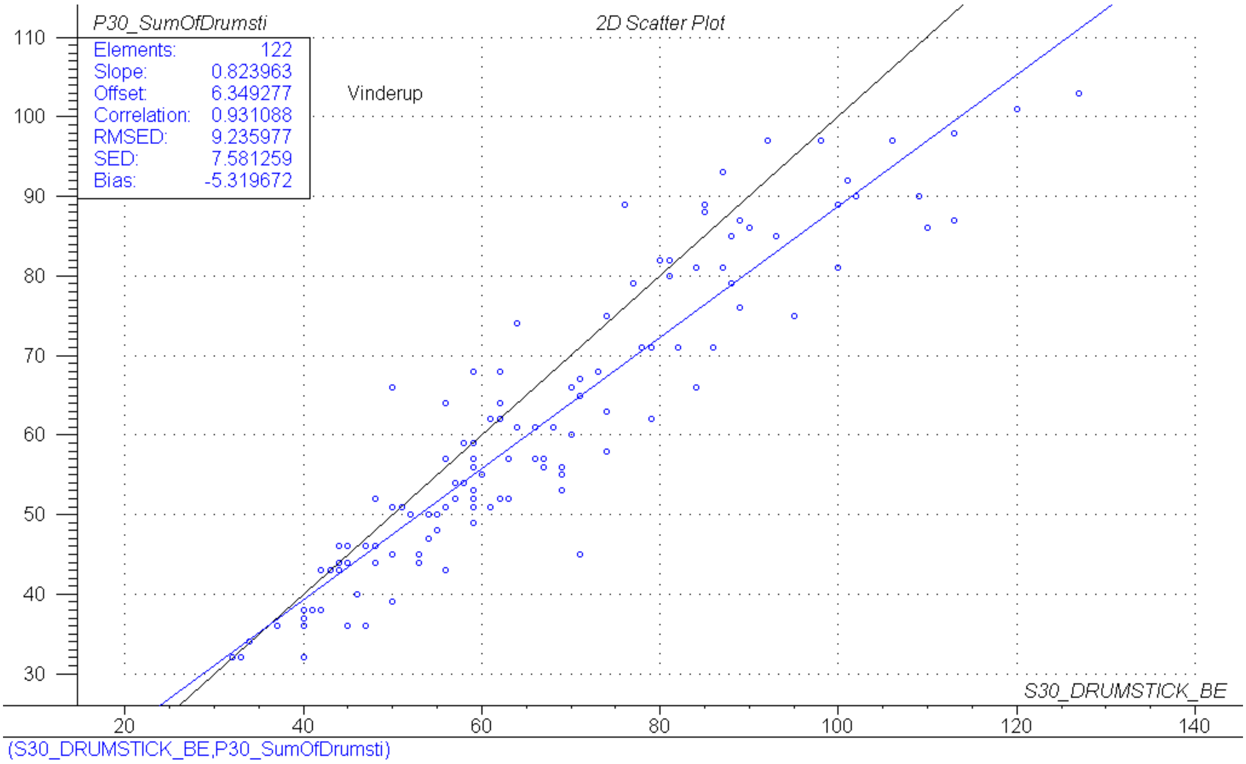
Thigh *skin and fat weight E+V*



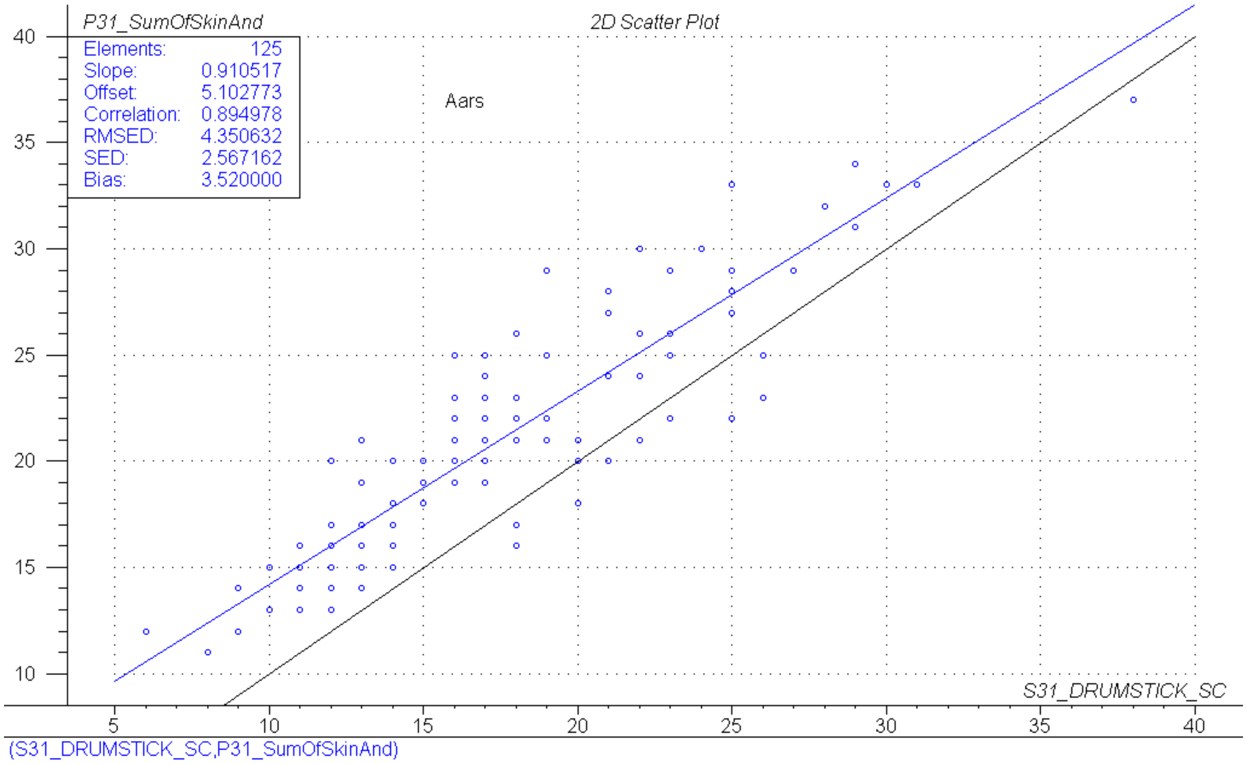


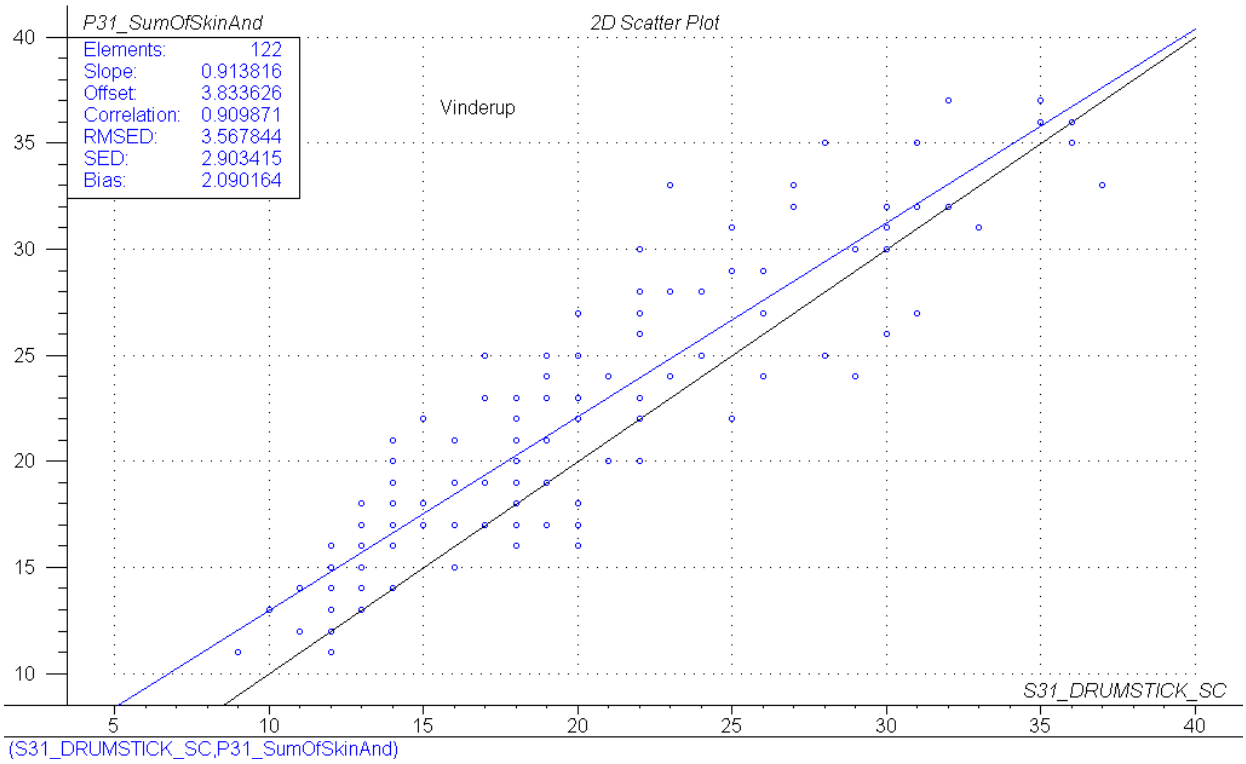
Drumstick bone weight E+V





Drumstick skin and fat weight E+V





Appendix 3. Quick reference

Enclosed

Appendix 4. Short Manual

Enclosed

Appendix 5. Menu Overview

Enclosed