UNDERSTANDING CHROMOSOMES TO MAKE GENETIC IMPROVEMENTS IN RUMINANT LIVESTOCK SPECIES

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Authorization to Submit Thesis

This thesis of Anna Marissabel Rodriguez, submitted for the degree of Master of Science with a Major in Animal Science and titled "UNDERSTANDING CHROMOSOMES TO MAKE GENETIC IMPROVEMENTS IN RUMINANT LIVESTOCK SPECIES," has been revised in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

With a changing world, there is a need to produce adaptable and efficient livestock. Producers have been using selective breeding for the production of better livestock. As technologies have advanced, so has our understanding of genetics, however there is much work needed to continue improving livestock species. This work aims to create a better understanding of methods associated with making genetic improvements in ruminant livestock species. One focus area is the observation of meiotic recombination or crossovers in the spermatocytes of Beefalo, a cattle-bison hybrid, cattle, and sheep. These data show differences in crossover numbers, the positive correlation between the number of crossovers per homologous chromosome pair compared to chromosome length, location of crossovers on homologous chromosome pairs, and defects present in those chromosomes, which will provide insight into genetic predictions and hybrid mating. Another part of this thesis discusses a method to isolate the sex chromosomes in sheep to provide sequencing of the Y chromosome, which is not well characterized in ruminant livestock. These projects provide insight to the livestock industry in understanding methods for genetic improvements.

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Dedication

I would like to dedicate this thesis to:

—My crew, Michael and Andres, for keeping me sane and making sure I balance my career goals with fun, and for providing unlimited love and support.

—My parents Andy and Lupe Rodriguez, and my Tia Chayo, for their encouragement, support, and being amazing role models in my life.

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List of Abbreviations

ARS	Agricultural Research Service
bp	Base pairs
CO	Crossover
DNA	Deoxyribonucleic Acid
DSB	Double strand break
EBV	Estimated breeding value
FACS	Fluorescence activated cell sorting
FWEC	Fecal worm egg count
FISH	Fluorescence in situ hybridization
GIN	Gastrointestinal nematode
KHSI	Katahdin Hair Sheep International
NASS	National Agricultural Statistics Service
PAR	Pseudoautosomal region
PGM	Primordial germ cell
QTL	Quantitative trail locus
SC	Synaptonemal complex
SNP	Single nucleotide polymorphism
USDA	United States Department of Agriculture
US	United States of America
VDCG	Vibrant dye cycle green

CHAPTER 1

Review of Literature

Livestock genetics

With a changing world, there is a need to produce adaptable and efficient livestock. Producers have been using selective breeding for the production of livestock that are more adaptable and efficient. The United States of America (US) Census created a model to estimate the number of people in the world and in the US. They estimate that currently there are 7.49 billion people in the world, and 328 million people in the US (United States Census Bureau, 2018). They also estimate that in the US there is a birth every 8 seconds. The world and US populations are both quickly growing, and it is important that ways to increase livestock efficiency are explored. Protein is an important part of diet, and meat is a good source of protein, therefore, working towards making meat sources more efficient is favorable. In 2018, NASA has reported global temperatures to be 1.8˚F warmer than in 1880, and arctic ice minimum has decreased 13.2% per decade (NASA, 2018). Due to changing climate, we want to ensure our livestock are adaptable, so they are able to adjust to varying climates. Understanding livestock genetics and chromosomes will allow us to make genetic improvements in our livestock to make them more efficient and adaptable.

Beef cattle genetics

A major source of protein in the US is beef. In 2017, The United States (US) had the highest production of beef (in pounds) in the world, with the focus being on high quality, grain fed beef (USDA & NASS, Cattle, 2018). In addition, the US was the fourth largest contributor of beef exports (in pounds), behind Brazil, India and Australia (USDA & FAS,

2018). According to the National Agricultural Statistics Service (USDA & NASS, Cattle, 2018), January 31, 2018 report by the United States Department of Agriculture (USDA), there are 94.4 million head of cattle and calves. The report also stated the number of cattle is up 1% from last year, and the calf crop is up 2%. The US produced over 26 billion pounds of beef in 2017 (USDA, Beef Pivot, 2018), and it was estimated that in the year 2017, the per capita consumption of beef was 56.9 retail pounds. The state of Idaho had 2.3 million head of cattle used for meat production (USDA & NASS, Cattle, 2018). Additionally in 2017, Idaho produced 1.2 billion pounds of beef and brought in 1.7 billion dollars (USDA & NASS, Cattle, 2018). From these USDA reports it is evident that the beef industry is important in the United States and the state of Idaho. Because of the large economic importance of beef in the US, it is important we work to improve the efficiency of livestock, and a method to do this is through selective genetics.

In an effort to better understand beef cattle genetics, scientists are working to characterize the genome of cattle. Scientists at the First International Reading Conference for Standardizing of Banded Karyotypes of Domestic Animals, (Ford et al., 1980) determined the karyotype of domestic animals. Cattle were one of the species characterized at the conference. They reported that cattle have 29 pairs of autosomal homologous chromosomes, all of which are telocentric. The X chromosome is submetacentric and the Y chromosome is metacentric in cattle. In addition to having the karyotype determined, the whole cattle genome was first sequenced by Elsik, Tellam, & Worley, (2009). Since then, the genome has been re-sequenced and annotated several times with the latest version by USDA-ARS (ARS-UCD1.2). The most recent assembly was released April 11, 2018 and has more than 10 times the coverage of the first, with 80X coverage. The total genome length is 2.7 billion base pairs

(bp), covering all chromosomes except the Y chromosome. The Y chromosome in cattle has not yet been characterized, and therefore cannot be included.

Beefalo genetics

In an effort to make adaptable livestock, hybrid mating has been explored. One of the hybrids implemented to explore the possibility of adaptability is Beefalo. Beefalo is a hybrid of *Bison bison* X *Bos taurus*, consisting of 3/8 *B. Bison,* and 5/8 *B. taurus*, according to the American Beefalo Association (ABA, 2018). This ratio has been established over a 150 year period by producers to be the "ideal mix" of both animals. Beefalo is recognized by the USDA as a breed, as long at the animal fits the ratios listed. If an animal has more *B. bison* genetics, then it is considered cattalo, and is not recognized as the same USDA breed (ABA, 2018).

Beefalo were bred for meat production to contain the favorable qualities from both *B. taurus* and *B. bison*. The cross provides the hardiness of bison and the easy temperament and carcass quality of domestic cattle. Overall, Beefalo have long reproductive life spans, ease of calving, rapid growth rates on forage/roughage without grains or hormones, extreme climate adaptability, disease resistance, and lean carcasses with good structure (ABA, 2018). The USDA-ARS National Nutrient Database for Standard Reference Legacy Release has determined that Beefalo meat has higher levels of vitamins and protein, while containing less fat and cholesterol than conventional beef (USDA & ARS, Basic Report: 13795 and Basic Report: 17152, 2018).

Although Beefalo have great features, they are a hybrid animal and therefore have also been known to have fertility problems. The American Beefalo Association gives a brief

history on the creation of this hybrid (ABA, 2018). It was known that in the first generation (F1) of hybrid animals, females were fertile, but males were not. For this reason, females were bred back to *B. taurus* bulls. The second (F2) generation had the same results, fertile females and sterile males. It is not until the third generation (F3) that both females and males are fertile and usable for breeding stock, and mixed to create the "ideal mix" for the Beefalo breed (ABA, 2018). Fertility problems in F1 and F2 hybrid males have been seen in other hybrid species (Haldane, 1922). Researcher Haldane, (1922) found, "when in the F1 offspring of two different animal races one sex is absent, rare or sterile, that sex is the heterozygous sex". Additionally, Gyllensten, Wharton, & Wilson, (1985) found that fertility of hybrid male mice is returned after a few generations of backcrossing.

Despite being a hybrid, Beefalo (3/8 *B. bison* X 5/8 *B. taurus*) are fertile and used as breeding stock (ABA, 2018). Part of the reason this is possible is that *B. bison* have the same number of chromosomes as *B. taurus* (Bhambhani and Kuspira, 1969). Additionally, both species have similar types of chromosomes. Because Beefalo are hybrids, the genetic profile is more challenging to find, and the chromosomes of Beefalo have not yet been characterized. To understand how this cross is possible, we can look at the chromosomes of *B. bison* and compare them to what we know about *B. taurus.* There are 29 autosomal chromosome pairs in *B. bison*; the autosomal chromosomes and X chromosome have similar constitution to *B. taurus*, telocentric and submetacentric, respectfully (Bhambhani and Kuspira, 1969). The Y chromosome in *B. bison* is telocentric, but it is metacentric in *B. taurus.* In addition to the chromosomes being characterized, the genome of *B. bison* was sequenced and assembled with 60X coverage by the University of Maryland on October 8, 2010 (Bison_UMD1.0). The length of the genome is over 2.8 billion bp.

Sheep genetics

In addition to beef being of importance in the US and the world, sheep have also been a valuable source of protein, and in some breeds wool is produced. In the US, we have 5.23 million sheep, as of January 2018, according to the USDA agriculture counts (USDA & NASS, Sheep and Goats, 2018). Sheep are used for wool production and for meat production. In 2017, 24.7 million pounds of wool was shorn, although this production is 5% lower than 2016, the industry made 36.4 million dollars (USDA & NASS, Sheep and Goats, 2018). In addition to wool production, sheep are a source of red meat. In 2017, lamb and mutton production reached 150 million pounds, and the per capita consumption was 1.1 pounds of retail cuts (UDSA, Lamb and Mutton, 2018). Idaho has profitable wool, and lamb and mutton production. The NASS report stated that in Idaho, 180,000 sheep were shorn for a total of 1.6 million pounds of wool produced. Additionally, Idaho produced 50,000 market sheep and lambs for over 6 million pounds of lamb and mutton produced (USDA & NASS, Sheep and Goats, 2018).

Like cattle, understanding sheep karyotype and genomic advancements are tools which can be used to make genetic improvements. Bunch & Foote, (1977) discussed the evolution of the karyotype of domestic sheep, *Ovis aries.* Bunch & Foote, (1977) and Hansen, (1973) report that current domestic sheep have 27 homologous chromosome pairs with three of the chromosomes being bi-armed or metacentric and the rest telocentric. The additional 3 arms from the three metacentric chromosomes make for a total of 29 arms in autosomal chromosome pairs. The Y chromosome is metacentric while the X chromosome is acrocentric. The reference genome of domestic sheep was a Texel and was first submitted in 2014 by the International Sheep Genome Consortium (Oar_v4.0). The latest version of the

sheep genome is a Rambouillet, done at 126X coverage and submitted November 2, 2017 by Baylor College of Medicine Human Genome Sequencing Center (Oar_rambouillet_v1.0). The length of the genome is over 2.8 billion bp, which is similar to the genome lengths of both cattle and bison, and therefore Beefalo.

Male livestock gamete production

Reproduction is an important component to maintain sustainable livestock populations. In the production of offspring in mammals, half of the genetic contribution is from each parent. In males, sperm are the product that contributes their half of the genetic material to their offspring. The process to generate male gametocytes, sperm, is called spermatogenesis, and this process is described below.

Spermatogenesis and spermiogenesis

Spermatogenesis is the process by which sperm are made. In mammals, the primordial germ cells (PGM) move to the genital ridge in male embryos, and become part of the sex chords (McLaren, 1998). The sertoli cells then work closely with the PGM to make the seminiferous tubules (Gilbert, 2000). To understand the process, the anatomy involved is important. Sperm are produced in the testes within the complex formation of the seminiferous tubules (Gilbert, 2000). ***Figure 1.1*** shows the seminiferous tubules, the site where PGM mature to become spermatozoa. The PGM proliferate to generate a large population of gonadocytes which will remain as they are until puberty (Gilbert, 2000).

At puberty, the seminiferous tubes will form with a hollowing creating a lumen, and the epithelium of the testes become sertoli cells (Gilbert, 2000). The sertoli cells help to

protect and nourish the spermatogonia (Newton et al., 1993). Bone morphogenetic protein 8b (BMP8B) is produced by testicular germs cells and is responsible for the initiation of spermatogenesis once the threshold is reached, by causing differentiation of spermatogonia (Günesdogan and Surani, 2016; Zhao et al., 1996). In mice that did not produce enough BMP8B, no sperm were made (Zhao et al., 1996). The developing sperm cells are bound to sertoli cells via N-cadherin molecules and galactosyltransferase molecules (Gilbert, 2000).

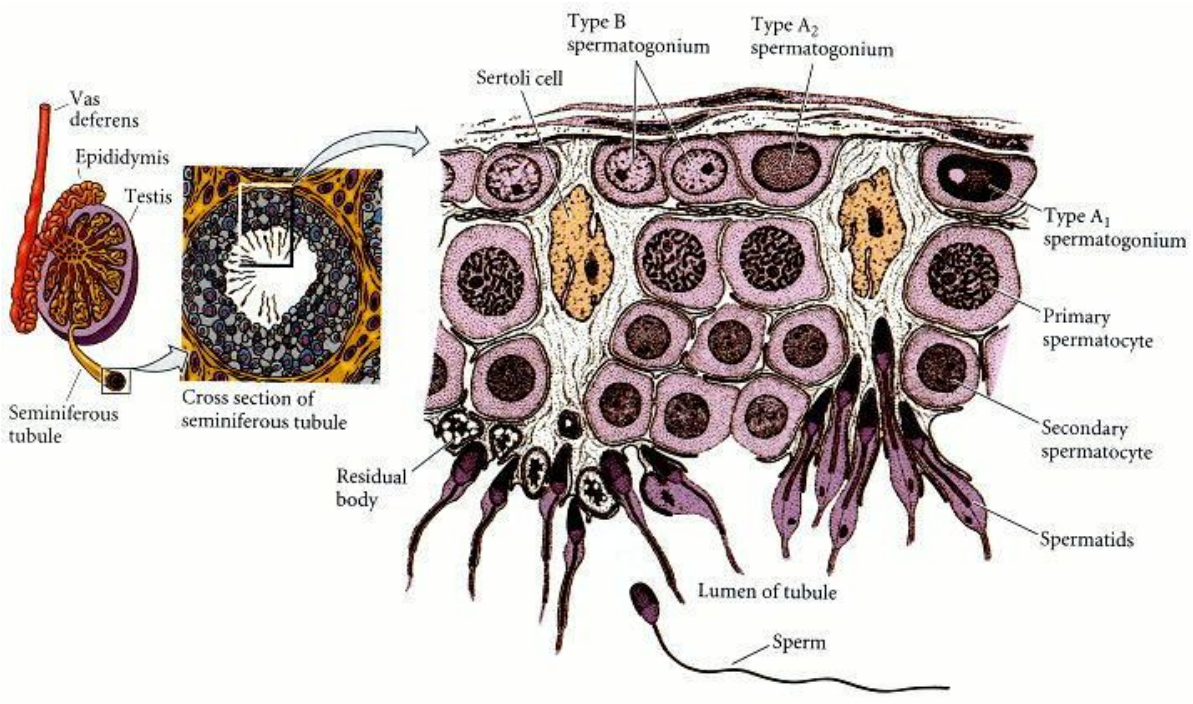


Figure 1.1 *A diagram of the testes with a cross section of the seminiferous tubules.* Various cell types present in the testes are enlarged to give an understanding of structure and direction cells travel within the seminiferous tubules, and within testes. Sperm will travel through seminiferous tubules to the Epididymus, and remain until ejaculation (Dym, 1977).

Gilbert, (2000) provided an overview of the process of spermatogenesis as it will be discussed in this section. It begins with Type A1 spermatogonium, which divide to make more of themselves via mitosis, and to generate Type A2 spermatogonium. Type A2

spermatogonium can make Type A3 spermatogonium and Type A3 spermatogonium generate Type A4 spermatogonium. All of these cells are stem cells and can self generate. The Type A4 spermatogonium can generate an intermediate spermatogonium. The intermediate spermatogonium can divide once to make type B spermatogonium. The type B spermatogonium then divide mitotically. These freshly divided cells will become the primary spermatocytes and continue in the pathway to enter meiosis I, which will be described in detail, later. These cells produce two secondary spermatocytes which undergo meiosis II, ultimately generating two haploid spermatids per secondary spermatocyte (Gilbert, 2000) ***Figure 1.2*** shows the cells produced from this process. As the cells are undergoing the divisions, they move farther from the basal membrane of the seminiferous tubules and closer to the lumen. Spermatids lose connections and continue maturation in the seminiferous tubules.

Gilbert, (2000) and Alberts et al., (2002) provided a summary of spermiogenesis. Once in the seminiferous tubules, the spermatids will undergo spermiogenesis (differentiation), which is the maturation to spermatozoa. It is crucial that the sperm are able to attach to the egg to fertilize it; hence one of the first steps in maturation is the differentiation of the Golgi apparatus to an acrosomal vesicle. The vesicle will form into a cap above the nucleus and face the basal membrane. The flagellum of the sperm will develop in towards the lumen of the seminiferous tubules with the mitochondria near the flagellum to provide energy. In addition to changes to the cell components, the Deoxyribonucleic Acid (DNA) will undergo changes. The histones are replaced by protamines, which are small proteins that will prevent transcription, and will result in the DNA being tightly packaged. Additionally, the nucleus will compact and flatten. The sperm enter the lumen of the

seminiferous tubule and travel through the testis into the epididymus, ready for ejaculation (Gilbert, 2000)

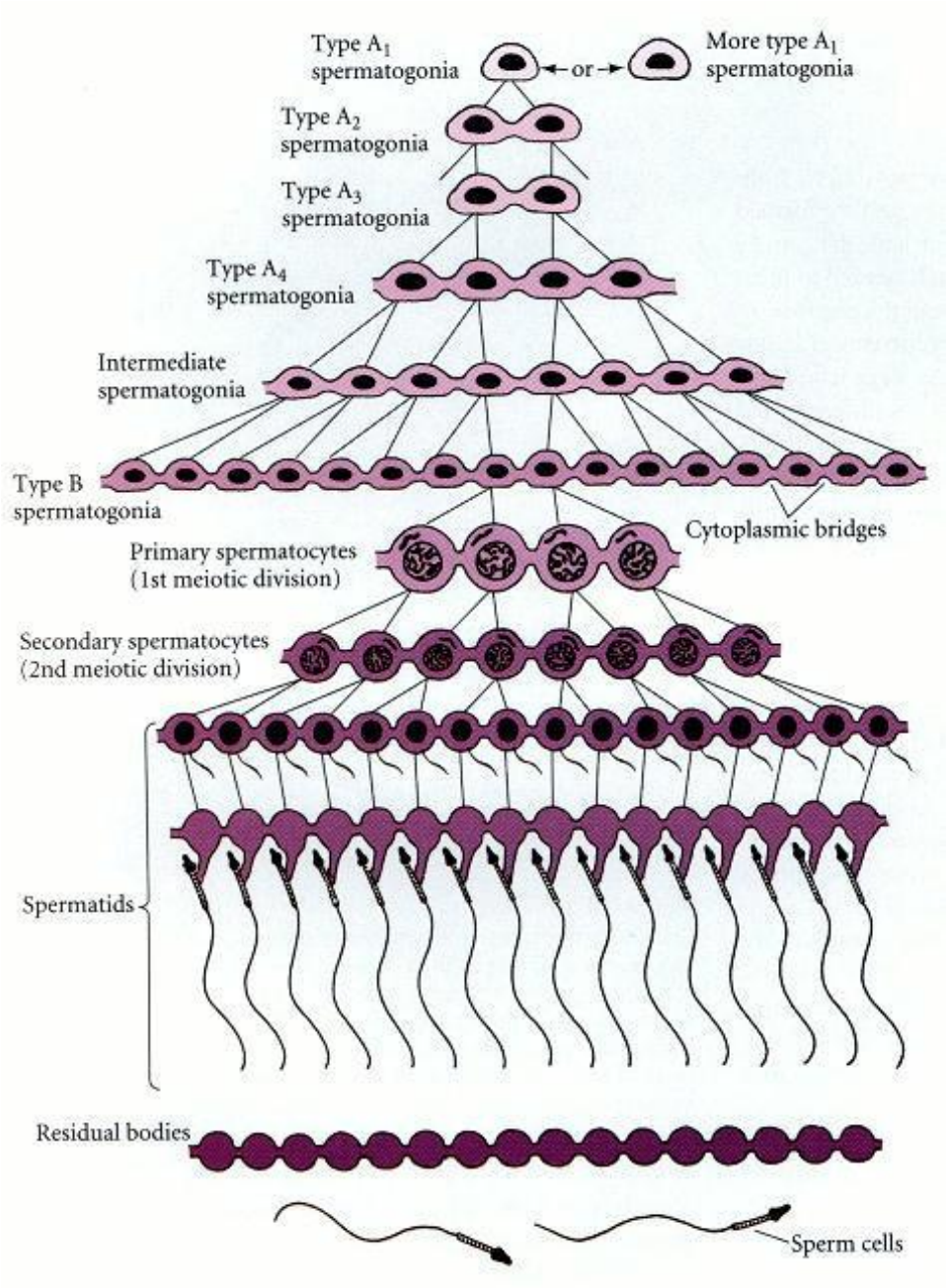


Figure 1.2 *A diagram of spermatogenesis.* Type A and Type B spermatogonia through primary and secondary spermatocytes to spermatids and sperm cells. This diagram shows the progression of these cells as they move through the seminiferous tubules to the lumen. Additionally, the number of cells generated from each step is shown (Cross, 1995).

Meiosis

Overview of meiosis I and meiosis II

Meiosis is a crucial step in the production of spermatocytes. To provide an outline of meiosis, a review from Ohkura, (2015) will be discussed. In spermatocytes, meiosis results in the production of four haploid spermatids via a two-step division. Prior to meiosis, when cells are dividing mitotically to go from Type A1 spermatogonium to Type B spermatogonium, cells are diploid and have two sets of chromosomes, each organized in a pair of sister chromatids. Replication of DNA occurs in the S-phase of interphase before meiosis I begins. During meiosis I there are recombination or crossover events that take place, and the process ultimately results in two haploid cells, each with one pair of sister chromatids. Meiosis II has no S-phase and therefore, results in a further reduction. The lack of S-phase in meiosis II results in one sister chromatid of each chromosome in each of the four cells, and therefore the effective production of haploid gametes.

In meiosis I there are four phases: prophase I, metaphase I, anaphase I, and telophase I. Prophase I is the longest consisting of several stages. Prophase I is the phase in which meiotic recombination occurs. The first stage of prophase I is called leptotene or leptonema. In leptotene, axes and double-stranded break (DSB) develop. The second stage is zygotene or zygonema in which the homologous chromosome pairs are beginning to synapse together by a tripartite protein complex called the synaptonemal complex (SC). The synapsis of homologous chromosome pairs will be discussed in greater detail in the next section. Pachytene or pachynema is described as the time at which chromosomes are fully synapsed and meiotic recombination or crossover (CO) of genetic material happen. This will also be discussed in greater detail in the following sections. Following the pachytene stage is

diplotene or diplonema. In diplotene, the SC degrades and homologous chromosomes separate except at the location of the CO, called the chiasmata. Finally, spermatocytes enter diakinesis where the nuclear membrane disappears and spindles form. These stages described can be seen in ***Figure 1.3*** (Morgan et al., 2017; Pierce, 2012).

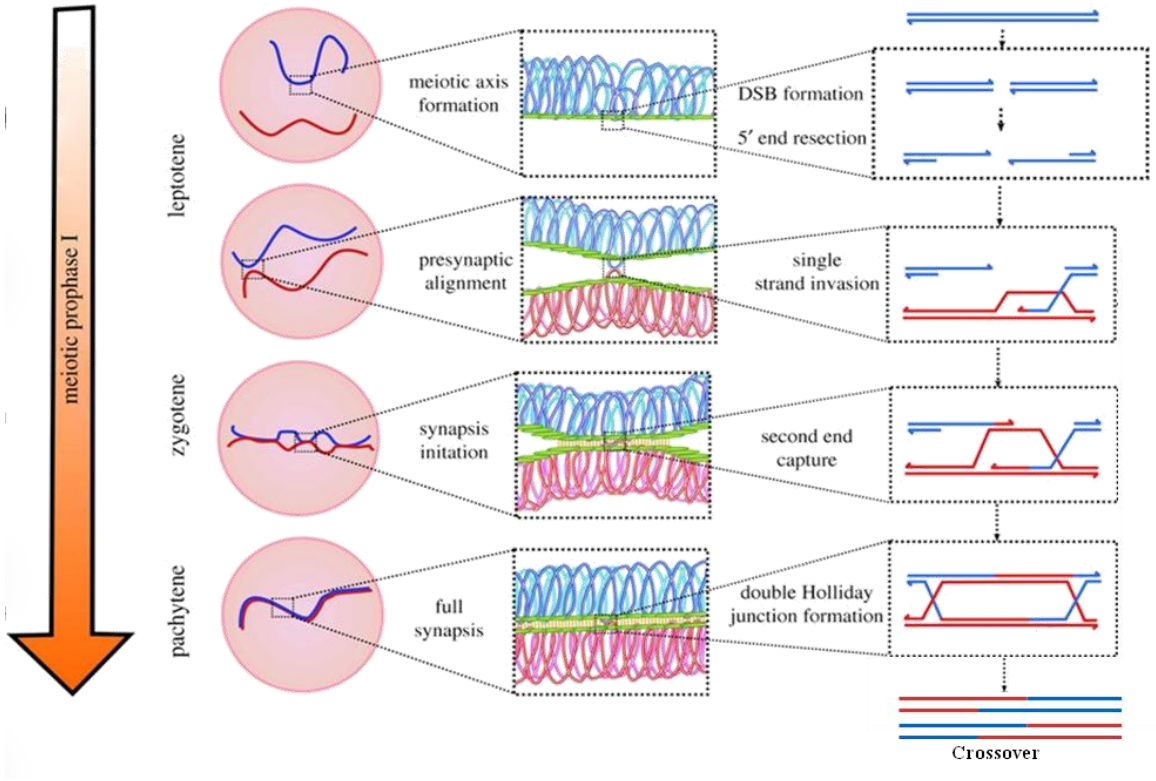


Figure 1.3 *The stages in meiosis prophase I.* In Leptotene, meiotic axis and DSB form. In Zygotene , the SC begins to form. In Pachytene, SC formation is complete, and COs occur. The formation of the SCs are depicted, along with the formation and result of a CO. Adapted from, Morgan et al., 2017.

After prophase I, spermatocytes begin metaphase I, and homologous chromosomes align on the metaphase plate. Kinetochores are proteins on the centromere of a chromosome where the microtubules attach to the chromosomes and the COs help align them properly, which means one CO per chromosome arm is required (Ohkura, 2015). As spermatocytes enter anaphase I, the kinetochore microtubules shorten and pull chromosomes to opposite sides of the cell (Kirschner and Mitchison, 1986). Cohesin forms and is what keeps sister

chromatids together (Nasmyth and Haering, 2009). In telophase I, one set of sister chromatids from each chromosome should be in each cell and the cell will cleave via cytokinesis. After this process, there are two cells with one chromosome consisting of two sister chromatids in each cell.

Meiosis II is similar to meiosis I, except there are no COs. Prophase II will result in the nuclear envelope disappearing, and centrosomes moving to polar regions. Metaphase II will align sister chromatids along the metaphase plate, but it is perpendicular to the last split. Spindles form and attach to centrosomes. In anaphase, sister chromatids will segregate and the cohesin holding the sister chromatids together will be cleaved (Watanabe et al., 2001). The chromatids will move to opposite poles. Finally, telophase will cause cytokinesis of the spermatocyte and will result in four spermatids from the original spermatocyte, which will contain one chromatid of each chromosome (Pierce, 2012).

Chromosome paring and synapses in prophase I

One of the first steps in meiotic recombination is homologous chromosome pairs finding one another to pair and synapse. One theory is that meiotic recombination begins with DSBs initiated by Initiator of Meiotic Double Stranded Breaks (SPO11) (Baudat et al., 2013). Keeney et al., (1997) report, SPO11 is a catalytic subunit of DSB cleavage activity. In eukaryotes, it is thought that DSBs are made by a reaction similar to that of Topoisomerase, in bacteria. The authors also make the connection that SPO11 is related to an archaebacterial Topoisomerase, which has similar function. It is also hypothesized to be evolutionarily conserved across eukaryotes (Keeney et al., 1997).

This process requires many proteins including, Meiotic Double-Stranded Break Formation Protein 4 (MEI4), REC114 Meiotic Recombination Protein (REC114), Meiotic Double-Stranded Break Formation Protein 1 (MEI1), and HORMA Domain-Containing Protein 1 (HORMAD1) (Baudat et al., 2013). SPO11 is responsible for creation of DSBs and homologous chromosome pairing with the help of SUN Domain-Containing Protein 1 (SUN1), which is involved in mediated telomere tethering to the nuclear envelope (Boateng et al., 2013). The recombinases DNA Repair Protein RAD51 Homolog (RAD51) and DNA Meiotic Recombinase 1 (DMC1) are also involved in bringing homologous chromosomes together (Baudat et al., 2013). Homologous chromosomes are ultimately tethered together by the synaptonemal complex proteins 1, 2, and 3 among other proteins (Fraune et al., 2012). To understand the process more clearly, each of these components will be discussed in more detail.

A study by Boateng et al., (2013) used immunofluorescence staining and fluorescent *in situ* hybridization (FISH) for visualization of mouse meiotic cells undergoing recombination of mice spermatocytes. Additionally, Fluorescence-Activated Cell Sorting (FACS) was used to sort out spermatocytes and distinguish between early, mid, and late pre-leptotene spermatocytes. This experiment suggested SPO11 is necessary for homologous chromosome pairing, but not because it needs DSBs. They used mice that did not have DSBs during the first prophase of meiosis and saw normal SPO11 expression. There are two isoforms of *Spo11*, α and β, which are expressed at different times. *Spo11α* is primarily expressed after the pachytene stage and its absence is deleterious for the sex chromosomes. *Spo11β* is expressed in early spermatocytes and involved in generating most meiotic DSBs (Bellani et al., 2010; de Massy, 2013; Metzler-Guillemain and de Massy, 2000; Romanienko

and Camerini-Otero, 1999). Mice with an amino acid change (mutant) in *Spo11*, causes asynapsis, but it can be restored if *Spo11β* is replenished during pre-leptotene. However, *Spo11* knockout mice don't have synapsis restored, with normal levels of *Spo11α*. These results suggest SPO11 is also needed in early chromosome pairing.

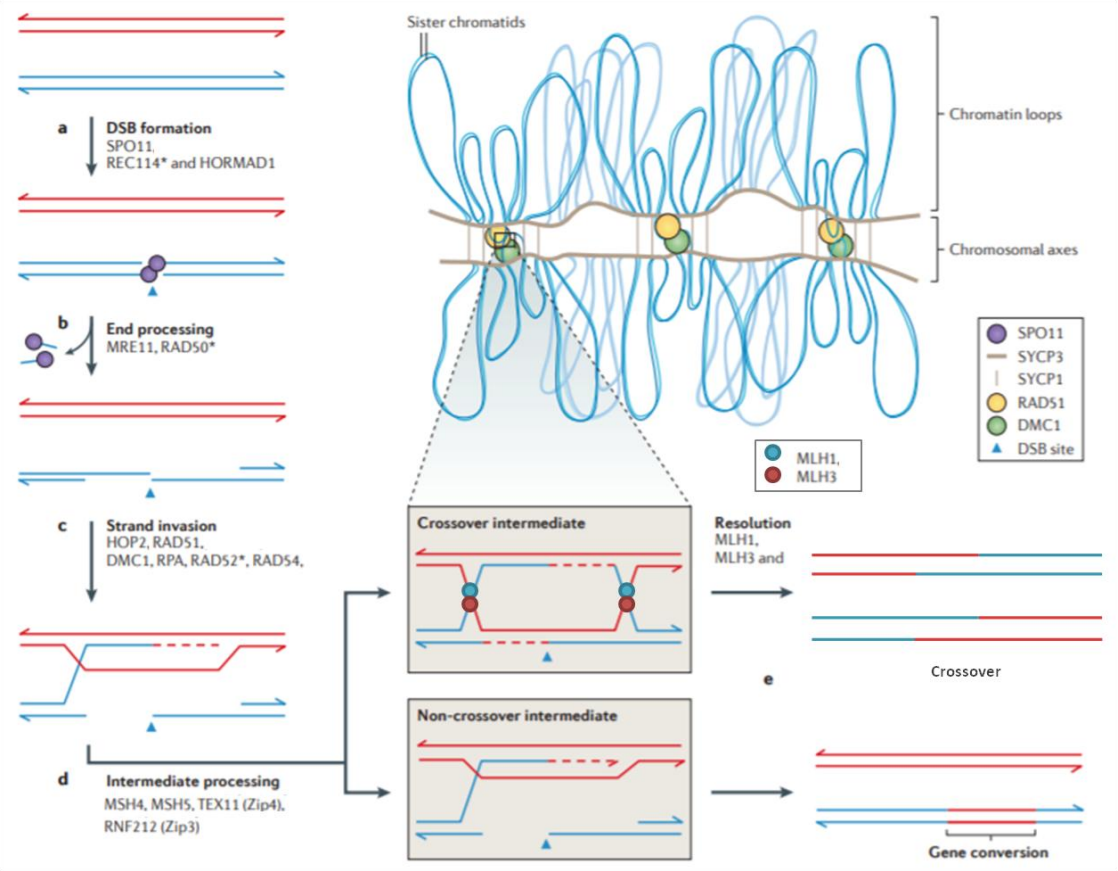


Figure 1.4 *Double Holliday junction resolve and result in crossovers and non-crossovers*. After DNA undergoes DSBs, RPA binds the DNA and recruits other proteins like RAD51 and RAD54. The search for homologous chromosomes begins with RAD52. Strand invasion begins and there is a formation of a D loop and the Holliday junction, which can be resolved via a crossover or a non-crossover (Adapted from Baudat et al., 2013).

Some research suggests SPO11 is involved in homologue pairing in pre-leptotene stage, before DSBs begin to form. Replication protein A (RPA) binds single stranded DNA during DSBs (Khalil et al., 2012). Next, RPA recruits the recombinase exchange proteins RAD51 and DMC1 to work together to cause strand invasion with the help of homologous-

pairing protein 2 homologue (HOP2), RAD52, RAD54, BRIT1 (microcephalin), and the two genes involved in breast cancer, Breast Cancer 1 and 2 (BRCA1, and BRCA2), to bring homologous chromosomes together (Baudat et al., 2013). In combination with RAD51, RAD54 acts as a helicase to form a nucleoprotein at the DSB site (Khalil et al., 2012). A structure is formed with RAD52, and is capable of interacting with the double stranded and single stranded DNA to search for homologous strands (Khalil et al., 2012). Brown and Bishop, (2015) determined DMC1 is important as the DNA strand–exchange factor for recombination, and RAD51 is necessary for a regulatory role. The BRCA1 and BRCA2 proteins are recruited as scaffolding proteins to give structure to help bring homologous chromosomes together (Khalil et al., 2012). The protein SUN1 also helps with this by tethering telomeres to the nuclear envelope (Boateng et al., 2013). These processes can be seen in ***Figure 1.4.*** Additionally, Boateng et al., (2013) found that SUN1 anchors telomeres to the nuclear envelope to help with pre-DSB pairing. They report, SUN1 is highly expressed in early mouse spermatogenesis. Additionally, spermatocytes that were lacking SUN1 resulted in asynapsis and ultimately, mutant mice had no homologous chromosome pairing. This data suggests that pre-leptotene pairing of homologous chromosomes requires SUN1 (Boateng et al., 2013).

Homologous chromosomes are ultimately tethered together by the synaptonemal complex proteins 1, 2, and 3, (SYCP1, 2 and 3) among other proteins, which are recruited at DSB repair sites (Fraune et al., 2012). Boateng et al., (2013), also found that pre-DSB subtelomeric pairing is more stable and most likely aids in synapsis initiation. Most of the Telomeric Repeat Binding Factor 1 (TRF1) and Chromatin Remodeling Complex Subunit (CREST) (telomere and centromere) associates with the ends of most SYCP1, which

suggests, in male mice, spermatocytes synapsis usually begins at the chromosome ends (Boateng et al., 2013).

Crossovers and DSB repair mechanisms

Meiotic recombination results in crossovers and non-crossovers, defined by Baudat et al., (2013). A crossover is an exchange of genetic material between homologous chromosomes. A non-crossover is the unidirectional passing of genetic material as the mechanism for repairing DSBs. It is thought that non-crossovers may also aid in the pairing of homologous chromosomes (Baudat et al., 2013). After the synaptonemal complex (SC) is formed, recombination intermediates are processed, with either double Holliday junctions, which result in crossovers, or with single-end strand invasions, which result in non-crossovers (Sarbajna and West, 2014). ***Figure 1.4*** is an image showing double Holliday junctions. The search by RAD52 results in the formation of D-loop structures to be resolved with double Holliday Junctions (Baudat et al., 2013).

The detection of DSBs is done by H2AX, because it is phosphorylated by ATMkinase, which is known to trigger DSB repair (Baudat et al., 2013). Homologues are stabilized by proteins like MutS proteins 4 and 5 (MSH4 and MSH5) (Baudat et al., 2013). Nishant et al., (2010) determined that MSH 4 and MSH 5 are also important for DNA binding domains in yeast. Teste Expressed sequence (TEX11), and Ring Finger Protein 212 (RNF212) act like molecular zippers, which prepare the strands with intermediate processing (summarized in a review by Baudat et al., (2013)). A study by Reynolds et al., (2013) showed that RNF212 is necessary in COs and serves to connect chromosome synapsis and formation of CO complexes, in mice. When *Rnf212* is knocked out in mice, those mice are

healthy, but show no spermatocytes past anaphase I and are therefore sterile. When *Rnf212* is absent, the SC forms normally, but COs are reduced by 90% and therefore, the cells undergo apoptosis.

An important protein in meiotic recombination is MutL Homologue 1 (MLH1). A study by Edelmann et al., (1996) sought to understand the role of MLH1 in normal growth and development. To understand the normal role of MLH1, mice with a null mutation in MLH1 were studied. Both males and females were included in the study to determine the impact of mutated MLH1 in each sex. The study found that in both males and females the null mutation resulted in sterility. The stage at which the mice were affected was different for males and females. In males, there were no spermatozoa made, but there were spermatocytes to begin. Males with the mutation exhibited meiosis I arrest. Sertoli cells were present in the testes, indicating other conditions for sperm production were normal. Females had normal oocyte production and hormone levels. Females were able to mate with wild type males normally, however oocyte development stopped after the single cell stage. Another experiment, within the study, reported mating of two F1 heterozygous animals that have one mutant allele for *Mlh1* (deletion of exon 2), can still produce viable offspring that are homozygous for the deletion. This was tested by mating heterozygous mice and observing all three genotypes in the pups. However, in a study by Lipkin et al., (2002) where *Mlh1* was completely knocked out, spermatocytes died at diplonema. MLH1 and MLH3 work together to form a complex and both are required for CO resolution, so Lipkin et al., (2002) also knocked out *Mlh3*. Overall, loss of MLH3 resulted in loss of chiasmata, associated proteins like MLH1, and MLH1-MLH3 complexes, because MLH3 preloading is required for MLH1 binding. Mice that had *Mlh3* knockout, lost the ability to recombine. The study resulted in

finding that loss of MLH1 does not compromise crossover frequency. This suggests that MLH1 and MLH3 may act as crossover checkpoint regulators and are necessary for COs to occur.

Crossover numbers reported in cattle and sheep

To understand meiosis, an important component of gamete production, the number of COs per spermatocyte have been characterized and reported in livestock. A study by Fröhlich et al., (2015) used a cytological approach to determine crossovers per spermatocyte in the spermatocytes of 4 sexually mature Czech Spotted cattle and 11 sexually mature mixed breed sheep. In the study, 720 cattle spermatocytes were evaluated and were reported to have an average of 47.53 ± 4.26 SD COs per spermatocyte. The study also had 1,297 sheep spermatocytes evaluated, and were reported to have an average of 62.9 ± 6.04 SD COs per spermatocyte.

Another study by (Zhou et al., 2018), also measured CO numbers per spermatocyte, but used a different method. The study constructed recombination maps from genotypes in the form of Single Nucleotide Polymorphisms (SNP). A single Holstein bull's CO numbers were evaluated using pedigrees of 556 of his offspring, and 56 sperm were single sperm-typed. They reported the average number of COs from the pedigree to be 21.91 ± 0.5 SE and 21.91 ± 0.12 SE from sperm. These numbers are less than half of what was reported by Fröhlich et al., (2015). To explain this, consider the following. In pachytene stage spermatocytes, COs occur on two of the four chromatids that recombined, for a given chromosome pair. However, after the reduction from Meiosis I and the further reduction from Meiosis II, only two of the four spermatocytes, and ultimately two of four or half of a

bull's offspring show any given CO. Therefore, a study looking at SNP data only reports approximately half of COs that occurred.

Hybrid sterility

It is known that fertility and ultimately sterility is an issue in hybrid animals, in part due to complications in meiosis. Research from Mihola et al., (2009), determined that PR/SET domain 9 (*Prdm9*) serves two functions, one controls meiotic recombination hot spots, and the other acts as a hybrid sterility gene in mice. Later, a study by Balcova et al., (2016), tried to determine whether meiotic recombination rate at the genome wide level was related to hybrid sterility. Balcova and colleagues used two different subspecies of mice, PWD/Ph and C57BL/6, to understand recombination rates in cells from hybrid animals using a cytological approach. In mice, the genes Hybrid Sterility, X Chromosome Quantitative trait locus (QTL) 1 (*Hstx1)* and Hybrid Sterility, X Chromosome QTL2 (*Hstx2)* are shown to cause hybrid sterility. *Hstx1* reduces fertility due to abnormal sperm production. *Hstx2* impacts intra-meiotic arrest and causes full sterility in the mice that were studied. Global recombination in males is impacted by the X-linked hybrid sterility locus. In mutant males with allele *Hstx2* at the Meiotic recombination 1 (*Meir1)* loci, small testis and lack of sperm is reported. Furthermore, in mutant males, *Hstx1* causes malformations in sperm. When looking at X-linked control of meiotic crossovers in females, C57BL/6 female mice had almost 5 more CO per spermatocyte when compared to males, but in PWD/Ph mice, males exhibited higher CO numbers. In hybrid females, CO numbers decreased, unlike in males, this indicated that the X-linked modifier acted like the mutant and suppressed global CO numbers. This study shows that in F1 hybrids, the X chromosome plays a major role in

global meiotic recombination numbers. The gene, *Prdm9* plays a major role in determining meiotic recombination "hotspots" and acts as a sterility gene in hybrids. Despite having one parent with high CO numbers, F2 mice with varying alleles at *Meir1* had low CO numbers. Meiotic recombination is controlled by *Prdm9* and *Meir1,* and their loci being at the same locus as *Hstx2*, indicates a link to sterility in hybrids (Balcova et al., 2016). This information shows that meiotic recombination can be impacted by genes that may also be part of the reason for hybrid sterility. This study also explains why males often experience hybrid sterility more than females. Although reduced CO numbers are observed, this is not correlated with reduced fertility, unless the required one CO per chromosome arm is not met.

Further research by Balcova et al., (2016) evaluated CO rate in PRDM9 deficient males and in *Prdm9* transgenic males, or males containing DNA (the *Prdm9* gene) from another subspecies, to compare gene dosage on meiotic recombination and hybrid sterility. To quantify COs, immunofluorescence staining was used and MLH1 was counted. Mice of the C57BL/6 strain with the PWD/Ph allele on chromosome 7 had increased meiotic recombination and those with the allele on chromosome 11 had reduced meiotic recombination. Additionally, mice were tested with more and fewer copies of *Prdm9*. The global recombination rate did not change based on number of *Prdm9* copies.

In addition to these genes, the psudoautosomal region (PAR) of the X and Y chromosomes must be compatible for meiosis to occur properly. The PAR is the region which the X and Y chromosomes are similar and must synapse and recombine/CO to ensure proper segregation and continuation of the spermatocytes through the process. A study by Dumont, (2017) looked at the sex chromosomes to determine how they were synapsing, the CO, and overall cell continuation. Dumont found that genetic difference in the sex

chromosomes resulted in less synapsing, and lack of COs in the PAR, which would increase nondisjunction, and therefore, higher rates of apoptosis in spermatocytes.

Chromosomal defects

In addition to hybrid sterility, many hybrid animals also experience autosomal chromosomal defects during meiosis I, which can impact fertility. Dollin et al., (1991, 1989), described chromosome paring behavior in full-blood *B. indicus, B. taurus,* and *B. indicus* X *B. taurus* hybrids. In hybrid animals, they found on average, 23% of meiotic chromosome pairing had synapsis abnormalities, which was significantly greater than the 9% exhibited in the spermatocytes of full-blood cattle. Forejt and Iványi, (1974) discussed that random pairing failure and other abnormalities, like gaps in the synaptonemal complex of meiotic chromosomes, may be due to the genetic incompatibility between the parents of hybrid animals.

In a review on nondisjunction, Koehler et al., (1996) states, "in both, a proportion of nondisjunction is associated with failure to pair and/or recombine and in both, exchanges which are either too distal or too proximal increase the likelihood of malsegregation." Another defect that can lead to segregation error is having ring chromosomes. Yip, (2015) wrote about the negative effects of ring chromosomes, such as breakage of chromosomes during meiosis, irregular chromosome sizes, and loss of genetic material. These defects often lead to apoptosis of these spermatocytes. A study by Murdoch et al., (2013) looked at the effect of altered cohesin gene dosage on meiotic chromosome structure and synapsing in mice. Not many meiosis I and meiosis II cells were found in males with a mutated cohesin. This suggests that most of these cells are eliminated, and do not continue through

spermatogenesis. Ultimately, this means that cells with defects will undergo apoptosis, reducing the number of spermatocytes that can continue through spermatogenesis to become mature sperm.

Project overview

Overall, it is understood that meiotic recombination is a crucial process necessary to create genetic diversity and ensure proper chromosome segregation. Spermatogenesis has stringent checkpoints to ensure correct chromosomal content, therefore, when chromosomes do not segregate properly, this can lead to apoptosis. Additionally, it is important to note that it is a complex process with many factors and proteins involved. It is thought that a major contributor to the location and regulation of meiotic recombination is due to PRDM9 (Balcova et al., 2016). Another important protein is SPO11, which creates DSBs for the crossover events to occur. It is also known that MLH1 and MLH3 are necessary in production of gametes due to the role they may play as crossover checkpoint regulators. In my research I am characterizing meiotic recombination frequency and location in Beefalo, cattle, and sheep. Meiotic recombination is an important process necessary for production of viable and fertile offspring.

Hypotheses

Given the information presented above, we hypothesize is that global CO numbers will not differ between Beefalo, cattle, and sheep. We also hypothesize that COs will occur in similar locations between Beefalo and cattle. Finally we hypothesize that there will be defects in spermatocytes of the hybrid, Beefalo. Therefore the objectives are to quantify CO

numbers per spermatocyte in Beefalo, cattle, and sheep, measure SC length, determine relative position of COs on SCs. Additionally, we will quantify defects in spermatocytes from Beefalo and cattle.

Impact

Understanding meiotic recombination, a crucial part of spermatogenesis, may help understand fertility in livestock and hybrid animals. Errors in genes that control meiotic recombination can lead to spermatocyte arrest. Additionally, defects in chromosomes of spermatocytes can lead to apoptosis. In Beefalo, F1 and F2 generations of males are sterile, but females are not. Incompatibilities in genes of hybrid animals, can also lead to reduced CO numbers, and potentially chromosomes lacking COs. A chromosome pair lacking a CO may lead to improper chromosome segregation and ultimately apoptosis for the spermatocyte. Therefore, all of these components are important for meiotic recombination and help us better understand livestock and more specifically, hybrid matings. Hybrid animals can provide valuable traits to make more efficient and adaptable livestock to account for the needs of consumers.

Further, understanding meiotic recombination in livestock animals will allow us to have a better understanding of how traits are passed on to offspring. Although the application is downstream, and may take more research to be directly valuable in an application usable by producers and the livestock industries, this research provides novel characteristics of chromosomes and how they recombine meiotically. By knowing where COs occur on a chromosome, we may be able to predict which genes are more likely to be recombined. Knowing this would allow for more accurate genetic predictions based on where genes are

located spatially on a chromosome. Therefore, this research, which characterizes meiotic attributes of the chromosomes, in a downstream application, may help create a system with more accurate genetic predictions. Ultimately, understanding chromosome biology will aid in making genetic improvements in ruminant livestock species.

CHAPTER 2

Meiotic Recombination in Ruminant Livestock Species

A. Rodriguez, Davenport, K., Glaze, B., McKay, S., Gill, C., and Murdoch, B., "Meiotic Recombination in Ruminant Livestock Species", Proceedings of the World Congress on Genetics Applied to Livestock Production, vol. Biology - Reproduction 1, p. 934, 2018.

Summary

Homologous recombination is an important component of gametogenesis that contributes to genetic variation and ensures proper chromosome segregation. Despite the importance of this process, we know very little about the factors that control and/or influence global meiotic recombination/crossover (CO) in livestock. Previous research recognizes that at least one CO per chromosome arm is required to ensure proper chromosome segregation (Koehler and Hassold, 1998). Even though cattle and sheep are different species and Beefalo are a cattle hybrid, they have the same number of chromosome arms. This study uses a direct cytological approach to quantify and characterize the number of COs in Beefalo, cattle, and sheep spermatocytes. Here we report that Beefalo exhibit on average 5% fewer COs per spermatocyte compared to cattle, and cattle exhibit 28% fewer COs compared to sheep. Furthermore, we examined the number of COs for each homologous chromosome pair in a subset of Beefalo, cattle, and sheep spermatocytes. We found a positive correlation between the numbers of COs and the length of a chromosome. Overall, sheep exhibited as many as 9 COs per chromosome; whereas the maximum number observed in cattle and Beefalo was 5 and 4, respectively. Importantly, when compared with cattle, 11% of Beefalo spermatocytes

exhibited chromosomes with structural defects and 9% were lacking a CO, both of which can lead to improper chromosome segregation, apoptosis, and reduced fertility. While hybrid species and subspecies crosses have the potential to provide valuable phenotypic traits, understanding chromosomal differences will help resolve breeding difficulties. This research contributes valuable information towards understanding meiotic recombination in livestock for use in both genetic predictions and selection strategies. This paragraph was taken from (Rodriguez et al., 2018).

Keywords: meiosis, cattle, sheep, Beefalo, crossovers

Introduction

Homologous recombination is an important component of gametogenesis that contributes to genetic variation and ensures proper chromosome segregation. Despite the importance of this process, little is known about the factors that control or influence global meiotic recombination in livestock species. However, it is clear from previous studies in humans and model organisms, that at least one recombination event/CO per chromosome arm is necessary for proper chromosome segregation (Handel and Schimenti, 2010; Vogt et al., 2008). Furthermore, inadequate or misplaced COs can lead to improper segregation of homologous chromosomes during meiosis (Hassold et al., 2007).

Meiotic recombination is initiated by the protein SPO11, which establishes double strand breaks (DSB) (Boateng et al., 2013; Keeney et al., 1997). Subsequently, DSBs are resected to yield 3’ overhangs, and strand invasion proteins RAD51 and DMC1 produce double-Holliday junctions (Hunter and Kleckner, 2001). Mismatch repair proteins, MLH1 and MLH3, then localize to the majority of CO events (Edelmann et al., 1996; Lipkin et al.,

2002). In order for a CO to occur, homologous chromosomes must pair and synapse together by a protein complex called the synaptonemal complex (SC), composed of synaptonemal complex proteins 1 and 3 (SYCP1 and SYCP3) among other proteins (Baudat et al., 2013). The location of COs can exhibit preferences (hotspots) and the presence of one CO can "interfere" with a second CO in close proximity. Histone methyl transferase PRDM9 binds specific DNA motifs and different alleles of PRDM9 exhibit altered binding specificity for recombination hotspots (Baudat et al., 2010; Grey et al., 2011). Additionally, linkage studies in humans have identified an association between number of COs and genetic variation in *RNF212* (Kong et al., 2008; Reynolds et al., 2013).

While these analyses have provided valuable insight into meiotic recombination, only a few studies, to date, have been done in livestock species. Previous studies reported single nucleotide polymorphisms (SNP) in *REC8*, *RNF212* and *PRDM9* associated with COs in cattle (Sandor et al., 2012). A different study utilizing SNP data in Holstein cattle, reported a decrease in male COs over time (Ma et al., 2015). Furthermore, other studies have identified chromosomal regions associated with global CO numbers in mice (Dumont and Payseur, 2011; Murdoch et al., 2010) and cattle (Weng et al., 2014). The previous studies in cattle used genome based approaches, which rely on the quality of the reference genome assembly, can only detect COs in genomic regions with genetic variation, and require large pedigrees to provide meaningful statistical comparisons. Additionally, due to independent assortment of chromosomes, this approach only captures approximately half of the CO events that occurred during meiosis. In contrast, the use of cytogenetics, commonly used in humans and model organisms, does not suffer from these constraints. Cytogenetics can identify all meiotic recombination events and detect meiotic, synaptic, and chromosomal defects.

Despite Beefalo being a bison/cattle hybrid, and cattle and sheep being different species, they have similar sized genomes and the same number of chromosome arms. Cattle and Beefalo have 29 telocentric (one arm) autosomes and sheep have 23 telocentric and 3 metacentric (two arms) autosomes. The objectives of this study were to quantify the number of global CO events, examine the relationship between CO numbers and chromosome length, and characterize CO location on homologous chromosome pairs in spermatocytes of Beefalo, cattle, and sheep. It is important to note that the mating of two different species can lead to reduced fertility from hybrid crosses. Improper chromosome pairing and/or misplaced CO placement during gametogenesis can result in sterility in hybrid males. Therefore, we also quantified the number of chromosomal defects observed in spermatocytes of Beefalo and cattle. This research will allow us to better understand the chromosomal properties of speciation, to move towards improved and successful breeding strategies of hybrid livestock. Additionally, these data contribute valuable information towards a greater understanding of meiotic recombination in livestock for use in both genetic predictions and selection strategies. This section has been taken from Rodriguez et al., (2018).

Materials and methods

Since the publication of Rodriguez et al., (2018) more spermatocytes and an additional animal were added to this study, but methods and analysis remain the same.

Animals

Testicles were collected from sexually mature Beefalo (n=7, unknown bison and cattle cross), cattle (n=11; 7 Angus, 1 Charolais, 1 Gelbvieh, 1 Jersey, and 1 Lowline), and

sheep (n=27; 5 Icelandic, 17 Suffolk, and 5 Targhee). Beefalo are the hybrid (3/8 bison) resulting from cattle (*Bos taurus*) and bison (*Bison bison)* matings. All of the Beefalo, cattle, and sheep samples were acquired post mortem from local abattoirs.

Immunofluorescence staining of testicular samples

Testicles were collected immediately postmortem and transported on ice to the laboratory for surface spread preparation as described in Murdoch et al., (2010). Testicular tissue was dissected into approximately one-gram pieces of parenchyma and incubated in a hypotonic buffer (30mM Tris, 50mM sucrose, 17 mM sodium citrate, 5 mM EDTA, 2.5 mM DTT, and 0.5 mM PMSF). Small sections of the seminiferous tubules were cut to remove all cells present, then the cut section was mixed with 100mM sucrose and fixed on slides with 1% paraformaldehyde. Slides were placed in a humid chamber overnight and either stained immediately or stored at -20ºC.

Immunofluorescent staining was performed to identify MLH1 and SYCP3 proteins using a modified protocol outlined previously (Murdoch et al., 2010). Slides were blocked in 1% Normal Donkey Serum, 3 mg/mL BSA, 0.05% Triton X-100, PBS for 1 h at 23 ºC. The rabbit polyclonal MLH1 antibody (Calbiochem, PC56-100UG) was applied to each slide. Slides were cover slipped, incubated at 37ºC for 12-14 h and washed twice with PBS. AlexaFluor 488-conjugated donkey anti-rabbit secondary antibody (Jackson ImmunoResearch, 711-005-152) was placed on the slides and incubated at 37ºC for 4 h. Slides were washed before the polyclonal rabbit anti-human SYCP3 antibody (Abcam, ab15093) was added. The slides were cover slipped and incubated for 2 h at 37ºC, then washed twice before Rhodamine donkey anti-rabbit secondary antibody (Santa Cruz

Biotechnology, sc-516249) was added. Slides were cover slipped and incubated for 1 h at 37ºC, then washed three times in PBS. Lastly, ProLong® Gold Antifade (Fisher Scientific, P36930) was applied to slides and cover slipped.

Acquisition of data and analysis

A Leica DM6 B fluorescence microscope with appropriate filters (405, GFP, and Y3 cubes) was used for imaging. Pachytene stage cell images were captured with the use of Leica LASX software version 3.0. Quantification of COs were determined by counting the number of MLH1 foci observed on the SC for each of 100 spermatocytes. MLH1 foci observed on the pseudoautosomal region of the sex chromosomes were not included. Total defects were quantified using 50 randomly identified pachytene stage spermatocytes per animal. Each cell was evaluated for absence or presences of defect(s). The SC length was measured (μm) for all individual SCs in a subset of 10 spermatocytes per individual. The distance was measured starting at one end of the SC to the first MLH1 focus, then subsequent MLH1 foci and to the distal end of the SC using ImageJ v1.51 software.

Data were tested for normality using a Shapiro test, and were determined not to be normal; therefore, statistical analysis was performed using a non-parametric test to examine differences in the number of MLH1 foci between species and individuals within each breed. RStudio version 3.3.3 was used to run a Kruskal-Wallis with post-hoc Tukey-Kramer test for significant differences in number of MLH1 foci per spermatocyte. Significance is declared at $P< 0.05$. The statistical analysis used, is based on non-parametric median ranks, and constitutes the differences seen. To examine potential relationships between chromosome length and number of COs, Spearman's correlation was calculated between the number of

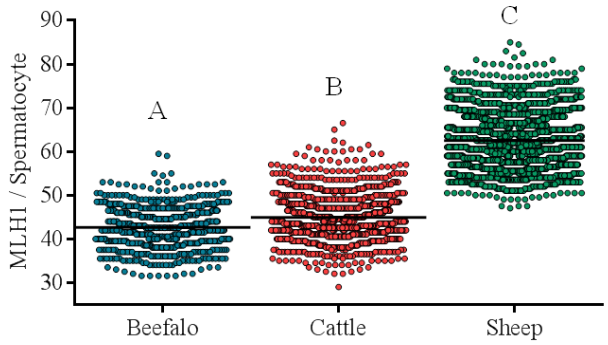
MLH1 foci and SC length. Spearman's correlation is a non-paramentric test, and was used because the data weren't normal. To detect differences in defects between Beefalo and cattle, variances of data were compared, and determined to be equal. After a variance test was performed, a pooled, unpaired T-test was used to detect significant differences ($P < 0.05$) in the number of cells with chromosomal defects between Beefalo and cattle.

Results and discussion

Number of crossovers in Beefalo, cattle, and sheep spermatocytes

Between strains of mice, recombination numbers differ, however, this has not been evaluated extensively in livestock. We examined COs in meiotic cells from Beefalo, cattle, and sheep. In total, 4,594 spermatocytes were examined and the number of MLH1 foci were quantified; 725 spermatocytes were from Beefalo (n=7), 1,120 spermatocytes from cattle (n=11), and 2,749 sheep spermatocytes (n=27). Beefalo bulls exhibited significantly ($P<1.5X10^{-4}$) fewer COs ($\bar{X}$=42.6±0.17 SE) in comparison to cattle ($\bar{X}$=44.9±0.16 SE) and sheep ($P<2.2X10^{-16}$), ($\bar{X}$=61.7±0.15 SE) which exhibited the greatest (Rodriguez et al., 2018). It is important to note that the statistical analysis used, is based on non-parametric median ranks, and constitutes the differences seen. The global number of COs for each spermatocyte in the three species is shown in ***Figure 2.1.*** Significance was based on non-parametric ranks, not on means reported. These data uphold our hypothesis that despite all three species having the same number of chromosome arms, they exhibit significantly different global recombination.

A



B

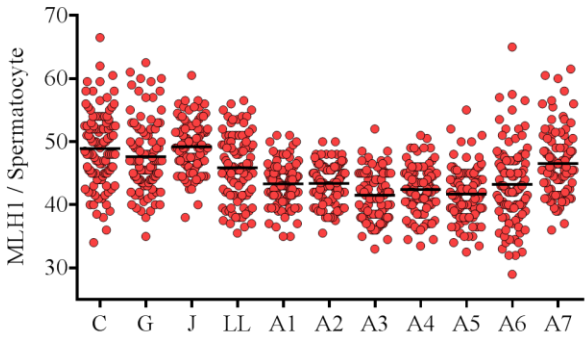
Individual	Spermatocytes	Avg. CO ± SE
Beefalo	725	42.6 ± 0.17
Cattle	1120	44.9 ± 0.16
Sheep	2749	62.5 ± 0.78

Figure 2.1 *Meiotic crossovers in Beefalo, cattle, and sheep spermatocytes.* A) The number of COs (MLH1) for each spermatocyte from Beefalo (n=7), cattle (n=11), and sheep (n=27). Each dot represents the number of COs from individual spermatocyte, black bars represent breed mean, and the letters above denote significant differences (A-B, $P \leq 1.5x10^{-4}$; C-A and C-B, $P \leq 2.2x10^{-16}$). B) Table of the mean CO number (MLH1) plus and minus the standard error for Beefalo, cattle, and sheep. Significance was based on non-parametric ranks, not on means reported (Rodriguez et al., 2018).

To evaluate the variation in meiotic recombination within a species, individual cattle were compared to each other. The number of COs per spermatocyte were plotted for each individual animal in ***Figure 2.2.*** It is important to note that the statistical analysis used, is based on non-parametric median ranks, and constitutes the differences seen. The P values are reported in Figure 2.2C. Charolais, Gelbvieh and Jersey had no significant differences in CO numbers. However, Angus 1 through Angus 6 had significantly less COs compared to Charolais, Gelbvieh, Jersey, and Angus 7. It is important to note that only one bull from each of 4 breeds; Charolais, Gelbvieh, Jersey, and Lowline bulls are represented here (Rodriguez et al., 2018). The Lowline had no statistical differences detected when compared to Gelbvieh, and Angus 7 (the Angus animal with higher CO numbers), however, was statistically different that the rest. Interestingly, when examining breeds of sheep, breed differences were detected (Murdoch, unpublished). Angus1 through Angus 6 have statistically different number of COs compared to Charolais, Gelbvieh, Jersery and Lowline, indicating there may

differences in some breeds; these trends should be tested with more animals added to each breed. We hypothesize, differences in number of COs in different breeds could be due to differences in genes that control COs, like *PRDM9*. This approach may provide valuable insight into breed-specific genetic predictions in livestock.

A



B

Individual	Spermatocytes	Avg. CO ± SE
Charolais	112	48.9 ± 0.55
Gelbvieh	100	47.6 ± 0.56
Jersey	102	49.2 ± 0.39
Lowline	100	45.9 ± 0.51
Angus 1	100	43.3 ± 0.33
Angus 2	100	43.4 ± 0.30
Angus 3	101	41.5 ± 0.36
Angus 4	100	42.4 ± 0.37
Angus 5	100	41.7 ± 0.41
Angus 6	101	43.2 ± 0.61
Angus 7	100	46.5 ± 0.52

C

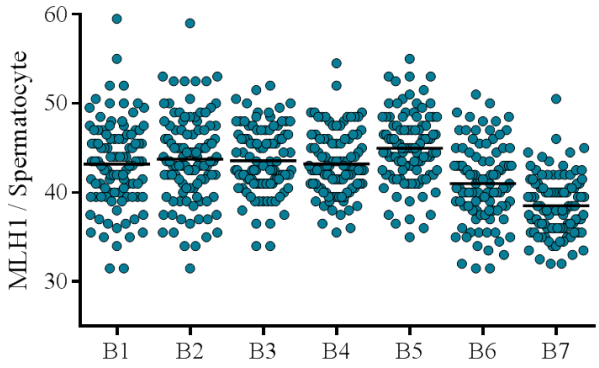
	A1	A2	A3	A4	A5	A6	A7	C	G	J
A2	$1x10^{0}$	-	-	-	-	-	-	-	-	-
A3	$2.58x10^{-1}$	$1.69x10^{-1}$	-	-	-	-	-	-	-	-
A4	$9.79x10^{-1}$	$9.43x10^{-1}$	$9.61x10^{-1}$	-	-	-	-	-	-	-
A5	$4.22x10^{-1}$	$3.01x10^{-1}$	$1.00x10^{0}$	$9.99x10^{-1}$	-	-	-	-	-	-
A6	$1.00x10^{0}$	$1.00x10^{0}$	$2.15x10^{-1}$	$9.68x10^{-1}$	$3.67x10^{-1}$	-	-	-	-	-
A7	$1.42x10^{-3}$	$3.12x10^{-3}$	$6.70x10^{-10}$	$3.20x10^{-6}$	$4.30E^{-09}$	$1.44x10^{-3}$	-	-	-	-
C	$4.20x10^{-11}$	$1.7x10^{-10}$	$1.10x10^{-13}$	$1.10x10^{-13}$	$8.70\x10^{-14}$	$3.20x10^{-11}$	$1.35x10^{-1}$	-	-	-
G	$3.30x10^{-6}$	$9.30x10^{-06}$	$2.10x10^{-13}$	$1.60x10^{-9}$	$6.30x10^{-13}$	$3.10x10^{-6}$	$9.79x10^{-1}$	$8.84x10^{-1}$	-	-
J	$1.30x10^{-13}$	$1.70x10^{-13}$	$1.10x10^{-13}$	$9.10x10^{-14}$	$1.10x10^{-13}$	$1.20x10^{-13}$	$2.33x10^{-3}$	$9.68x10^{-1}$	$1.46x10^{-1}$	-
LL	$1.46x10^{-2}$	$2.80x10^{-2}$	$3.50x10^{-8}$	$7.50x10^{-5}$	$1.90x10^{-07}$	$1.52x10^{-2}$	$1.00x10^{0}$	$2.18x10^{-2}$	$7.64x10^{-1}$	$1.60x10^{-4}$

Figure 2.2 *Comparison of crossovers per spermatocyte for individual cattle.* A) The number of COs (MLH1) for each spermatocyte for individual bulls. Each dot represents the number of COs from individual spermatocyte, black bars represent individual bull mean. B) The mean number of crossovers (MLH1) plus and minus the standard error for each bull. C) P values reported from statistical comparisons. Significance was based on non-parametric ranks, not means reported.

Number of COs per spermatocyte in individual Beefalo bulls were also compared against one another. The mean number of COs per spermatocyte was plotted for each individual Beefalo in ***Figure 2.3.*** Beefalo1 through Beefalo 4 had no significant differences in COs per spermatocyte, and Beefalo 2 through Beefalo 5 had no significant differences in

COs per spermatocyte. Beefalo 6 had significantly fewer COs per spermatocyte when compared to Beefalo 1 through Beefalo 5, and Beefalo 7 had significantly fewer COs per spermatocyte when compared to all other Beefalo. As with the cattle, analysis used to compare Beefalo, is based on non-parametric median ranks, and constitutes the differences seen. The exact P values are reported in Figure 2.3C. As suggested by the cattle data, it could be possible that the breed of *B. tuarus* used in the hybrid cross could be contributing to the differences seen between individual Beefalo.

A



B

Individual	Spermatocytes	Avg. CO ± SE
Beefalo 1	100	43.2 ± 0.48
Beefalo 2	104	43.7 ± 0.48
Beefalo 3	100	43.7 ± 0.37
Beefalo 4	100	43.2 ± 0.36
Beefalo 5	100	45.0 ± 0.40
Beefalo 6	100	41.0 ± 0.43
Beefalo 7	100	38.5 ± 0.30

C

	B1	B2	B3	B4	B5	B6
B2	$9.82x10^{-1}$	-	-	-	-	-
B3	$9.93x10^{-1}$	$1.00x10^{0}$	-	-	-	-
B4	$1.00x10^{0}$	$9.84x10^{-1}$	$9.95x10^{-1}$	-	-	-
B5	$4.84x10^{-2}$	$3.20x10^{-1}$	$2.58x10^{-1}$	$5.27x10^{-2}$	-	-
B6	$1.14x10^{-2}$	$3.7x10^{-4}$	$8.00x10^{-4}$	$1.02x10^{-2}$	$3.80x10^{-9}$	-
B7	$9.90x10^{-13}$	$6.90x10^{-14}$	$8.30x10^{-14}$	$7.90x10^{-13}$	$7.20x10^{-14}$	$7.20x10^{-4}$

Figure 2.3 *Comparison of crossovers per spermatocyte for individual Beefalo.* A) The number of COs (MLH1) for each spermatocyte for individual bulls. Each dot represents the number of COs from individual spermatocyte, black bars represent individual bull mean. B) The mean number of crossovers (MLH1) plus and minus the standard error for each bull. C) P values reported from statistical comparisons. Significance was based on non-parametric ranks, not means reported.

Characterizing crossover numbers and synaptonemal complex length

To characterize meiotic recombination in livestock spermatocytes, we examined the relationship between SC length and the number of COs present on that SC. In total 520 spermatocytes were evaluated, 70 spermatocytes from Beefalo (n=7), 110 from cattle (n=11) and 340 from Suffolk sheep (n=17). We examined the correlation between length of individual SC and the number of COs in Beefalo (r=0.53, $P \leq 0.0001$), cattle (r=0.57, $P \leq 0.0001$), and sheep (r=0.70, $P \leq 0.0001$) in ***Figure 2.4***. Sheep have the strongest correlation, which may be explained by having longer SC and more CO per SC (Rodriguez et al., 2018). These data suggest that longer SCs have a greater number of COs. Confirming the correlation between SC length and the number of COs per SC provides valuable insight for understanding how many COs occur on chromosomes of differing sizes (Rodriguez et al., 2018).

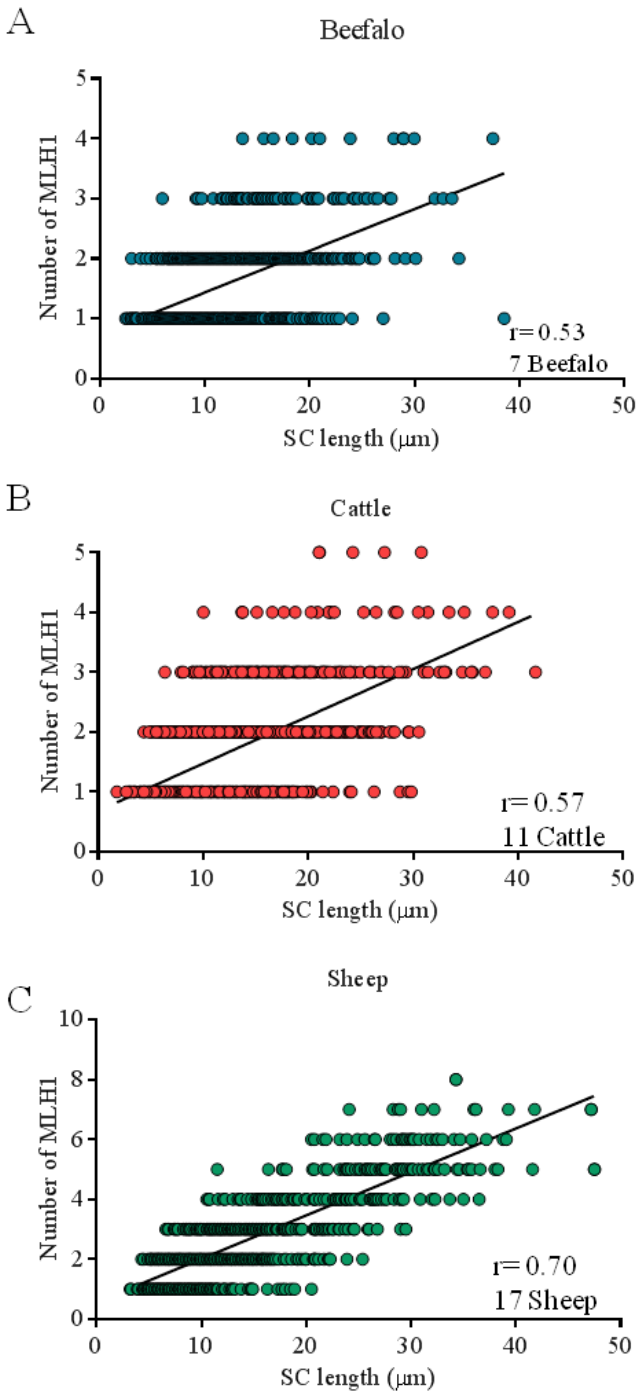


Figure 2.4 *The number of crossovers for each synaptonemal complex compared to chromosome pair length from Beefalo, cattle and sheep spermatocytes.* Each dot is plotted according to the number of COs (MLH1) and the length of the SC for individual spermatocytes. A) Beefalo (61 cells, r=0.53), B) Cattle (92 cells, r=0.57) and C) Sheep (340 cells, r=0.70) have positive correlations for SC length compared to number of MLH1. Sheep have the strongest correlation (Rodriguez et al., 2018).

Furthermore, the frequency of COs was evaluated and compared in Beefalo, cattle, and sheep by comparing the percentages of SCs with different number of COs (***Figure 2.5***). Beefalo had the greatest proportion of SCs with only one CO, and the next most present number of COs per SC was 2. Additionally, Beefalo only had as many as 4 COs present. Cattle also primarily had 1 and 2 COs per SC, but had as many as 5 COs present on one SC. The most common number of COs on an SC for sheep was 2 at 50%, and the next most common was 1 CO at 20% and 3 COs at 17%. Approximately 29% of sheep SCs have 3 or more COs per individual SC. The sheep in this study exhibited as many as 8 COs per SC. The results of this analysis align well with previous data, due to the fact that sheep have significantly greater global CO numbers, but the same number of chromosome arms as cattle and Beefalo. Additionally, cattle have significantly higher global CO numbers when compared to Beefalo.

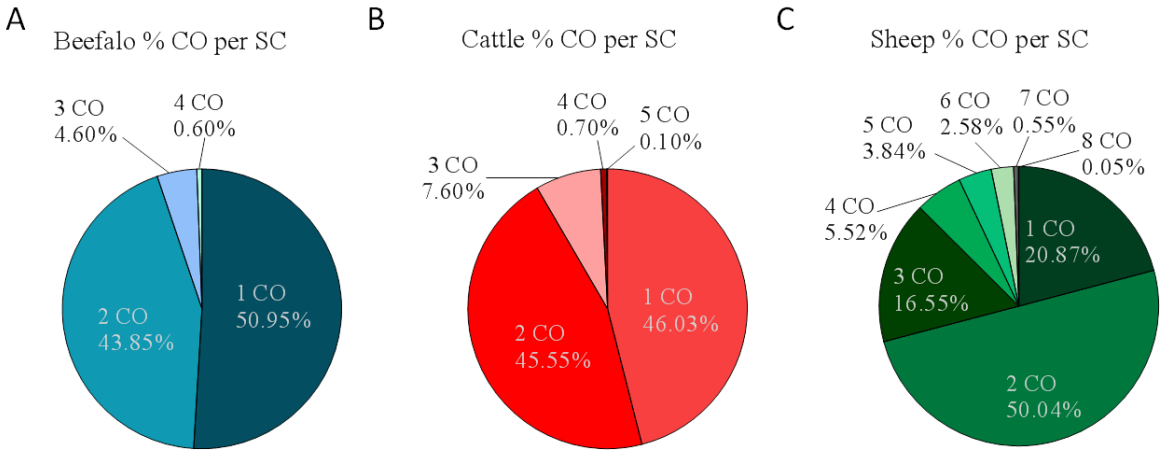


Figure 2.5 *Percent of SCs with various CO numbers in* A) Beefalo, B) cattle, and C) sheep. Beefalo have the highest proportion of SCs with 1 CO. The most COs on a single SC in Beefalo is 4, and 5 in cattle. Sheep exhibit as many as 8 COs per SC.

In addition to number of COs per SC, the locations of COs on the SCs were evaluated from Beefalo and cattle from the same 70 and 110 spermatocytes, respectively. The SCs were

grouped by number of COs. The percent of COs at each relative location on the SCs were plotted. The positions can be seen in ***Figure 2.6*** for Beefalo and cattle. The SCs containing 1, 2, or 3 COs all have distinct patterns that are similar for both Beefalo and cattle. One CO on an SC has the most variability in where it is positioned being anywhere from 5%-50% of the chromosome. When there are SCs with 2 COs, over 90% of the first CO occurs between 10% and 35% of the chromosome. The second CO has over 85% occurring between 50% and 90% of the chromosome. The SCs with 3 COs, act similarly with having 85% or more of the first CO between 5% and 20% of the SC, the second CO at 30%-65% of the SC, and the third CO between 65% and 90% of the SC. Additionally, less than 5% of COs are positioned in the first or last 10% of the chromosome. SCs with greater than 3 COs also tend to have a pattern, but it is not as clear cut as those with less than 3 COs. These data suggest that position of the CO is related to how many COs are present on a SC. Furthermore, understanding where COs occur along a SC can help make better genetic predictions, by taking into consideration where genetic material is recombining.

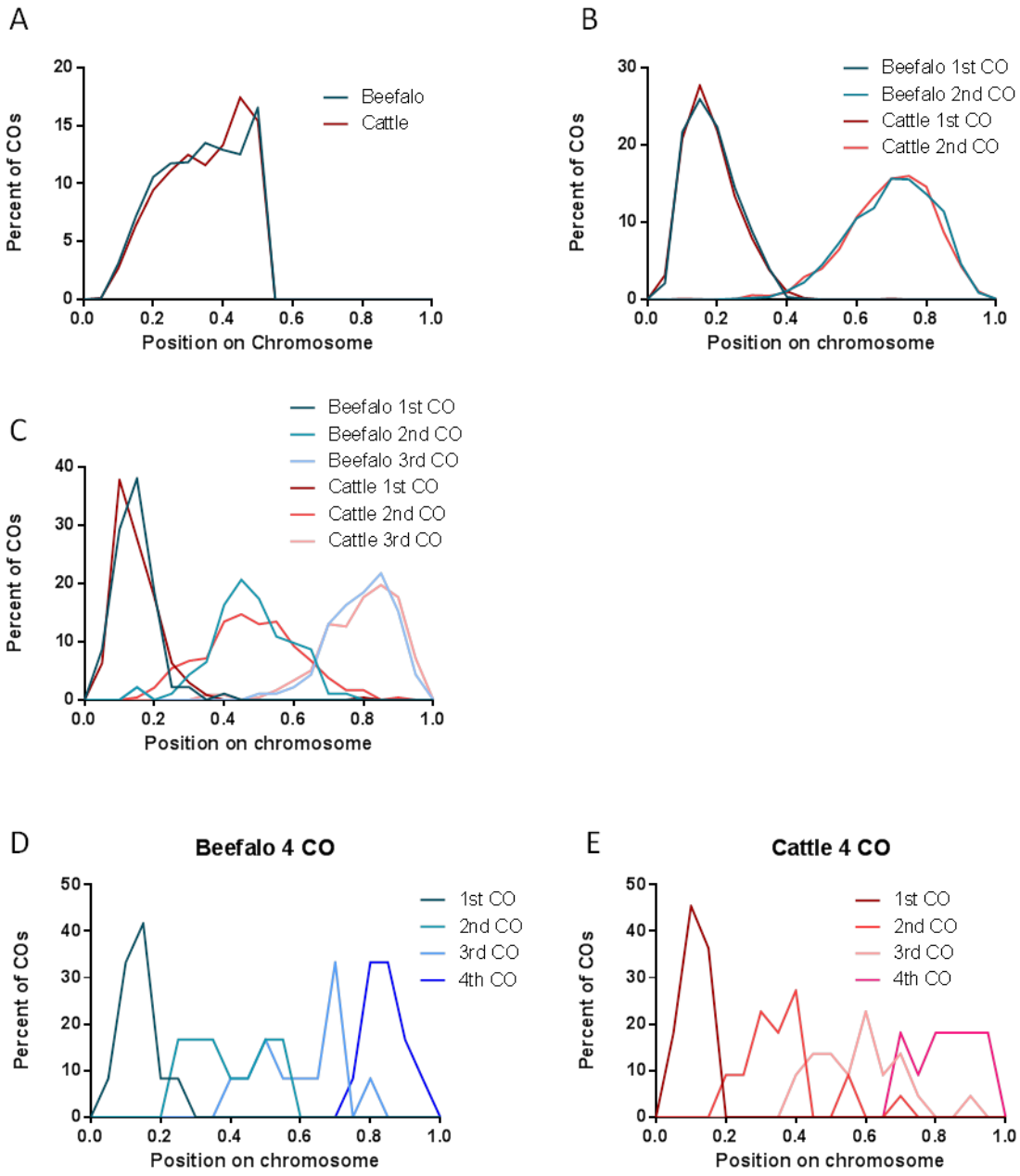
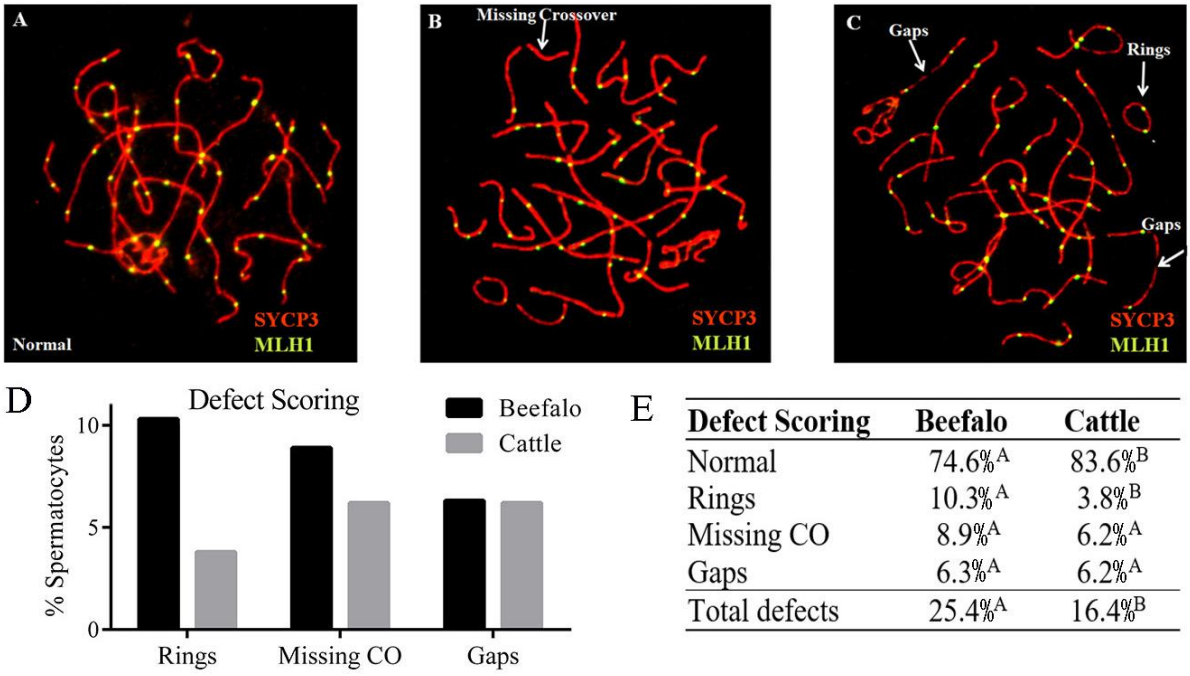


Figure 2.6 *Location of COs on SC in Beefalo and cattle.* A) Position of CO on SC with 1 CO. B) Position of CO on SC with 2 COs. C) Position of CO on SC with 3 COs. D) Position of CO on SC with 4 COs in Beefalo and E) cattle. The placement of CO on the SC seems to be in specific regions and is similar between Beefalo and cattle.

Chromosomal defects in spermatocytes of Beefalo and cattle

We identified a variety of chromosomal defects in the spermatocytes of Beefalo in comparison to cattle. To quantify defects, 350 Beefalo spermatocytes and 500 cattle

spermatocytes were examined. The defects that were observed included ring chromosomes, missing COs on an SC, and gapping on the SC. On average, Beefalo exhibit 10% more defects than cattle in spermatocytes (***Figure 2.4)***. Ring chromosomes occurred at significantly higher levels in Beefalo ($P<0.01$) than cattle. Representative images of each type of defect can be seen in ***Figure 2.4 A, B, C.*** Overall, Beefalo exhibited greater numbers of defects in their spermatocytes when compared to cattle. This suggests, spermatocytes of hybrid species crosses can result in chromosomal defects which ultimately affect fertility; an important consideration with other hybrid animals, including *Bos indicus* x *Bos taurus*. This paragraph has been used in Rodriguez et al., (2018). Understanding the types of defects present can indicate the types of problems occurring in these hybrid animals.



E

Defect Scoring	Beefalo	Cattle
Normal	74.6%^{A}	83.6%^{B}
Rings	10.3%^{A}	3.8%^{B}
Missing CO	8.9%^{A}	6.2%^{A}
Gaps	6.3%^{A}	6.2%^{A}
Total defects	25.4%^{A}	16.4%^{B}

Figure 2.7 *Representative images of Beefalo spermatocytes scored for defects.* A) An image of a normal Beefalo spermatocyte with no defects. B) A spermatocyte with a pair of homologous chromosomes, observable by the SC, with no MLH1 (CO). C) A spermatocyte with gaps in the SC and a ring/fused chromosome. D) The percentage of chromosomal defects (ring/fused, missing MLH1, and gaps) in Beefalo (n=7) and cattle (n=10) spermatocytes. E) A table representing the percent of defects observed in Beefalo and cattle. The total percentage of chromosomes with defects in Beefalo and cattle spermatocytes are 25.4% and 16.4%, respectively. Letters denote significant differences (A, B; $P<0.01$)(Rodriguez et al., 2018).

Conclusion

The use of cytogenetics to determine the number of COs has distinct advantages. This approach allows direct visualization of COs and can detect meiotic, synaptic, and chromosomal defects (Rodriguez et al., 2018). Additionally, this method is independent of a reference genome, genetic variation and large pedigrees (Rodriguez et al., 2018). Our data suggest there is variation between individuals, and the number of COs may differ in different breeds of the same species (Rodriguez et al., 2018). Despite similar genome size and the same number of chromosome arms, the number of COs is greater in sheep than in cattle and Beefalo (Rodriguez et al., 2018), therefore we reject the null hypothesis that global CO numbers will not differ between Beefalo, cattle, and sheep. Furthermore, there is a positive correlation between the length of a chromosome and the number of COs observed (Rodriguez et al., 2018). Beefalo have the most SCs with 1 and 2 COs. Sheep exhibit as many as 8 COs per SC. In cattle and Beefalo, COs occur in similar locations for SCs containing 1, 2, and 3 CO, therefore we fail to reject the null hypothesis that COs will occur in similar locations between Beefalo and cattle. Additionally, Beefalo, hybrid animals, have significantly greater numbers of chromosomal defects when compared to cattle, therefore we fail to reject the null hypothesis, which states, that there will be defects in spermatocytes of the hybrid, Beefalo. These differences may be reflected in other hybrid matings. The most common of the defects in Beefalo is ring chromosome. The large proportion of the ring defect causes the significant difference in the “total defects” observed between Beefalo and cattle.

In the future it would be valuable to compare different breeds of cattle by adding more of each breed to this study. Due to the tendencies in these data, we expect to see

differences between breeds. Furthermore, it would be interesting to compare this study to a study using other bovine hybrids like *Bos indicus* X *Bos taurus*. It would be interesting to determine if other hybrid animals also experience reduced number of COs. Although synapsis of the X and Y chromosomes was not reported in this study, it is also important for the X and Y chromosomes to synapse in the Psuedo Autosomal Region (PAR) and recombine (Dumont, 2017). For this reason, it would also be valuable to examine X and Y chromosome synapsis and COs in livestock and particularly hybrid animals to determine if the PAR is a problem in hybrid sperm production. Additionally, there are many genes that control meiotic recombination, therefore evaluation of these genes combined with this type of phenotypic data may also provide valuable insight into fertility, and hybrid mating.

Overall, this research provides valuable insight into chromosome pairing and synapsis. Additionally, it provides insight into chromosome crossovers, such that we can predict how many COs are likely to occur on different size chromosomes, further enhancing our ability to forecast how genetic material will be recombined. Ultimately, understanding chromosome biology will help us make genetic improvements in ruminant livestock species.

CHAPTER 3

Isolation of the Sex Chromosomes for Sequencing

Introduction

To understand male infertility, it is important to understand the male sex specific Y chromosome, and one method of doing this is with sequencing. Although it is important, sequencing the Y chromosome is challenging due to degradation from gene loss and addition of repeats causing it to be highly repetitive (Charlesworth and Charlesworth, 2000; Skaletsky et al., 2003). The Y chromosome has only been fully sequenced in six mammals: human, chimpanzee, rhesus macaque, mouse, pig, and gorilla (Hughes et al., 2012, 2010; Skaletsky et al., 2003; Skinner et al., 2016; Soh et al., 2014; Tomaszkiewicz et al., 2016). Additionally, it has been partially sequenced in bulls, dogs, cats, marmosets, opossum, and rats (Bellott et al., 2014; Chang et al., 2013; Li et al., 2013). The method to complete the sequence of the Y chromosome of human, chimpanzee, macaque, and mouse was single-haplotype interactive mapping and sequencing, but this method is expensive and requires a great deal of work (Hughes et al., 2010; Skaletsky et al., 2003; Soh et al., 2014).

Although the Y chromosome has been partially sequenced in bulls, it would be beneficial for all livestock to have it fully sequenced. Walker et al.,(2009) stress the importance of fertility in bulls to make a more efficient livestock facility. In addition to understanding more about fertility, characterizing the Y chromosome may help in understanding problems with the production of hybrid animals. In hybrid animals it is important that the PAR on the X and Y chromosomes are compatible, therefore understanding the Y chromosome may aid in understanding incompatibilities in hybrids. The

objective was to develop a method to isolate the sex chromosomes in sheep for long read sequencing.

Materials and methods

Overview

Our goal was to find an efficient and reliable manner to isolate the sex chromosomes and create XY enriched DNA for sequencing. To isolate the sex chromosomes, we used a multi-step process. First, a single cell suspension was created from testicular tissue, which was prepared for fluorescence activated cell sorting (FACS). Using the FACS-Aria sorter, Pachytene stage cells were sorted into a tube. Cells were lysed and an immunoprecipitation pull down was used to isolate the X and Y chromosomes.

Single cell suspension

Testicular tissue samples were collected from sexually mature rams, immediately put on ice, and processed within 24 hours of collection. The protocol used was adapted from (Rodríguez-Casuriaga et al., 2014). Parenchyma tissue was dissected into 3-4 mm pieces and put directly into ice cold anti-clump buffer (1%BSA, 5mM EDTA, 5mM $MgCl_2$, 1XdPBS). Tissue was teased with tweezers, in a 6 well plate with 2mL anti-clump buffer, to release spermatocytes. The solution was then filtered twice through 70µm nylon mesh. Cells were counted using the Life technologies-Countess and adjusted to a concentration of $4x10^6$cells per mL with anti-clump buffer. Vibrant Dye Cycle Green (VDCG, Invitrogen) was added at a concentration of 10µM to the cell suspension and incubated in the dark at 37˚C for 1 hour.

Fluorescent Activated Cell Sorting

A blue laser was used with a 530/130 bandwidth filter (FIT-C) on the FACS-Aria. We measured Forward Scatter (FSC), Side Scatter (SSC), and FIT-C, to detect cell populations. After appropriate cell groups were detected, cells were sorted for pachynema. Approximately 400,000 to 1,250,000 pachytene events were isolated and collected. A small amount of collected cells were used for a surface spread preparation, stained for SYCP3 and γH2AX to confirm they were pachynema, and confirm the sex body was present.

Immunoprecipitation

Cells were lysed by adding an adapted RIPA Buffer (50mM Tris-HCl pH8.0, 150mM NaCl, 2mM EDTA pH8.0, 1% NP-40, 0.1% SDS, 0.5% sodium deoxycholate, and 1X protease and phosphotase inhibitors), and incubated on ice for 20 minutes. Once cells were lysed, 4μg γH2AX antibody (ab 26350) was added to the lysate and the mixture was incubated at 4˚C for 2 hours, while rotating. Diagenode magnetic G-coupled beads were added to the cell lysate with the bound antibody and left to incubate over night at 4˚C, while rotating. Beads were washed 3 times the following day by rotating for 5 minutes each time with wash buffer (10mM Tris-HCl, 1mM EDTA, 1mM EGTA, 150mM NaCl, 1% Triton X, and H_2O to volume). Tubes were place on a magnetic rack and allowed to settle for 1 minute, and supernatant was discarded. Samples were eluted off the beads using an elution buffer (1% SDS, 100mM $NaCO_3$, and H_2O to volume), and incubated at 23˚C for 30 minutes, while rotating. After incubation tubes were placed on magnetic rack for 1 minute and supernatant was moved to a clean tube. DNA in each sample was quantified. To determine the size of the

DNA collected, we ran a 0.5% agarose gel for 9 hours at 45 volts in a cold room at 4˚C, to keep the gel from melting.

Results and discussion

FACS analysis

To have an understanding of how the cell populations would separate, we referenced Rodríguez-Casuriaga et al., (2014). These scientists defined cell populations of the different stages of spermatocytes in mice and how these difference cell populations would be detected on the FACS-Aria. We found similar spermatocyte populations and dye profiles in ram spermatocytes, used in the current study (***Figure 3.1)*.** Pachynema are large cells that have a bright signal from the VDCG. To confirm this was the correct population, we stained cells from 3 groups labeled "dull," "middle," and "pachytene" to determine spermatocyte stage. Pachynema were sorted and used, because during this stage the X and Y chromosomes are synapsed together in the sex body (Mahadevaiah et al., 2001). Having the sex chromosomes together made it easier to isolate them.

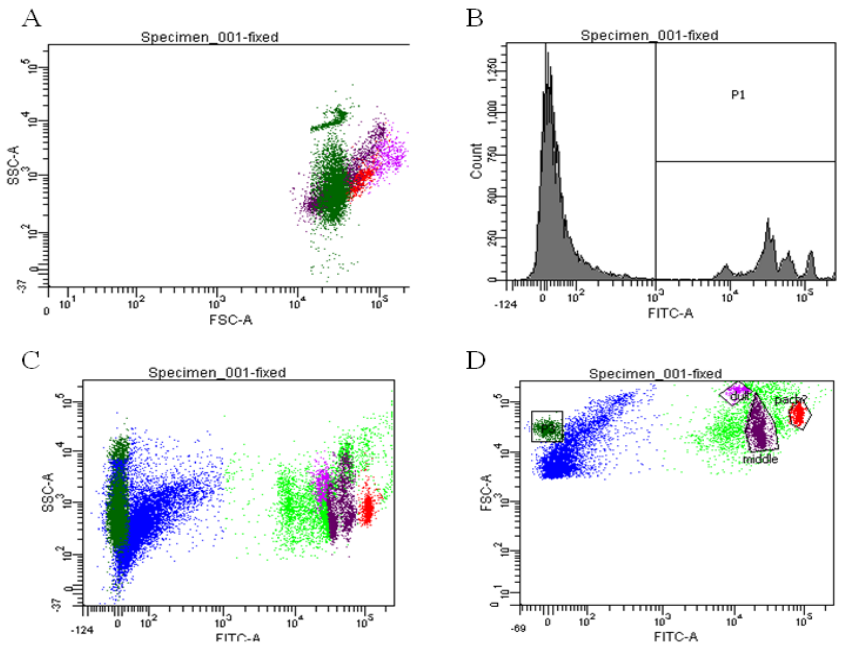


Figure 3.1 *Analysis of FACS.* A) Cell population sorted FSC against SSC. Pachytene stage cells are represented by the red population. B) Cell population evaluated from FIT-C only. C) Cell populations organized FIT-C against SSC, the red population is pachytene. Distinct populations can be observed. D) FIT-C plotted against FSC, and distinct cell populations can be observed.

Immunoprecipitation

To isolate only the X and Y chromosomes, we used an antibody specific to γH2AX because it is known to be present in DSBs and is present on the sex body until diplonema (Mahadevaiah et al., 2001). To ensure the presence of γH2AX in the sex bodies, we prepared a surface spread prep of sorted cells and stained for it; the presence of it can be seen in ***Figure 3.2.*** The red lines are SYCP3, which indicates where the SC is located. The green is where γH2AX is concentrated. In pachytene stage spermatocytes, γH2AX is only present around the sex body. In leptotene or zygotene stage spermatocytes, the γH2AX is located on DSBs, and is therefore, concentrated all around the SCs. The concentrations of DNA after the immunoprecipitation were small. To determine the size of the DNA collected, we ran a gel.

We observed bands above 12,000 bp (***Figure 3.3)***, meaning the DNA captured was large. Because we hoped to collect an entire chromosome we expected the product to be quite large.

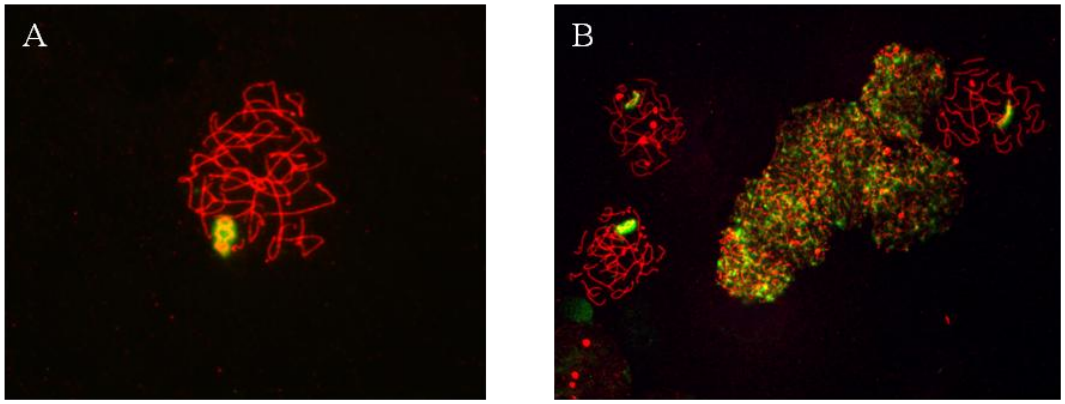


Figure 3.2 *Cells stained for γH2AX.* A) An image taken of a pachytene stage spermatocyte with γH2AX antibody (Green) and SYCP3 (Red). The γH2AX is only around the sex body (X and Y chromosomes). B) An image taken of several spermatocyte cell types. The γH2AX is present around the sex body in pachytene cells. γH2AX is present in DSBs, and so the cells with green all over are either late leptotene or zygotene.

After this step, creation of library preparations for sequencing was unsuccessful. Because the FACS-Aria was decommissioned, we could not continue to trouble shoot the issues of low DNA yield and therefore, were left to changed the experimental approach of isolating the Y chromosome for sequencing.

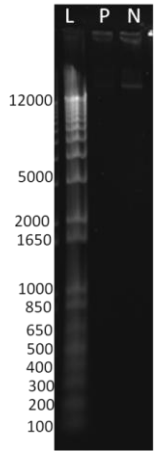


Figure 3.3 *An image of a gel taken after immunoprecipitation.* The L, represents the ladder, P is the product, and N is the no sort product. In this image, there are two distinct bands formed much higher than the 12,000 bp mark on the ladder, indicating the product of the immunoprecipitation is very large.

Conclusion

Characterizing the Y chromosome may provide insight on male fertility, particularly hybrid animals. It can also provide insight on genes located on the Y chromosome. Through FACS these data have been acquired to characterize spermatocyte populations in rams. Knowing where these populations of cells are in a FACS sort can be useful in trying to study individual spermatocytes. Due to our FACS sorter breaking, this project has gone in a new direction. However, future research aiming to accomplish a similar goal, may use our methods.

REFERENCES

ABA, 2018. The True American Breed; What Makes a Beefalo; Breed History [WWW Document]. Am. Beefalo Assoc. URL http://americanbeefaloassociation.com/benefits/

Albers, G.A.A., Gray, G.D., 1987. Breeding for worm resistance: A perspective. Int. J. Parasitol. 17, 559–566.

Alberts, B., Johnson, A., Lewis, J., Raff, M., Roberts, K., Walter, P., 2002. Molecular Biology of the Cell, 4th ed, New York.

Balcova, M., Faltusova, B., Gergelits, V., Bhattacharyya, T., Mihola, O., Trachtulec, Z., Knopf, C., Fotopulosova, V., Chvatalova, I., Gregorova, S., Forejt, J., 2016. Hybrid Sterility Locus on Chromosome X Controls Meiotic Recombination Rate in Mouse. PLOS Genet. 12.

Baudat, F., Buard, J., Grey, C., Fledel-Alon, A., Ober, C., Przeworski, M., Coop, G., de Massy, B., 2010. PRDM9 is a major determinant of meiotic recombination hotspots in humans and mice. Science. 327, 836–840.

Baudat, F., Imai, Y., De Massy, B., 2013. Meiotic recombination in mammals: Localization and regulation. Nat. Rev. Genet. 14, 794–806.

Bellani, M.A., Boateng, K.A., McLeod, D., Camerini-Otero, R.D., 2010. The Expression Profile of the Major Mouse SPO11 Isoforms Indicates that SPO11 Introduces Double Strand Breaks and Suggests that SPO11 Has an Additional Role in Prophase in both Spermatocytes and Oocytes. Mol. Cell. Biol. 30, 4391–4403.

Bellott, D.W., Hughes, J.F., Skaletsky, H., Brown, L.G., Pyntikova, T., Cho, T.J., Koutseva, N., Zaghlul, S., Graves, T., Rock, S., Kremitzki, C., Fulton, R.S., Dugan, S., Ding, Y., Morton, D., Khan, Z., Lewis, L., Buhay, C., Wang, Q., Watt, J., Holder, M., Lee, S., Nazareth, L., Rozen, S., Muzny, D.M., Warren, W.C., Gibbs, R.A., Wilson, R.K., Page, D.C., 2014. Mammalian y chromosomes retain widely expressed dosage-sensitive regulators. Nature 508, 494–499.

Besier, R.B., Kahn, L.P., Sargison, N.D., Van Wyk, J.A., 2016. Diagnosis, Treatment and Management of Haemonchus contortus in Small Ruminants, in: Advances in Parasitology. pp. 181–238.

Bhambhani, R., Kuspira, J., 1969. The somatic karyotypes of American bison and domestic cattle. Can. J. Genet. Cytol. 11, 243–249.

Boateng, K.A., Bellani, M.A., Gregoretti, I. V, Pratto, F., Camerini-Otero, R.D., 2013. Homologous Pairing Preceding SPO11-Mediated Double-Strand Breaks in Mice. Dev. Cell 24, 196–205.

Brown, M.S., Bishop, D.K., 2015. DNA Strand Exchange and RecA Homologs in Meiosis. Cold Spring Harb. Perspect. Biol. 7.

Bunch, T.D., Foote, W.C., 1977. Evolution of the 2n = 54 karyotype of Domestic sheep (Ovis aries). Genet. Sel. Evol. GSE 9, 509–515.

Chang, T.-C., Yang, Y., Retzel, E.F., Liu, W.-S., 2013. Male-specific region of the bovine Y chromosome is gene rich with a high transcriptomic activity in testis development. Proc. Natl. Acad. Sci. 110, 12373–12378.

Charlesworth, B., Charlesworth, D., 2000. The degeneration of Y chromosomes. Philos. Trans. R. Soc. B Biol. Sci. 355, 1563–1572.

Cross, C.E., 1995. Bloom and Fawcett: A Textbook of Histology. J. Am. Med. Assoc. 274, 352.

de Massy, B., 2013. Initiation of Meiotic Recombination: How and Where? Conservation and Specificities Among Eukaryotes. Annu. Rev. Genet. 47, 563–599.

Dollin, A.E., Murray, J.D., Gillies, C.B., 1991. Synaptonemal complex analysis of hybrid cattle. II. Bos indicus x Bos taurus F1 and backcross hybrids. Genome / Natl. Res. Counc. Canada 34, 220–227.

Dollin, A.E., Murray, J.D., Gillies, C.B., 1989. Synaptonemal complex analysis of hybrid cattle. I. Pachytene substaging and the normal full bloods. Genome / Natl. Res. Counc. Canada 32, 856–864.

Dumont, B.L., 2017. Meiotic consequences of genetic divergence across the murine pseudoautosomal region. Genetics 205, 1089–1100.

Dumont, B.L., Payseur, B.A., 2011. Genetic analysis of Genome-Scale recombination rate evolution in house mice. PLoS Genet. 7.

Dym, M., 1977. The male reproductive system, in: Weiss, Greep (Eds.), Histology. McGraw-Hill, New York, pp. 979–1038.

Edelmann, W., Cohen, P.E., Kane, M., Lau, K., Morrow, B., Bennett, S., Umar, A., Kunkel, T., Cattoretti, G., Chaganti, R., Pollard, J.W., Kolodner, R.D., Kucherlapati, R., 1996. Meiotic pachytene arrest in MLH1-deficient mice. Cell 85, 1125–1134.

Elsik, C.G., Tellam, R.L., Worley, K.C., 2009. The Genome Sequence of Taurine Cattle: A window to ruminant biology and evolution. Science. 324, 522–528.

Ford, C.E., Pollock, D.L., Gustavsson, I., 1980. Proceedings of the First International Conference for the Standardisation of Banded Karyotypes of Domestic Animals University of Reading Reading, England 2nd - 6th August 1976. Hereditas.

Forejt, J., Iványi, P., 1974. Genetic studies on male sterility of hybrids between laboratory and wild mice (Mus musculus L.). Genet. Res. 24, 189–206.

Fraune, J., Schramm, S., Alsheimer, M., Benavente, R., 2012. The mammalian synaptonemal complex: Protein components, assembly and role in meiotic recombination. Exp. Cell Res. 318, 1340–1346.

Fröhlich, J., Vozdova, M., Kubickova, S., Cernohorska, H., Sebestova, H., Rubes, J., 2015. Variation of Meiotic Recombination Rates and MLH1 Foci Distribution in Spermatocytes of Cattle, Sheep and Goats. Cytogenet. Genome Res. 146, 211–221.

Gilbert SF, 2000. Developmental Biology, 6th ed, The Epidermis and the Origin of Cutaneous Structures.

Grey, C., Barthès, P., Friec, G., Langa, F., Baudat, F., de Massy, B., 2011. Mouse Prdm9 DNA-binding specificity determines sites of histone H3 lysine 4 trimethylation for initiation of meiotic recombination. PLoS Biol. 9.

Günesdogan, U., Surani, M.A., 2016. Chapter Twenty-Eight – Developmental Competence for Primordial Germ Cell Fate, in: Current Topics in Developmental Biology. pp. 471–496.

Gyllensten, U., Wharton, D., Wilson, A.C., 1985. Maternal inheritance of mitochondrial dna during backcrossing of two species of mice. J. Hered. 76, 321–324.

Haldane, J.B.S., 1922. Sex ratio and unisexual sterility in hybrid animals. J. Genet. 12, 101–109.

Handel, M.A., Schimenti, J.C., 2010. Genetics of mammalian meiosis: Regulation, dynamics and impact on fertility. Nat. Rev. Genet. 11, 124–136.

Hansen, K.M., 1973. The karyotype of the domestic sheep (Ovis aries) identified by quinacrine mustard staining and fluorescence microscopy. Hereditas 75, 233–240.

Hassold, T., Hall, H., Hunt, P., 2007. The origin of human aneuploidy: Where we have been, where we are going. Hum. Mol. Genet. 16.

Hughes, J.F., Skaletsky, H., Brown, L.G., Pyntikova, T., Graves, T., Fulton, R.S., Dugan, S., Ding, Y., Buhay, C.J., Kremitzki, C., Wang, Q., Shen, H., Holder, M., Villasana, D., Nazareth, L. V, Cree, A., Courtney, L., Veizer, J., Kotkiewicz, H., Cho, T.J., Koutseva,

N., Rozen, S., Muzny, D.M., Warren, W.C., Gibbs, R.A., Wilson, R.K., Page, D.C., 2012. Strict evolutionary conservation followed rapid gene loss on human and rhesus y chromosomes. Nature 483, 82–87.

Hughes, J.F., Skaletsky, H., Pyntikova, T., Graves, T.A., Van Daalen, S.K.M., Minx, P.J., Fulton, R.S., McGrath, S.D., Locke, D.P., Friedman, C., Trask, B.J., Mardis, E.R., Warren, W.C., Repping, S., Rozen, S., Wilson, R.K., Page, D.C., 2010. Chimpanzee and human y chromosomes are remarkably divergent in structure and gene content. Nature 463, 536–539.

Hunter, N., Kleckner, N., 2001. The single-end invasion: An asymmetric intermediate at the double-strand break to double-holliday junction transition of meiotic recombination. Cell 106, 59–70.

Keeney, S., Giroux, C.N., Kleckner, N., 1997. Meiosis-specific DNA double-strand breaks are catalyzed by Spo11, a member of a widely conserved protein family. Cell 88, 375–384.

Khalil, H., Tummala, H., Zhelev, N., 2012. ATM in focus: A damage sensor and cancer target. Biodiscovery.

KHSI, 2016. A Guide to Katahdin Hair Sheep. The Katahdin Hairald 1–45.

Kirschner, M., Mitchison, T., 1986. Beyond self-assembly: From microtubules to morphogenesis. Cell 45, 329–342.

Koehler, K.E., Hassold, T.J., 1998. Human aneuploidy: Lessons from achiasmate segregation in Drosophila melanogaster. Ann. Hum. Genet. 467–479.

Koehler, K.E., Hawley, R.S., Sherman, S., Hassold, T., 1996. Recombination and nondisjunction in humans and flies. Hum. Mol. Genet.

Kong, A., Thorleifsson, G., Stefansson, H., Masson, G., Helgason, A., Gudbjartsson, D.F., Jonsdottir, G.M., Gudjonsson, S.A., Sverrisson, S., Thorlacius, T., Jonasdottir, A., Hardarson, G.A., Palsson, S.T., Frigge, M.L., Gulcher, J.R., Thorsteinsdottir, U., Stefansson, K., 2008. Sequence variants in the RNF212 gene associate with genome-wide recombination rate. Science. 319, 1398–1401.

Li, G., Davis, B.W., Raudsepp, T., Wilkerson, A.J.P., Mason, V.C., Ferguson-Smith, M., O'Brien, P.C., Waters, P.D., Murphy, W.J., 2013. Comparative analysis of mammalian y chromosomes illuminates ancestral structure and lineage-specific evolution. Genome Res. 23, 1486–1495.

Lipkin, S.M., Moens, P.B., Wang, V., Lenzi, M., Shanmugarajah, D., Gilgeous, A., Thomas, J., Cheng, J., Touchman, J.W., Green, E.D., Schwartzberg, P., Collins, F.S., Cohen, P.E., 2002. Meiotic arrest and aneuploidy in MLH3-deficient mice. Nat. Genet. 31, 385–390.

Ma, L., O'Connell, J.R., VanRaden, P.M., Shen, B., Padhi, A., Sun, C., Bickhart, D.M., Cole, J.B., Null, D.J., Liu, G.E., Da, Y., Wiggans, G.R., 2015. Cattle Sex-Specific Recombination and Genetic Control from a Large Pedigree Analysis. PLoS Genet. 11.

Mahadevaiah, S.K., Turner, J.M.A., Baudat, F., Rogakou, E.P., De Boer, P., Blanco-Rodríguez, J., Jasin, M., Keeney, S., Bonner, W.M., Burgoyne, P.S., 2001. Recombinational DNA double-strand breaks in mice precede synapsis. Nat. Genet. 27, 271–276.

McLaren, a, 1998. Gonad development: assembling the mammalian testis. Curr. Biol. 8, R175--R177.

Metzler-Guillemain, C., De Massy, B., 2000. Identification and characterization of an SPO11 homolog in the mouse. Chromosoma 109, 133–138.

Mihola, O., Trachtulec, Z., Vlcek, C., Schimenti, J.C., Forejt, J., 2009. A mouse speciation gene encodes a meiotic histone H3 methyltransferase. Science. 323, 373–375.

Morgan, C.H., Zhang, H., Bomblies, K., 2017. Are the effects of elevated temperature on meiotic recombination and thermotolerance linked via the axis and synaptonemal complex? Philos. Trans. R. Soc. B Biol. Sci.

Murdoch, B., Owen, N., Shirley, S., Crumb, S., Broman, K.W., Hassold, T., 2010. Multiple loci contribute to genome-wide recombination levels in male mice. Mamm. Genome 21, 550–555.

Murdoch, B., Owen, N., Stevense, M., Smith, H., Nagaoka, S., Hassold, T., McKay, M., Xu, H., Fu, J., Revenkova, E., Jessberger, R., Hunt, P., 2013. Altered Cohesin Gene Dosage Affects Mammalian Meiotic Chromosome Structure and Behavior. PLoS Genet. 9.

NASA, 2018. Global Climate Change: Vital signs of the Planet [WWW Document]. URL https://climate.nasa.gov/

Nasmyth, K., Haering, C.H., 2009. Cohesin: Its Roles and Mechanisms. Annu. Rev. Genet. 43, 525–558.

Newton, S.C., Blaschuk, O.W., Millette, C.F., 1993. N-cadherin mediates sertoli cell-spermatogenic cell adhesion. Dev. Dyn. 197, 1–13.

Nishant, K.T., Chen, C., Shinohara, M., Shinohara, A., Alani, E., 2010. Genetic analysis of baker's yeast msh4-msh5 reveals a threshold crossover level for meiotic viability. PLoS Genet. 6.

Ohkura, H., 2015. Meiosis: An overview of key differences from mitosis. Cold Spring Harb. Perspect. Biol. 7, 1–15.

Pierce, B., 2012. Genetics: A Conceptual Approach, 4th ed, New York: W. H. Freeman and Company.

Reynolds, A., Qiao, H., Yang, Y., Chen, J.K., Jackson, N., Biswas, K., Holloway, J.K., Baudat, F., De Massy, B., Wang, J., Höög, C., Cohen, P.E., Hunter, N., 2013. RNF212 is a dosage-sensitive regulator of crossing-over during mammalian meiosis. Nat. Genet. 45, 269–278.

Rodríguez-Casuriaga, R., Santiñaque, F.F., Folle, G.A., Souza, E., López-Carro, B., Geisinger, A., 2014. Rapid preparation of rodent testicular cell suspensions and spermatogenic stages purification by flow cytometry using a novel blue-laser-excitable vital dye. MethodsX 239–243.

Rodriguez, A., Davenport, K., Glaze, B., Mckay, S., Gill, C., 2018. Meiotic Recombination in Ruminant Livestock Species. Proc. World Congr. Genet. Appl. to Livest. Prod. Biology Re, 934.

Romanienko, P.J., Camerini-Otero, R.D., 1999. Cloning, characterization, and localization of mouse and human SPO11. Genomics 61, 156–169.

Sandor, C., Li, W., Coppieters, W., Druet, T., Charlier, C., Georges, M., 2012. Genetic variants in REC8, RNF212, and PRDM9 influence male recombination in cattle. PLoS Genet. 8.

Sarbajna, S., West, S.C., 2014. Holliday junction processing enzymes as guardians of genome stability. Trends Biochem. Sci. 39, 409–419.

Skaletsky, H., Kuroda-Kawaguchl, T., Minx, P.J., Cordum, H.S., Hlllier, L.D., Brown, L.G., Repplng, S., Pyntikova, T., All, J., Blerl, T., Chinwalla, A., Delehaunty, A., Du, H., Fewell, G., Fulton, L., Fulton, R., Graves, T., Hou, S.F., Latrielle, P., Leonard, S., Mardis, E., Maupin, R., McPherson, J., Miner, T., Nash, W., Nguyen, C., Ozersky, P., Pepin, K., Rock, S., Rohlfing, T., Scott, K., Schultz, B., Strong, C., Tin-Wollam, A., Yang, S.P., Waterston, R.H., Wllson, R.K., Rozen, S., Page, D.C., 2003. The male-specific region of the human Y chromosome is a mosaic of discrete sequence classes. Nature 423, 825–837.

Skinner, B.M., Sargent, C.A., Churcher, C., Hunt, T., Herrero, J., Loveland, J.E., Dunn, M., Louzada, S., Fu, B., Chow, W., Gilbert, J., Austin-Guest, S., Beal, K., Carvalho-Silva, D., Cheng, W., Gordon, D., Grafham, D., Hardy, M., Harley, J., Hauser, H., Howden, P., Howe, K., Lachani, K., Ellis, P.J.I., Kelly, D., Kerry, G., Kerwin, J., Ng, B.L., Threadgold, G., Wileman, T., Wood, J.M.D., Yang, F., Harrow, J., Affara, N.A., Tyler-Smith, C., 2016. The pig X and y Chromosomes: Structure, sequence, and evolution. Genome Res. 26, 130–139.

Soh, Y.Q.S., Alföldi, J., Pyntikova, T., Brown, L.G., Graves, T., Minx, P.J., Fulton, R.S., Kremitzki, C., Koutseva, N., Mueller, J.L., Rozen, S., Hughes, J.F., Owens, E., Womack, J.E., Murphy, W.J., Cao, Q., De Jong, P., Warren, W.C., Wilson, R.K., Skaletsky, H., Page, D.C., 2014. Sequencing the mouse y chromosome reveals convergent gene acquisition and amplification on both sex chromosomes. Cell 159, 800–813.

Tomaszkiewicz, M., Rangavittal, S., Cechova, M., Sanchez, R.C., Fescemyer, H.W., Harris, R., Ye, D., O'Brien, P.C.M., Chikhi, R., Ryder, O.A., Ferguson-Smith, M.A., Medvedev, P., Makova, K.D., 2016. A time- and cost-effective strategy to sequence mammalian Y chromosomes: An application to the de novo assembly of gorilla Y. Genome Res. 26, 530–540.

United States Census Bureau, 2018. U.S. and World Population Clock [WWW Document]. URL https://www.census.gov/popclock/

USDA, 2018a. Beef Pivot Table [WWW Document]. Econ. Res. Serv. URL https://www.ers.usda.gov/data-products/livestock-meat-domestic-data/livestock-meat-domestic-data/#Beef

USDA, 2018b. Lamb and Mutton Pivot Table [WWW Document]. Econ. Res. Serv. URL https://www.ers.usda.gov/data-products/livestock-meat-domestic-data/livestock-meat-domestic-data/#Lamb and mutton

USDA, ARS, 2018a. Basic Report: 13795, Beef, composite of trimmed retail cuts, separable lean and fat, trimmed to 1/8" fat, all grades, raw [WWW Document]. Natl. Nutr. Database Stand. Ref. Leg. Release. URL https://ndb.nal.usda.gov/ndb/foods/show/302838?manu=&fgcd=&ds=&q=Beef,

USDA, ARS, 2018b. Basic Report: 17152, Game meat, beefalo, composite of cuts, raw [WWW Document]. Natl. Nutr. Database Stand. Ref. Leg. Release. URL https://ndb.nal.usda.gov/ndb/foods/show/17152?fgcd=&manu=&format=&count=&max=25&offset=25&sort=default&order=asc&qlookup=game+meat&ds=&qt=&qp=&qa=&qn=&q=&ing=

USDA, FAS, 2018. Livestock and Poultry: World Markets and Trade [WWW Document]. URL http://usda.mannlib.cornell.edu/usda/current/livestock-poultry-ma/livestock-poultry-ma-04-10-2018.pdf

USDA, NASS, 2018a. Cattle [WWW Document]. Agric. Counts. URL http://usda.mannlib.cornell.edu/usda/current/Catt/Catt-01-31-2018.pdf

USDA, NASS, 2018b. Sheep and Goats [WWW Document]. Agric. Counts. URL http://usda.mannlib.cornell.edu/usda/current/SheeGoat/SheeGoat-01-31-2018.pdf

Vanimisetti, H.B., Greiner, S.P., Zajac, A.M., Notter, D.R., 2004. Performance of hair sheep composite breeds: Resistance of lambs to Haemonchus contortus. J. Anim. Sci. 82, 595–604.

Vogt, P.H., Falcao, C.L., Hanstein, R., Zimmer, J., 2008. The AZF proteins. Int. J. Androl. 31, 383–394.

Walker, J., Perry, G., Daly, R., Olson, K., 2009. Bull Management and Nutrition, in: Proceedings, The Range Beef Cow Symposium XXI. Casper, WY.

Watanabe, Y., Yokobayashi, S., Yamamoto, M., Nurse, P., 2001. Pre-meiotic S phase is linked to reductional chromosome segregation and recombination. Nature 409, 359–363.

Weng, Z.Q., Saatchi, M., Schnabel, R.D., Taylor, J.F., Garrick, D.J., 2014. Recombination locations and rates in beef cattle assessed from parent-offspring pairs. Genet. Sel. Evol. 46.

Yip, M.-Y., 2015. Autosomal ring chromosomes in human genetic disorders. Transl. Pediatr. 4, 164–174.

Zhao, G.Q., Deng, K., Labosky, P.A., Liaw, L., Hogan, B.L.M., 1996. The gene encoding bone morphogenetic protein 8B is required for the initiation and maintenance of spermatogenesis in the mouse. Genes Dev. 10, 1657–1669.

Zhou, Y., Shen, B., Jiang, J., Padhi, A., Park, K.E., Oswalt, A., Sattler, C.G., Telugu, B.P., Chen, H., Cole, J.B., Liu, G.E., Ma, L., 2018. Construction of PRDM9 allele-specific recombination maps in cattle using large-scale pedigree analysis and genome-wide single sperm genomics. DNA Res. 25, 183–194.

APPENDIX A

Beefalo and Cattle MLH1 Foci

Beefalo 1 MLH1 foci

Spermatocyte ID	MLH1 foci
1	41
2	44
3	45
4	45.5
5	40
6	36.5
7	43.5
8	46
9	59.5
10	42.5
11	43.5
12	40
13	39.5
14	43.5
15	44
16	47
17	35.5
18	41.5
19	39.5
20	44
21	31.5
22	38
23	39.5
24	39.5
25	46
26	40.5
27	35.5
28	45
29	41.5
30	41
31	42
32	42
33	47
34	45.5
35	43

Spermatocyte ID	MLH1 foci
36	36.5
37	41.5
38	41
39	39.5
40	50.5
41	31.5
42	45.5
43	39.5
44	39
45	42.5
46	43.5
47	42.5
48	37
49	35
50	39.5
51	34
52	40.5
53	47
54	40
55	36
56	45
57	37
58	37.5
59	37.5
60	39.5
61	35
62	45
63	43
64	45
65	46
66	43.5
67	45.5
68	48.5
69	41.5
70	41

Spermatocyte ID	MLH1 foci
71	44
72	43
73	42
74	49
75	42
76	42
77	47
78	49.5
79	45.5
80	50
81	46.5
82	49.5
83	44
84	47.5
85	46.5
86	43.5
87	39
88	50
89	52
90	47.5
91	47.5
92	46.5
93	48
94	47.5
95	50
96	55
97	52
98	46
99	41
100	48
101	47
102	44
103	45.5

Beefalo 2 MLH1 foci

Spermatocyte ID	MLH1 foci
1	47.5
2	42
3	43
4	45
5	50
6	43
7	34
8	35.5
9	42
10	50
11	43
12	39
13	39
14	46
15	35
16	44
17	48
18	44.5
19	37
20	52.5
21	43
22	43.5
23	52.5
24	47
25	45
26	45.5
27	40.5
28	45
29	44
30	49
31	44.5
32	48
33	44
34	59
35	50.5
36	45

Spermatocyte ID	MLH1 foci
37	40
38	46.5
39	50
40	47.5
41	42
42	42
43	42
44	49
45	53
46	41.5
47	47
48	39
49	37.5
50	43
51	36.5
52	35.5
53	48.5
54	47.5
55	42.5
56	53
57	43
58	39
59	41
60	39.5
61	45
62	49.5
63	49
64	49
65	44
66	42
67	46
68	40.5
69	39.5
70	37
71	47
72	43

Spermatocyte ID	MLH1 foci
73	39.5
74	31.5
75	35.5
76	43
77	45
78	46.5
79	34
80	38.5
81	41.5
82	40.5
83	41.5
84	47
85	37.5
86	42.5
87	45
88	41
89	52.5
90	44.5
91	48
92	43.5
93	43
94	46
95	48.5
96	44.5
97	48.5
98	39
99	37.5
100	42.5
101	37
102	45.5
103	43.5
104	43.5
105	42
106	52.5
107	45.5

Beefalo 3 MLH1 foci

Spermatocyte ID	MLH1 foci
1	40
2	36.5
3	46
4	40.5
5	47.5
6	48
7	48
8	47.5
9	41
10	40.5
11	50
12	45.5
13	48
14	39
15	41
16	50
17	48
18	41
19	41
20	42.5
21	42.5
22	39
23	42
24	41
25	42
26	36.5
27	41.5
28	52
29	40.5
30	45.5
31	45
32	46.5
33	41.5
34	46
35	50.5

Spermatocyte ID	MLH1 foci
36	42
37	42
38	44.5
39	49
40	46.5
41	47
42	46
43	42.5
44	46
45	47.5
46	42.5
47	45.5
48	48.5
49	41.5
50	44.5
51	42
52	49.5
53	44.5
54	43.5
55	47
56	45.5
57	42
58	42
59	42.5
60	45
61	42.5
62	39
63	48.5
64	41
65	39
66	39
67	41.5
68	51.5
69	44
70	42.5

Spermatocyte ID	MLH1 foci
71	42
72	47
73	43.5
74	41
75	49
76	46
77	46.5
78	43
79	41
80	48
81	34
82	44.5
83	38
84	41.5
85	37.5
86	42.5
87	43.5
88	34
89	45.5
90	40
91	47
92	42
93	48
94	47.5
95	45.5
96	41
97	41.5
98	39
99	39.5
100	39.5
101	42.5
102	41
103	45.5

Beefalo 4 MLH1 foci

Spermatocyte ID	MLH1 foci
1	42.5
2	43.5
3	49
4	42.5
5	46
6	40
7	40.5
8	40.5
9	40.5
10	41.5
11	39.5
12	39.5
13	42.5
14	52
15	48
16	37.5
17	42.5
18	47
19	48
20	45.5
21	39
22	46.5
23	43
24	47.5
25	43
26	41.5
27	41.5
28	42.5
29	45
30	44
31	43.5
32	41
33	38.5
34	46.5
35	43.5

Spermatocyte ID	MLH1 foci
36	43.5
37	49
38	42
39	39.5
40	44.5
41	42.5
42	48.5
43	43.5
44	42.5
45	36
46	43
47	46
48	44.5
49	49
50	46.5
51	41.5
52	40.5
53	38.5
54	39
55	45.5
56	54.5
57	45.5
58	43
59	47.5
60	48.5
61	47.5
62	39.5
63	48.5
64	46
65	38
66	41
67	36.5
68	41
69	46
70	41

Spermatocyte ID	MLH1 foci
71	35.5
72	42.5
73	41
74	43.5
75	42
76	41
77	40
78	44
79	42
80	48.5
81	39.5
82	45
83	42
84	48.5
85	39
86	42.5
87	40
88	48.5
89	42.5
90	39.5
91	46
92	46.5
93	42
94	41.5
95	42
96	45
97	44
98	44
99	43
100	48.5
101	40
102	39.5
103	38

Beefalo 5 MLH1 foci

Spermatocyte ID	MLH1 foci
1	45
2	43
3	43.5
4	46
5	44.5
6	41.5
7	39.5
8	43
9	44
10	53
11	40
12	44
13	55
14	43.5
15	45
16	44
17	42
18	46.5
19	45.5
20	43
21	42
22	48.5
23	50
24	46.5
25	48.5
26	48.5
27	52.5
28	50
29	44
30	46
31	47.5
32	42.5
33	47.5
34	39
35	41

Spermatocyte ID	MLH1 foci
36	42
37	46
38	48.5
39	46
40	50
41	50.5
42	44
43	45.5
44	42.5
45	45
46	42.5
47	42
48	41
49	40.5
50	47
51	44.5
52	48.5
53	36
54	41.5
55	47.5
56	41.5
57	51.5
58	46
59	46.5
60	44
61	50
62	41
63	49
64	43.5
65	53
66	47.5
67	44.5
68	46.5
69	45
70	44.5

Spermatocyte ID	MLH1 foci
71	44.5
72	41.5
73	39.5
74	48.5
75	49
76	51
77	49.5
78	43.5
79	46
80	45
81	44.5
82	47
83	42.5
84	35
85	41
86	37
87	36.5
88	37.5
89	37.5
90	41
91	43.5
92	46
93	45.5
94	47
95	45
96	45
97	48.5
98	53
99	48.5
100	47
101	47
102	47
103	41.5

Beefalo 6 MLH1 foci

Spermatocyte ID	MLH1 foci
1	41
2	39
3	43
4	43
5	43.5
6	47
7	40
8	47
9	43
10	40
11	47
12	45.5
13	38
14	36
15	41
16	41.5
17	38.5
18	39.5
19	35.5
20	40
21	38
22	35.5
23	42.5
24	39
25	39
26	42.5
27	39
28	41.5
29	40
30	40
31	48.5
32	46
33	40.5
34	39
35	47

Spermatocyte ID	MLH1 foci
36	44.5
37	33
38	40
39	49
40	38
41	40
42	48
43	50
44	43
45	41.5
46	45
47	38.5
48	43
49	42.5
50	40
51	43
52	44
53	41
54	41.5
55	42
56	45
57	48
58	40.5
59	34
60	45.5
61	37
62	42
63	48.5
64	40.5
65	47
66	43.5
67	43
68	45
69	40
70	40.5

Spermatocyte ID	MLH1 foci
71	51
72	42
73	35.5
74	37
75	42
76	45
77	42.5
78	37
79	41.5
80	35.5
81	40
82	42
83	46
84	38.5
85	39.5
86	42
87	35
88	32
89	38
90	33.5
91	43
92	40
93	35
94	35
95	34.5
96	31.5
97	37.5
98	31.5
99	38.5
100	37.5
101	38
102	44.5
103	46.5

Beefalo 7 MLH1 foci

Spermatocyte ID	MLH1 foci
1	38
2	37
3	43.5
4	39.5
5	42.5
6	38.5
7	42
8	43
9	39.5
10	38
11	35
12	38
13	35
14	32
15	36
16	36
17	37
18	37
19	36.5
20	35.5
21	40
22	33.5
23	43
24	34
25	41
26	40.5
27	35.5
28	35
29	32
30	40
31	34.5
32	32.5
33	35.5
34	41
35	34.5

Spermatocyte ID	MLH1 foci
36	40.5
37	33
38	36
39	36.5
40	35.5
41	38.5
42	38
43	36
44	36
45	42
46	37.5
47	37.5
48	38.5
49	37.5
50	37
51	33.5
52	39.5
53	38
54	42
55	37
56	38
57	41
58	40
59	42
60	38.5
61	41.5
62	40
63	44.5
64	40.5
65	42
66	36.5
67	40
68	42.5
69	40
70	37.5

Spermatocyte ID	MLH1 foci
71	36
72	41.5
73	40.5
74	37
75	35
76	42.5
77	36
78	39.5
79	35.5
80	36.5
81	38
82	36.5
83	39.5
84	41
85	46
86	40
87	40
88	44
89	39.5
90	40.5
91	35
92	38
93	44.5
94	42
95	40
96	38.5
97	36
98	36.5
99	41.5
100	34
101	34.5
102	50.5
103	45

Charolais MLH1 foci

Spermatocyte ID	MLH1 foci
1	34
2	36
3	38
4	38.5
5	39
6	40
7	40
8	40
9	41
10	41
11	41.5
12	41.5
13	42
14	42
15	42
16	42.5
17	42.5
18	43
19	43
20	43
21	44
22	44
23	44
24	44
25	44.5
26	45
27	45
28	45
29	45
30	45
31	45
32	45
33	45.5
34	45.5
35	45.5
36	58
37	58
38	59.5

Spermatocyte ID	MLH1 foci
39	45.5
40	46
41	46
42	46
43	46.5
44	46.5
45	47
46	47
47	47
48	47
49	47.5
50	48
51	48
52	48
53	48
54	48
55	48
56	48
57	48
58	48
59	48.5
60	49
61	49.5
62	49.5
63	50
64	50
65	50
66	50
67	50
68	50.5
69	50.5
70	50.5
71	51
72	51
73	51
74	59.5
75	60.5
76	62

Spermatocyte ID	MLH1 foci
77	51
78	51.5
79	52
80	52
81	52
82	52
83	52
84	52
85	52
86	52
87	52.5
88	52.5
89	52.5
90	52.5
91	52.5
92	52.5
93	53
94	53
95	53.5
96	54
97	54
98	54
99	54
100	54
101	54
102	54
103	55
104	55
105	55.5
106	55.5
107	56
108	56
109	56.5
110	57
111	58
112	66.5

Gelbvieh MLH1 foci

Spermatocyte ID	MLH1 foci
1	35
2	38
3	39
4	39
5	39.5
6	40
7	40
8	40
9	40.5
10	41
11	41.5
12	41.5
13	41.5
14	42
15	42
16	42
17	42
18	42.5
19	43
20	43
21	43
22	43.5
23	43.5
24	43.5
25	44
26	44
27	44
28	44
29	44
30	44
31	44.5
32	44.5
33	44.5
34	44.5

Spermatocyte ID	MLH1 foci
35	45
36	45
37	45.5
38	45.5
39	45.5
40	45.5
41	45.5
42	46
43	46
44	46
45	47
46	47
47	47
48	47
49	47
50	47
51	47
52	47
53	47
54	47
55	48
56	48
57	48
58	48
59	48
60	48.5
61	49
62	49
63	49
64	49
65	49.5
66	50
67	50
68	50

Spermatocyte ID	MLH1 foci
69	51
70	51
71	51.5
72	52
73	52
74	52
75	52
76	52
77	52.5
78	53
79	53
80	53
81	53
82	53.5
83	54
84	55
85	55
86	57
87	57
88	58
89	58
90	59
91	59.5
92	60
93	60
94	61
95	62.5
96	47.5
97	48.5
98	47
99	45
100	50

Jersey MLH1 foci

Spermatocyte ID	MLH1 foci
1	42.5
2	51.5
3	52.5
4	50.5
5	56
6	51.5
7	52.5
8	50
9	47
10	46
11	47.5
12	51.5
13	51
14	50
15	50.5
16	48.5
17	55.5
18	54
19	46.5
20	47
21	46.5
22	52
23	54.5
24	47.5
25	48.5
26	44.5
27	50
28	46
29	47.5
30	47
31	47.5
32	48
33	49
34	52

Spermatocyte ID	MLH1 foci
35	46.5
36	46
37	53.5
38	47.5
39	44.5
40	47
41	44
42	53
43	44.5
44	49
45	53.5
46	55
47	47
48	49
49	55.5
50	43.5
51	48.5
52	45.5
53	49
54	49
55	54
56	51.5
57	45
58	54
59	56
60	54.5
61	50.5
62	50.5
63	52.5
64	53
65	43.5
66	56.5
67	48.5
68	51

Spermatocyte ID	MLH1 foci
69	40
70	44.5
71	47
72	45
73	47.5
74	55.5
75	51.5
76	45
77	44.5
78	42.5
79	47.5
80	51.5
81	52
82	46.5
83	44
84	47.5
85	48
86	49
87	51.5
88	52
89	50
90	60.5
91	47
92	47
93	56.5
94	49
95	49
96	44
97	49.5
98	44.5
99	49.5
100	54
101	52
102	38

Lowline MLH1 foci

Spermatocyte ID	MLH1 foci
1	42
2	48
3	51
4	43.5
5	48
6	42.5
7	48.5
8	46
9	45
10	45.5
11	45
12	44.5
13	51
14	35.5
15	49
16	44.5
17	49
18	41.5
19	49.5
20	47.5
21	51
22	51
23	54
24	39.5
25	45
26	44
27	53.5
28	49
29	38
30	36.5
31	45
32	39.5
33	44.5
34	55

Spermatocyte ID	MLH1 foci
35	56.5
36	37.5
37	44
38	48.5
39	37
40	39
41	38
42	49.5
43	39
44	43.5
45	51
46	47
47	46
48	49.5
49	49
50	45
51	41.5
52	50
53	51
54	41.5
55	42
56	52
57	39
58	46
59	45.5
60	49.5
61	55
62	51
63	39.5
64	45
65	54
66	46
67	47.5
68	50

Spermatocyte ID	MLH1 foci
69	45.5
70	42.5
71	38.5
72	53
73	39.5
74	49
75	48.5
76	38
77	41
78	53.5
79	46.5
80	38.5
81	43.5
82	40.5
83	46
84	46
85	50
86	42
87	49
88	56
89	46.5
90	43
91	41.5
92	37
93	45
94	41.5
95	41.5
96	53
97	51.5
98	46.5
99	54
100	52

Angus 1 MLH1 folci

Spermatocyte ID	MLH1 foci
1	48
2	40.5
3	39
4	43.5
5	48
6	41.5
7	44.5
8	39
9	42.5
10	48.5
11	39
12	45
13	42
14	42
15	38
16	46
17	35
18	44
19	45
20	46
21	35
22	39.5
23	40.5
24	44
25	46
26	41.5
27	41
28	44
29	44
30	42
31	40
32	43
33	45
34	44

Spermatocyte ID	MLH1 foci
35	46
36	40.5
37	48.5
38	45.5
39	42
40	43
41	41.5
42	42.5
43	39.5
44	44
45	42
46	49.5
47	45.5
48	41.5
49	44
50	45
51	42
52	46.5
53	43
54	42.5
55	44.5
56	41
57	42
58	41.5
59	43.5
60	39
61	39.5
62	43.5
63	44
64	44.5
65	41.5
66	42.5
67	45.5
68	51

Spermatocyte ID	MLH1 foci
69	43
70	51
71	47.5
72	45.5
73	47
74	37
75	42.5
76	47
77	48
78	50
79	45
80	39.5
81	41.5
82	37
83	44
84	48
85	45
86	46
87	39.5
88	40.5
89	46
90	45
91	43
92	50
93	36.5
94	41.5
95	46.5
96	41.5
97	46
98	44
99	42.5
100	39.5

Angus 2 MLH1 foci

Spermatocyte ID	MLH1 foci
1	40
2	44.5
3	46.5
4	41.5
5	46
6	45.5
7	45.5
8	41
9	35.5
10	38.5
11	46
12	45
13	45
14	43
15	43.5
16	45
17	37.5
18	50
19	43.5
20	45.5
21	43
22	42
23	42
24	46.5
25	44.5
26	42.5
27	39.5
28	46.5
29	48
30	46
31	41.5
32	39
33	43.5
34	48

Spermatocyte ID	MLH1 foci
35	39.5
36	38
37	44
38	39.5
39	48
40	47
41	47
42	39
43	38
44	43
45	45
46	44
47	45
48	43.5
49	43
50	45
51	44
52	39
53	40.5
54	45.5
55	42
56	43.5
57	43
58	46.5
59	42
60	42.5
61	41.5
62	40.5
63	43
64	48
65	46.5
66	43.5
67	45
68	46

Spermatocyte ID	MLH1 foci
69	39
70	43
71	41
72	45
73	46
74	39.5
75	44.5
76	48
77	44
78	43
79	43.5
80	38
81	44
82	42
83	42.5
84	43
85	42.5
86	41.5
87	45.5
88	46
89	39
90	50
91	40.5
92	48
93	46
94	47.5
95	40
96	47
97	43.5
98	43.5
99	43
100	38

Angus 3 MLH1 foci

Spermatocyte ID	MLH1 foci
1	41.5
2	45
3	44
4	38.5
5	44
6	44
7	45
8	39.5
9	41
10	42
11	37
12	43
13	44
14	44
15	45.5
16	41.5
17	39.5
18	36.5
19	43
20	40
21	41
22	38.5
23	48.5
24	38
25	45
26	41
27	45
28	45.5
29	41.5
30	45
31	43
32	36
33	41.5
34	42.5

Spermatocyte ID	MLH1 foci
35	36.5
36	39
37	43.5
38	45
39	42
40	36
41	44
42	38.5
43	47
44	47
45	47.5
46	52
47	48.5
48	34.5
49	35
50	43
51	44
52	40
53	38
54	43
55	33
56	41.5
57	42
58	38.5
59	41
60	39.5
61	42.5
62	37
63	40
64	45
65	45
66	41.5
67	46
68	45

Spermatocyte ID	MLH1 foci
69	47
70	47
71	45
72	42.5
73	45.5
74	46.5
75	41
76	42
77	41
78	36
79	37.5
80	38
81	37
82	42
83	41
84	37
85	42
86	36
87	45
88	38
89	37.5
90	40
91	42
92	36.5
93	39
94	37
95	38
96	37
97	41
98	38
99	40
100	43
101	46.5

Angus 4 MLH1 foci

Spermatocyte ID	MLH1 foci
1	49
2	42.5
3	42.5
4	44.5
5	38.5
6	47
7	43
8	44
9	38.5
10	45
11	41
12	45
13	45
14	40.5
15	33.5
16	42
17	39
18	42
19	37
20	40.5
21	40.5
22	41.5
23	37
24	45
25	46
26	45
27	43.5
28	44
29	37.5
30	43
31	40
32	50.5
33	43
34	46

Spermatocyte ID	MLH1 foci
35	46.5
36	36
37	45
38	41
39	37
40	43.5
41	40.5
42	40
43	47.5
44	42.5
45	42.5
46	49
47	45.5
48	34.5
49	40
50	42.5
51	37
52	48.5
53	44.5
54	41
55	45
56	40
57	38.5
58	39.5
59	37
60	36.5
61	41
62	42.5
63	42.5
64	34.5
65	45
66	43.5
67	42
68	42

Spermatocyte ID	MLH1 foci
69	44.5
70	45.5
71	43.5
72	47.5
73	41
74	49
75	40.5
76	51
77	37.5
78	42
79	44
80	46.5
81	44.5
82	42
83	43.5
84	44
85	42
86	42.5
87	46
88	46
89	42
90	46
91	46
92	49
93	41.5
94	41
95	38.5
96	43.5
97	36.5
98	36
99	43
100	40.5

Angus 5 MLH1 foci

Spermatocyte ID	MLH1 foci
1	41.5
2	45
3	41
4	42.5
5	42
6	39.5
7	39.5
8	38.5
9	45
10	38
11	43.5
12	39.5
13	44
14	44.5
15	40
16	37
17	46
18	35.5
19	41
20	37.5
21	36.5
22	46
23	45
24	52
25	44
26	39.5
27	43.5
28	50
29	38
30	42
31	45
32	44
33	45
34	42

Spermatocyte ID	MLH1 foci
35	39.5
36	45
37	45.5
38	45
39	42.5
40	42.5
41	38
42	40
43	32.5
44	36.5
45	46
46	48
47	42.5
48	43.5
49	38.5
50	39
51	45.5
52	39.5
53	45.5
54	55
55	40
56	39.5
57	40.5
58	36.5
59	45
60	41
61	35
62	38
63	40.5
64	40
65	43
66	44
67	47.5
68	38

Spermatocyte ID	MLH1 foci
69	51
70	39.5
71	40
72	40
73	38
74	43.5
75	34
76	38.5
77	41
78	43.5
79	39.5
80	39
81	35
82	45
83	36.5
84	41.5
85	44
86	42.5
87	46
88	43
89	35
90	36.5
91	46.5
92	38
93	47.5
94	42.5
95	41
96	41.5
97	42
98	33.5
99	44.5
100	50

Angus 6 MLH1 foci

Spermatocyte ID	MLH1 foci
1	42
2	33
3	40.5
4	52
5	41.5
6	47
7	45
8	38
9	45.5
10	39.5
11	48
12	48
13	40
14	37
15	35.5
16	38
17	39
18	34
19	32.5
20	45
21	48
22	47
23	41.5
24	46.5
25	48
26	44.5
27	40
28	42.5
29	47.5
30	44.5
31	37.5
32	47
33	53.5
34	52.5
35	44

Spermatocyte ID	MLH1 foci
36	42.5
37	43.5
38	43
39	40.5
40	35.5
41	39.5
42	38
43	34.5
44	45
45	46
46	34.5
47	55
48	47
49	52
50	36.5
51	37
52	35
53	48
54	45
55	42.5
56	29
57	57.5
58	32
59	46.5
60	42
61	40.5
62	38.5
63	47.5
64	42.5
65	49
66	42
67	44
68	32
69	40
70	41

Spermatocyte ID	MLH1 foci
71	34
72	36
73	40
74	42
75	45.5
76	36
77	45
78	43
79	39
80	45
81	40
82	41
83	42.5
84	48.5
85	51
86	43
87	47
88	40
89	47.5
90	50
91	50.5
92	40
93	56.5
94	57
95	65
96	47
97	43
98	42
99	42
100	39.5
101	51
102	45
103	45
104	48
105	43

Angus 7 MLH1 foci

Spermatocyte ID	MLH1 foci
1	45
2	42.5
3	48
4	39.5
5	39
6	47
7	40.5
8	48.5
9	51
10	47
11	56
12	41.5
13	50
14	45.5
15	54
16	61.5
17	44
18	44.5
19	44
20	45
21	41
22	42.5
23	49
24	41.5
25	39
26	48
27	42.5
28	41.5
29	41
30	41
31	41
32	36
33	48
34	47

Spermatocyte ID	MLH1 foci
35	42.5
36	45
37	46.5
38	58
39	47.5
40	50
41	44
42	46.5
43	45.5
44	51
45	39.5
46	49
47	40.5
48	45.5
49	46.5
50	44.5
51	45.5
52	47
53	41.5
54	43.5
55	45.5
56	40.5
57	43.5
58	53.5
59	44.5
60	56
61	51
62	37
63	40.5
64	44.5
65	42
66	55.5
67	45
68	52

Spermatocyte ID	MLH1 foci
69	52
70	41
71	46.5
72	40.5
73	49
74	52
75	48.5
76	60
77	53
78	51.5
79	56.5
80	46
81	50.5
82	51.5
83	60.5
84	41
85	48.5
86	48
87	50.5
88	41.5
89	47
90	45
91	45
92	45.5
93	47.5
94	47.5
95	46
96	46
97	48.5
98	46.5
99	53.5
100	43.5

APPENDIX B

Crossover Placement and Synaptonemal Complex Length in Cattle

Charolais

Spermatocyte 1

	CO 1	CO 2	CO 3	SC Length
SC 1	0.33222	-	-	9.24931
SC 2	0.17843	-	-	9.14032
SC 3	0.49519	-	-	11.13196
SC 4	0.33304	-	-	10.66261
SC 5	0.40532	-	-	11.85632
SC 6	0.48581	-	-	8.53972
SC 7	0.25961	-	-	6.46499
SC 8	0.09554	-	-	14.47796
SC 9	0.42633	0.650786	-	19.53364
SC 10	0.11457	0.579167	-	22.68154
SC 11	0.0759	0.596738	-	16.83248
SC 12	0.12166	0.732862	-	17.97362
SC 13	0.30469	0.667266	-	17.92315
SC 14	0.32674	0.873205	-	13.31988
SC 15	0.37984	0.947753	-	15.46517
SC 16	0.16788	0.733937	-	23.38364
SC 17	0.41243	0.655417	-	19.56381
SC 18	0.26746	0.722994	-	13.33507
SC 19	0.20105	0.652272	-	14.47054
SC 20	0.1344	0.655628	-	17.08553
SC 21	0.3476	0.892537	-	24.26424
SC 22	0.30668	0.703986	-	16.56179
SC 23	0.47102	0.724637	-	19.71193
SC 24	0.30866	0.675496	0.86224	26.12491
SC 25	0.36888	0.555851	0.756766	19.74896
SC 26	0.08311	0.399034	0.8436	18.92821
SC 27	0.14518	0.717813	0.918966	14.99365
SC 28	0.40888	-	-	8.43528
SC 29	0.45502	-	-	8.50024

Spermatocyte 2

	CO 1	CO 2	CO 3	SC Length
SC 1	0.31422	-	-	7.33866
SC 2	0.32943	-	-	10.8994
SC 3	0.2383	-	-	11.3966
SC 4	0.27425	-	-	8.53818
SC 5	0.47655	-	-	10.3712
SC 6	0.15465	-	-	12.7611
SC 7	0.46836	-	-	11.9105
SC 8	0.2787	-	-	13.7073
SC 9	0.40459	-	-	7.77259
SC 10	0.31314	-	-	11.401
SC 11	0.32192	-	-	9.68618
SC 12	0.29723	-	-	8.58543
SC 13	0.27092	0.88011	-	21.9375
SC 14	0.26415	0.65316	-	13.7445
SC 15	0.23324	0.95253	-	14.0247
SC 16	0.08485	0.85633	-	17.6054
SC 17	0.48508	0.89928	-	11.2737
SC 18	0.1652	0.70153	-	7.87374
SC 19	0.05791	0.88244	-	19.0988
SC 20	0.09387	0.70069	-	17.2038
SC 21	0.1607	0.52057	-	21.8392
SC 22	0.17971	0.66641	-	18.4078
SC 23	0.37872	-	-	15.9022
SC 24	0.38893	-	-	8.64192
SC 25	0.3113	-	-	7.65646
SC 26	0.1225	-	-	7.35826
SC 27	0.32515	0.48674	0.85398	29.3276
SC 28	0.09037	0.30526	0.77801	20.139
SC 29	0.06311	0.19843	0.72016	15.1439

Spermatocyte 3

	CO 1	CO 2	CO 3	SC Length
SC 1	0.40699	-	-	8.06876
SC 2	0.11217	-	-	6.6227
SC 3	0.43774	-	-	13.1482
SC 4	0.45892	-	-	9.22453
SC 5	0.36226	-	-	11.839
SC 6	0.4938	-	-	10.009
SC 7	0.4786	-	-	8.04426
SC 8	0.42214	0.69306	-	18.3055
SC 9	0.23554	0.73986	-	11.1521
SC 10	0.15725	0.79742	-	12.9938
SC 11	0.30203	0.85651	-	12.8236
SC 12	0.12767	0.6635	-	19.4807
SC 13	0.30504	0.74369	-	20.5937
SC 14	0.11425	0.63564	-	12.0686
SC 15	0.12551	0.90657	-	18.0546
SC 16	0.09129	0.59391	-	17.6408
SC 17	0.13099	0.71184	-	10.2483
SC 18	0.68598	0.90467	-	9.43096
SC 19	0.22736	0.52717	-	16.6937
SC 20	0.33913	0.87751	-	16.6517
SC 21	0.10525	0.69758	-	21.9836
SC 22	0.10077	0.79328	-	17.2799
SC 23	0.24435	0.93218	-	13.4502
SC 24	0.26302	0.86879	-	15.4006
SC 25	0.41262	-	-	9.51118
SC 26	0.3748	-	-	7.48027
SC 27	0.12648	0.59114	0.80601	17.8254
SC 28	0.12082	0.56166	0.90022	14.7963
SC 29	0.10201	0.62287	-	9.82898

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.16078	-	-	8.736
SC 2	0.3156	-	-	9.45147
SC 3	0.41417	-	-	9.8266
SC 4	0.35436	-	-	10.79463
SC 5	0.29571	-	-	16.73693
SC 6	0.35861	-	-	9.86118
SC 7	0.42384	-	-	5.77535
SC 8	0.48966	-	-	9.61548
SC 9	0.42872	-	-	8.064
SC 10	0.32107	-	-	8.16235
SC 11	0.47448	0.90167	-	15.52537
SC 12	0.4522	0.76575	-	11.0656
SC 13	0.29997	0.71352	-	11.72248
SC 14	0.29756	0.88763	-	13.34865
SC 15	0.1055	0.81608	-	10.815
SC 16	0.09407	0.68615	-	18.42365
SC 17	0.14512	0.92022	-	15.08262
SC 18	0.23723	0.65582	-	11.80676
SC 19	0.10717	0.72766	-	11.11957
SC 20	0.2814	0.78821	-	12.28745
SC 21	0.23745	0.79139	-	19.2934
SC 22	0.09629	0.53401	-	15.27659
SC 23	0.19046	0.89018	-	10.30708
SC 24	0.26419	0.90708	-	9.43901
SC 25	0.18418	0.8121	-	15.86732
SC 26	0.06106	0.86364	-	11.35253
SC 27	0.13263	0.65671	-	21.64995
SC 28	0.29348	0.6716	0.82516	19.32651
SC 29	0.47585	0.80461	-	19.13828

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.35631	-	-	8.83351
SC 2	0.43375	-	-	9.14872
SC 3	0.49335	-	-	12.1485
SC 4	0.40107	-	-	8.22073
SC 5	0.20435	-	-	12.63045
SC 6	0.40467	-	-	7.73976
SC 7	0.37421	-	-	9.36194
SC 8	0.481	-	-	7.57659
SC 9	0.49364	-	-	14.86023
SC 10	0.40938	-	-	9.12401
SC 11	0.46021	-	-	10.28685
SC 12	0.36754	0.92754	-	19.12904
SC 13	0.38537	0.58456	-	14.25263
SC 14	0.20999	0.68429	-	10.65267
SC 15	0.34338	0.69416	-	16.97507
SC 16	0.38012	0.78679	-	10.85658
SC 17	0.43415	0.94628	-	11.67264
SC 18	0.44297	0.87147	-	17.56076
SC 19	0.29286	0.73435	-	13.76277
SC 20	0.24711	0.71275	-	17.514
SC 21	0.21266	0.6172	-	15.86466
SC 22	0.07548	0.84861	-	21.75411
SC 23	0.34336	0.86702	-	12.18238
SC 24	0.37275	0.9342	-	17.54914
SC 25	0.12271	0.82831	-	13.33703
SC 26	0.21507	0.50779	0.77922	22.9859
SC 27	0.12003	0.48389	0.84671	14.4942
SC 28	0.26772	0.63652	0.846	10.23029
SC 29	0.21843	-	-	7.94045

Spermatocyte 6

	CO 1	CO 2	CO 3	SC Length
SC 1	0.18194	-	-	8.34477
SC 2	0.38932	-	-	7.05754
SC 3	0.4363	-	-	6.67296
SC 4	0.38362	-	-	8.5701
SC 5	0.44582	-	-	7.11053
SC 6	0.3882	-	-	10.2033
SC 7	0.44295	-	-	6.89906
SC 8	0.16822	0.80068	-	9.46869
SC 9	0.22219	0.61864	-	12.2114
SC 10	0.21508	0.78797	-	12.3775
SC 11	0.08086	0.78602	-	16.8179
SC 12	0.20839	0.92098	-	15.1666
SC 13	0.26184	0.83894	-	12.2685
SC 14	0.41565	0.80845	-	12.7968
SC 15	0.3165	0.81103	-	11.7814
SC 16	0.48243	0.73512	-	13.8923
SC 17	0.21592	0.69836	-	14.7303
SC 18	0.37497	0.83924	-	13.0629
SC 19	0.34214	0.87971	-	10.1199
SC 20	0.38958	0.74026	-	11.1943
SC 21	0.44064	0.75313	-	13.4221
SC 22	0.31148	0.84502	-	14.9336
SC 23	0.13038	0.7838	-	10.9882
SC 24	0.26591	0.83184	-	14.647
SC 25	0.05567	0.59004	0.84885	16.7614
SC 26	0.15604	0.43785	0.92569	17.3977
SC 27	0.09746	0.34065	0.94647	17.0485
SC 28	0.1903	0.62111	0.95783	15.9589
SC 29	0.17606	0.6076	0.73382	21.3895

Spermatocyte 7

	CO 1	CO 2	SC Length
SC 1	0.20677	-	7.0581
SC 2	0.43561	-	9.61506
SC 3	0.47853	-	11.6969
SC 4	0.46132	-	8.66474
SC 5	0.37722	-	10.3951
SC 6	0.47713	-	13.91
SC 7	0.48231	-	10.5893
SC 8	0.34968	-	11.7643
SC 9	0.25721	-	15.3651
SC 10	0.49294	-	17.7715
SC 11	0.12292	-	14.8609
SC 12	0.24558	-	9.47352
SC 13	0.25168	-	10.0869
SC 14	0.12987	-	15.294
SC 15	0.06838	-	13.3342
SC 16	0.15308	-	16.5018
SC 17	0.40614	-	17.9386
SC 18	0.4932	0.93086	16.1792
SC 19	0.31381	0.71723	19.1778
SC 20	0.28902	0.71261	16.3253
SC 21	0.34647	0.59096	20.111
SC 22	0.10529	0.82281	17.2535
SC 23	0.36734	0.88147	19.2935
SC 24	0.37483	0.92163	17.0153
SC 25	0.35189	0.7725	19.6258
SC 26	0.74725	0.84417	20.3841
SC 27	0.08586	0.80661	25.6509
SC 28	0.19215	0.92166	13.1856
SC 29	0.06836	-	18.7391

Spermatocyte 8

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.46496	-	-	-	11.2328
SC 2	0.45392	-	-	-	15.1749
SC 3	0.07494	-	-	-	13.2053
SC 4	0.42549	-	-	-	8.57717
SC 5	0.28434	-	-	-	11.2678
SC 6	0.29107	-	-	-	8.70247
SC 7	0.33401	0.73514	-	-	23.5168
SC 8	0.13771	0.54324	-	-	13.5763
SC 9	0.33807	0.67998	-	-	11.0865
SC 10	0.12263	0.66427	-	-	14.8866
SC 11	0.27465	0.89579	-	-	18.3253
SC 12	0.20808	0.72097	-	-	20.6534
SC 13	0.14585	0.50385	-	-	11.2363
SC 14	0.71236	0.93672	-	-	19.0583
SC 15	0.10996	0.6674	-	-	24.9073
SC 16	0.51802	0.774	-	-	17.429
SC 17	0.16357	0.65494	-	-	15.5413
SC 18	0.19927	0.58259	-	-	13.8762
SC 19	0.30114	0.46228	0.91988	-	15.3236
SC 20	0.27973	0.54964	0.84046	-	24.0484
SC 21	0.30383	0.44496	0.78565	-	21.6803
SC 22	0.10939	0.62708	0.85177	-	19.5506
SC 23	0.13473	0.46527	0.87297	-	18.8119
SC 24	0.37167	-	-	-	9.11323
SC 25	0.29403	-	-	-	12.138
SC 26	0.2815	-	-	-	10.0146
SC 27	0.38011	0.82727	-	-	23.6585
SC 28	0.32708	0.60347	0.81123	0.93964	39.1316
SC 29	0.10541	0.20254	0.94255	-	22.7739

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.3215	-	-	10.554
SC 2	0.3351	-	-	8.2648
SC 3	0.4295	-	-	8.515
SC 4	0.4971	-	-	8.0371
SC 5	0.4735	-	-	8.9531
SC 6	0.4592	-	-	7.2348
SC 7	0.168	0.8327	-	7.6369
SC 8	0.221	0.8648	-	7.4148
SC 9	0.3589	0.8508	-	11.223
SC 10	0.0995	0.6882	-	16.82
SC 11	0.3129	0.7213	-	16.733
SC 12	0.3413	0.8167	-	13.587
SC 13	0.4125	0.8952	-	21.568
SC 14	0.2358	0.7803	-	21.193
SC 15	0.5722	0.845	-	13.548
SC 16	0.3351	0.6772	-	7.2013
SC 17	0.0985	0.9205	-	16.196
SC 18	0.2129	0.8917	-	9.0485
SC 19	0.2808	0.688	-	14.452
SC 20	0.0978	0.8867	-	13.791
SC 21	0.2123	0.8257	-	12.801
SC 22	0.4527	0.8835	-	11.12
SC 23	0.2786	0.9205	-	19.781
SC 24	0.3795	0.6383	0.8499	17.67
SC 25	0.1528	0.3413	0.8856	17.315
SC 26	0.1606	0.4211	0.671	16.532
SC 27	0.0977	0.7189	0.8637	23.295
SC 28	0.2834	0.6566	0.8477	20.618
SC 29	0.133	-	-	11.577

Spermatocyte 10

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.26591	-	-	-	18.1548
SC 2	0.38712	-	-	-	10.0502
SC 3	0.35357	-	-	-	22.3678
SC 4	0.39801	-	-	-	11.2751
SC 5	0.15836	-	-	-	18.0669
SC 6	0.474	-	-	-	17.8867
SC 7	0.43177	-	-	-	7.72002
SC 8	0.31029	-	-	-	10.5744
SC 9	0.4198	-	-	-	20.316
SC 10	0.40155	-	-	-	8.07471
SC 11	0.3101	-	-	-	8.51963
SC 12	0.23521	-	-	-	10.1336
SC 13	0.49919	-	-	-	8.94866
SC 14	0.4314	-	-	-	11.4792
SC 15	0.3879	-	-	-	11.0111
SC 16	0.44465	-	-	-	23.9312
SC 17	0.47829	-	-	-	28.7597
SC 18	0.4229	-	-	-	16.1015
SC 19	0.49717	-	-	-	12.5847
SC 20	0.25069	-	-	-	12.8975
SC 21	0.29447	-	-	-	16.1045
SC 22	0.39511	0.53403	-	-	20.9782
SC 23	0.66844	0.89951	-	-	27.0073
SC 24	0.15179	0.81006	-	-	18.2482
SC 25	0.19597	0.87197	-	-	20.5156
SC 26	0.17206	0.49117	-	-	14.5718
SC 27	0.13627	0.21596	0.44002	0.72948	37.5619
SC 28	0.23194	0.7117	0.85531		41.6471
SC 29	0.21309	0.6157	0.79069	0.94322	34.8724

Jersey

Spermatocyte 1

	1 CO	2 CO	3 CO	SC Length
1 SC	0.29967	-	-	7.24318
2 SC	0.39116	-	-	6.93413
3 SC	0.08732	0.82786	-	13.3163
4 SC	0.36823	-	-	6.56964
5 SC	0.10814	-	-	7.28217
6 SC	0.11265	0.83321	-	12.8384
7 SC	0.17661	0.81373	-	16.5449
8 SC	0.11314	0.63865	-	14.522
9 SC	0.17796	-	-	8.25559
10 SC	0.23626	-	-	12.1597
11 SC	0.09513	0.73705	-	11.4988
12 SC	0.21256	0.52519	0.57251	19.4035
13 SC	0.16453	0.45437	-	10.2013
14 SC	0.10824	0.31475	0.48533	16.3653
15 SC	0.31903	0.23213	0.6217	10.9474
16 SC	0.24491	-	-	14.8824
17 SC	0.30398	-	-	18.0465
18 SC	0.31211	-	-	4.04306
19 SC	0.07087	-	-	10.8642
20 SC	0.12508	0.84705	-	13.3487
21 SC	0.25535	0.72377	-	22.6295
22 SC	0.13656	-	-	8.07709
23 SC	0.12664	-	-	4.95495
24 SC	0.66272	0.70888	-	6.93483
25 SC	0.43009	-	-	10.2982
26 SC	0.48366	-	-	1.76239
27 SC	0.42653	0.54951	-	14.7966
28 SC	0.45665	-	-	7.26579
29 SC	0.49908	-	-	4.43198

Spermatocyte 2

	CO 1	CO 2	CO 3	SC Length
SC 1	0.39273	-	-	7.24241
SC 2	0.04569	0.67988	-	7.66115
SC 3	0.36238	0.45949	-	5.01557
SC 4	0.08152	-	-	11.1854
SC 5	0.14703	-	-	4.28491
SC 6	0.16597	0.58705	0.74793	19.1278
SC 7	0.22291	0.90757	-	8.66369
SC 8	0.41409	-	-	6.02154
SC 9	0.16695	0.75928	-	6.85979
SC 10	0.31448	-	-	8.75028
SC 11	0.4862	-	-	7.3094
SC 12	0.36166	0.60122	-	11.2622
SC 13	0.08021	-	-	6.5975
SC 14	0.18416	0.67412	-	10.4444
SC 15	0.22118	-	-	5.47435
SC 16	0.40203	-	-	5.87307
SC 17	0.16095	-	-	10.7519
SC 18	0.26099	-	-	16.1921
SC 19	0.08648	0.7617	-	15.3459
SC 20	0.05625	0.63761	0.80971	11.8608
SC 21	0.0475	0.7485	-	8.75154
SC 22	0.258	-	-	6.45211
SC 23	0.45642	-	-	3.42622
SC 24	0.09035	-	-	12.012
SC 25	0.16177	0.44027	0.83571	6.33577
SC 26	0.07874	-	-	5.52132
SC 27	0.05226	0.50942	-	10.8632
SC 28	0.07586	-	-	4.77512
SC 29	0.44206	-	-	7.24381

Spermatocyte 3

	CO 1	CO 2	CO 3	SC Length
SC 1	0.49082	-	-	5.3249
SC 2	0.05996	-	-	5.5181
SC 3	0.12543	0.73659	-	7.53746
SC 4	0.1614	-	-	7.96369
SC 5	0.25857	-	-	5.88091
SC 6	0.36357	-	-	3.2858
SC 7	0.29324	-	-	5.47701
SC 8	0.49728	-	-	5.18938
SC 9	0.10863	0.76126	-	11.3208
SC 10	0.26634	-	-	6.86196
SC 11	0.11417	0.63184	-	12.0205
SC 12	0.3978	-	-	13.1369
SC 13	0.29471	-	-	4.98799
SC 14	0.05213	0.81343	-	9.03315
SC 15	0.08919	0.23726	0.76067	10.3883
SC 16	0.29938	-	-	11.9985
SC 17	0.29606	-	-	9.69423
SC 18	0.05062	0.85475	-	9.85453
SC 19	0.18463	0.35765	-	11.0844
SC 20	0.39946	-	-	9.20878
SC 21	0.14988	0.53621	-	10.8276
SC 22	0.11218	-	-	7.89229
SC 23	0.17263	0.84196	-	8.90582
SC 24	0.24729	0.86557	-	13.8699
SC 25	0.09139	-	-	12.5602
SC 26	0.13765	0.42442	0.47632	17.271
SC 27	0.12877	0.66459	-	7.0364
SC 28	0.46145	-	-	4.24676
SC 29	0.46014	-	-	4.1321

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.15607	0.81891	-	6.56341
SC 2	0.22365	-	-	7.06132
SC 3	0.07112	0.59789	-	9.09118
SC 4	0.40456	-	-	7.05992
SC 5	0.15437	0.6603	-	13.2986
SC 6	0.17858	0.68055	-	9.01481
SC 7	0.09976	0.6711	-	9.36418
SC 8	0.14727	-	-	7.87843
SC 9	0.07685	0.42035	-	9.96898
SC 10	0.04308	0.91146	-	15.3628
SC 11	0.16003	0.92671	-	10.4008
SC 12	0.03036	0.51704	-	9.17987
SC 13	0.4029	-	-	4.93157
SC 14	0.36875	0.50042	-	10.6495
SC 15	0.07828	0.82242	-	13.1699
SC 16	0.03248	0.8746	-	17.2031
SC 17	0.04119	0.71676	-	14.3663
SC 18	0.24834	0.52284	-	12.8557
SC 19	0.15012	0.82733	-	10.5211
SC 20	0.03154	0.6138	-	16.06
SC 21	0.07275	0.77609	-	10.144
SC 22	0.21287	-	-	10.0078
SC 23	0.18938	0.7716	-	14.8996
SC 24	0.05604	0.3001	0.80249	19.9868
SC 25	0.06764	0.79455	0.85084	15.1255
SC 26	0.25481	0.73237	-	13.1102
SC 27	0.06203	0.57677	-	17.1261
SC 28	0.33105	-	-	6.52876
SC 29	0.42247	-	-	8.18013

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.12575	-	-	5.69793
SC 2	0.4923	-	-	5.15438
SC 3	0.13335	-	-	5.52398
SC 4	0.18766	0.81667	-	8.34897
SC 5	0.40373	-	-	9.49158
SC 6	0.47177	-	-	6.69109
SC 7	0.14827	0.62811	0.74223	12.7452
SC 8	0.16943	0.6905	-	11.1644
SC 9	0.11289	0.62307	-	4.34042
SC 10	0.17149	0.64466	-	8.04468
SC 11	0.09925	0.93892	-	12.3229
SC 12	0.22924	-	-	4.79535
SC 13	0.38295	-	-	8.37669
SC 14	0.18236	-	-	3.51687
SC 15	0.26813	0.78736	-	5.77248
SC 16	0.11027	0.35141	0.91865	9.45161
SC 17	0.10893	0.22968	0.77057	10.7251
SC 18	0.18115	0.41446	-	7.45192
SC 19	0.09853	0.51002	-	7.4396
SC 20	0.12645	0.29906	0.79033	8.9677
SC 21	0.05898	0.52118	0.77648	17.6281
SC 22	0.12228	0.73083	-	13.8424
SC 23	0.46664	-	-	9.88806
SC 24	0.19198	-	-	4.57807
SC 25	0.26266	0.85355	-	11.1575
SC 26	0.35847	0.28033	0.50144	4.74999
SC 27	0.16082	-	-	10.7273
SC 28	0.46723	-	-	10.8038
SC 29	0.0511	-	-	14.2618

Spermatocyte 6

	CO 1	CO 2	CO 3	SC Length
SC 1	0.35532	-	-	8.13939
SC 2	0.11053	0.82381	-	15.7967
SC 3	0.26533	-	-	6.77747
SC 4	0.38942	-	-	8.19063
SC 5	0.09126	0.76731	-	17.102
SC 6	0.26328	-	-	4.68846
SC 7	0.09378	0.88418	-	10.0423
SC 8	0.17297	0.28225	-	9.87511
SC 9	0.36385	-	-	6.53135
SC 10	0.08863	0.67815	-	15.7056
SC 11	0.15932	0.49968	-	11.2694
SC 12	0.22081	-	-	4.50121
SC 13	0.08051	0.73956	-	10.434
SC 14	0.0876	0.81978	-	5.76674
SC 15	0.14837	0.4292	0.72683	17.8668
SC 16	0.26848	0.6969	0.91379	12.157
SC 17	0.46186	-	-	10.6553
SC 18	0.13994	0.69556	0.78579	7.88347
SC 19	0.09759	0.77723	0.86061	12.1147
SC 20	0.16469	0.73955	-	9.65636
SC 21	0.31055	-	-	13.1134
SC 22	0.07647	0.95411	-	10.9971
SC 23	0.14372	-	-	14.9852
SC 24	0.30243	-	-	6.72175
SC 25	0.29451	-	-	10.3381
SC 26	0.02761	0.24507	0.49092	13.9243
SC 27	0.03568	0.72904	-	13.6594
SC 28	0.20878	-	-	8.59033
SC 29	0.4855	-	-	11.0398

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.20078	-	-	6.2601
SC 2	0.10686	0.79007	-	7.78834
SC 3	0.43656	-	-	7.83846
SC 4	0.14731	-	-	7.8736
SC 5	0.18315	0.78775	-	10.6778
SC 6	0.37176	0.53616	-	10.1443
SC 7	0.26771	-	-	12.648
SC 8	0.44542	-	-	4.02269
SC 9	0.14809	0.75374	-	16.6551
SC 10	0.2925	0.53313	0.75799	9.01355
SC 11	0.1035	0.73779	-	13.0169
SC 12	0.11423	0.33168	0.73472	17.4979
SC 13	0.05257	0.78254	-	13.3155
SC 14	0.14355	-	-	8.03369
SC 15	0.19087	0.64358	-	15.269
SC 16	0.16668	0.86395	-	13.0925
SC 17	0.19051	0.76487	0.81922	12.1035
SC 18	0.15083	0.73327	0.86739	9.30825
SC 19	0.22811	0.51565	-	10.1649
SC 20	0.06138	0.91869	-	18.3374
SC 21	0.16758	0.69961	-	19.1494
SC 22	0.22427	0.65555	-	10.2675
SC 23	0.24239	0.71586	-	13.7819
SC 24	0.33021	0.71246	-	21.677
SC 25	0.14867	0.41068	0.81616	12.7215
SC 26	0.15376	0.43894	-	17.0994
SC 27	0.30302	-	-	9.66294
SC 28	0.4732	-	-	5.87881
SC 29	0.48534	-	-	4.2294

Spermatocyte 8

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.14956	-	-	-	8.26203
SC 2	0.45876	-	-	-	7.48139
SC 3	0.3266	-	-	-	3.00636
SC 4	0.09886	0.48352	0.87794	-	16.9942
SC 5	0.06559	0.70161	-	-	14.9014
SC 6	0.10688	0.71236	-	-	14.026
SC 7	0.09413	0.77983	-	-	17.1277
SC 8	0.43949	0.76301	-	-	5.24349
SC 9	0.07352	0.29011	0.53099	0.69405	21.9498
SC 10	0.12291	0.27225	0.32671	-	16.2339
SC 11	0.41272	-	-	-	10.8964
SC 12	0.14632	0.80475	-	-	11.5919
SC 13	0.09648	0.75977	-	-	17.1542
SC 14	0.21101	-	-	-	10.9764
SC 15	0.05687	0.22016	0.32826	-	18.7818
SC 16	0.08685	0.82615	-	-	12.7283
SC 17	0.1019	0.42608	-	-	13.3337
SC 18	0.06127	0.49241	-	-	16.5549
SC 19	0.03173	0.23999	0.72099	-	19.7754
SC 20	0.15861	0.39076	0.81596	-	36.868
SC 21	0.04162	0.413	-	-	11.7725
SC 22	0.39687	0.727	-	-	6.03393
SC 23	0.05758	0.29579	0.87804	0.92557	13.6772
SC 24	0.16664	-	-	-	11.3098
SC 25	0.12364	0.63716	-	-	12.4058
SC 26	0.19854	-	-	-	6.65035
SC 27	0.41096	-	-	-	8.86249
SC 28	0.39442	-	-	-	13.408
SC 29	0.12824	-	-	-	2.94651

Spermatocyte 9

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.09373	0.80978	-	-	6.69403
SC 2	0.18283	0.4917	0.5411	-	9.8672
SC 3	0.25013	0.60045	0.68196	-	16.0026
SC 4	0.13393	0.36338	0.4453	0.83506	15.118
SC 5	0.0904	0.61412	-	-	5.24839
SC 6	0.40804	-	-	-	5.18504
SC 7	0.31843	-	-	-	10.4329
SC 8	0.16505	0.71437	-	-	6.85433
SC 9	0.03615	0.69512	0.774	-	13.5211
SC 10	0.34607	-	-	-	10.4274
SC 11	0.0514	0.93605	-	-	15.6993
SC 12	0.08888	0.53749	0.80788	0.97438	21.9598
SC 13	0.09596	0.39382	0.89847	-	13.7376
SC 14	0.04583	0.53356	0.89789	-	17.1631
SC 15	0.34328	-	-	-	11.7785
SC 16	0.45037	-	-	-	11.3144
SC 17	0.24103	-	-	-	11.7387
SC 18	0.40645	-	-	-	7.35532
SC 19	0.20942	-	-	-	4.0803
SC 20	0.13529	-	-	-	7.60984
SC 21	0.02562	0.35691	-	-	28.0662
SC 22	0.38531	-	-	-	8.16746
SC 23	0.41972	-	-	-	7.17906
SC 24	0.2734	-	-	-	5.37544
SC 25	0.37587	-	-	-	6.42768
SC 26	0.44645	-	-	-	4.66501
SC 27	0.38006	-	-	-	5.51432
SC 28	0.37527	-	-	-	8.64178
SC 29	0.10621	0.39316	0.49578	0.73888	25.2848

Spermatocyte 10

	CO 1	CO 2	CO 3	CO 4	CO 5	SC Length
SC 1	0.13771	-	-	-	-	6.93728
SC 2	0.06569	-	-	-	-	8.44074
SC 3	0.35147	-	-	-	-	8.13288
SC 4	0.25052	0.66799	-	-	-	11.6386
SC 5	0.44433	-	-	-	-	5.69758
SC 6	0.13214	0.74296	-	-	-	10.5039
SC 7	0.25362	-	-	-	-	7.903
SC 8	0.1782	-	-	-	-	7.34741
SC 9	0.25163	0.64741	-	-	-	9.9372
SC 10	0.06351	0.93425	-	-	-	11.4009
SC 11	0.37908	-	-	-	-	6.30917
SC 12	0.39868	-	-	-	-	8.29283
SC 13	0.40285	-	-	-	-	3.98034
SC 14	0.46746	-	-	-	-	9.67813
SC 15	0.1648	0.40375	-	-	-	16.9394
SC 16	0.17573	0.55304	-	-	-	9.82975
SC 17	0.08548	0.75166	-	-	-	9.64131
SC 18	0.16265	0.76496	-	-	-	13.8711
SC 19	0.12516	0.71592	-	-	-	15.9515
SC 20	0.14102	-	-	-	-	5.88427
SC 21	0.25617	-	-	-	-	6.41123
SC 22	0.03289	0.42445	0.55002	0.71346	0.96497	24.2566
SC 23	0.08399	0.25939	0.62929	-	-	24.9619
SC 24	0.32518	-	-	-	-	17.7946
SC 25	0.13761	0.25924	0.39073	-	-	13.2607
SC 26	0.2461	0.32145	-	-	-	13.8508
SC 27	0.11427	0.47458	-	-	-	11.7011
SC 28	0.11027	0.80877	-	-	-	15.0979
SC 29	0.34787	0.42156	0.90959	-	-	16.9413

Gelbvieh

Spermatocyte 1

	CO 1	CO 2	CO 3	SC Length
SC 1	0.412	-	-	7.63532
SC 2	0.214	0.626	-	11.8717
SC 3	0.221	-	-	10.3957
SC 4	0.248	-	-	8.96385
SC 5	0.098	0.666	-	9.70137
SC 6	0.283	-	-	6.72847
SC 7	0.203	0.478	0.693	14.0715
SC 8	0.095	0.553	0.915	15.7091
SC 9	0.253	-	-	10.1463
SC 10	0.242	-	-	7.18571
SC 11	0.152	0.649	-	14.3105
SC 12	0.11	0.708	-	15.209
SC 13	0.372	-	-	10.9105
SC 14	0.296	0.946	-	13.1013
SC 15	0.11	0.592	0.843	19.0667
SC 16	0.123	0.812	-	14.4626
SC 17	0.242	0.943	-	8.85885
SC 18	0.351	-	-	12.1221
SC 19	0.303	-	-	15.2888
SC 20	0.267	-	-	6.75787
SC 21	0.061	0.41	0.91	18.5693
SC 22	0.185	0.413	-	12.6818
SC 23	0.271	0.768	-	10.6199
SC 24	0.195	0.709	-	11.6309
SC 25	0.433	-	-	13.8425
SC 26	0.343	-	-	8.83064
SC 27	0.175	-		8.84282
SC 28	0.194	-	-	9.87189
SC 29	0.125	0.421	-	8.69904

Spermatocyte 2

	CO 1	CO 2	CO 3	SC Length
SC 1	0.447	-	-	7.32375
SC 2	0.461	-	-	7.06111
SC 3	0.441	-	-	6.26493
SC 4	0.341	-	-	7.6888
SC 5	0.136	0.572	-	9.37006
SC 6	0.144	0.691	0.91	11.051
SC 7	0.121	0.768	-	15.2928
SC 8	0.521	-	-	7.41461
SC 9	0.51	-	-	11.2808
SC 10	0.317	-	-	7.20524
SC 11	0.29	-	-	7.18235
SC 12	0.156	0.635	-	8.57752
SC 13	0.151	0.467	0.77	15.0613
SC 14	0.207	0.684	-	15.1197
SC 15	0.088	0.766	-	17.4169
SC 16	0.459	-	-	8.89728
SC 17	0.199	0.762	-	11.611
SC 18	0.209	0.65	-	12.9546
SC 19	0.511	-	-	11.7098
SC 20	0.317	0.544	-	16.158
SC 21	0.206	0.498	-	12.4816
SC 22	0.108	0.731	-	16.5416
SC 23	0.363	-	-	13.7323
SC 24	0.22	-	-	10.6094
SC 25	0.111	0.417	0.602	21.8314
SC 26	0.267	-	-	18.7792
SC 27	0.484	-	-	6.24351
SC 28	0.19	-	-	6.69158
SC 29	0.401	-	-	7.79114

Spermatocyte 3

	CO 1	CO 2	CO 3	SC Length
SC 1	0.411	-	-	7.64792
SC 2	0.32	-	-	9.55276
SC 3	0.276	-	-	9.17203
SC 4	0.165	-	-	11.6092
SC 5	0.427	-	-	8.50703
SC 6	0.085	0.443	-	11.5826
SC 7	0.101	0.616	-	23.949
SC 8	0.095	0.382	0.798	31.0092
SC 9	0.396	-	-	16.1505
SC 10	0.152	0.807	-	21.4299
SC 11	0.021	0.653	-	25.1282
SC 12	0.467	-	-	8.13995
SC 13	0.355	0.691	-	14.841
SC 14	0.286	0.674	-	14.0021
SC 15	0.126	0.534	-	11.2334
SC 16	0.258	0.711	-	8.54861
SC 17	0.431	-	-	14.067
SC 18	0.098	0.401	-	22.2317
SC 19	0.232	0.663	-	16.6288
SC 20	0.143	0.946	-	29.5348
SC 21	0.045	0.364	0.935	34.6767
SC 22	0.15	0.369	0.614	33.092
SC 23	0.076	0.713	-	21.4324
SC 24	0.417	-	-	19.803
SC 25	0.335	-	-	10.7248
SC 26	0.091	-	-	24.0981
SC 27	0.406	-	-	14.5769
SC 28	0.419	-	-	12.4076
SC 29	0.249	0.771	-	15.5797

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.167	-	-	5.64368
SC 2	0.21	0.662	-	8.73754
SC 3	0.406	-	-	6.11828
SC 4	0.083	0.907	-	8.91387
SC 5	0.147	0.723	-	10.8723
SC 6	0.229	-	-	8.77009
SC 7	0.468	-	-	7.04774
SC 8	0.18	0.407	0.64	12.0791
SC 9	0.249	0.439	0.787	17.5258
SC 10	0.486	-	-	5.2745
SC 11	0.15	0.744	-	9.3968
SC 12	0.099	-	-	12.1076
SC 13	0.183	0.634	-	7.39333
SC 14	0.363	-	-	6.35481
SC 15	0.188	0.5	0.608	15.6726
SC 16	0.266	0.91	-	9.25505
SC 17	0.337	-	-	10.7967
SC 18	0.257	-	-	9.4108
SC 19	0.139	0.764	-	11.5119
SC 20	0.272	-	-	7.96635
SC 21	0.137	-	-	5.95819
SC 22	0.279	-	-	9.42753
SC 23	0.238	-	-	9.74085
SC 24	0.156	0.411	-	11.9733
SC 25	0.237	-	-	9.37125
SC 26	0.263	0.656	-	13.5066
SC 27	0.065	0.61	0.822	17.8301
SC 28	0.16	0.679	-	12.1574
SC 29	0.473	-	-	11.2843

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.279	0.735	-	8.55456
SC 2	0.117	-	-	5.6917
SC 3	0.18	0.616	-	6.25849
SC 4	0.207	0.703	-	9.38308
SC 5	0.24	0.633	-	8.2852
SC 6	0.159	0.584	0.827	11.1267
SC 7	0.39	-	-	5.9199
SC 8	0.248	-	-	6.62277
SC 9	0.166	0.657	-	7.48048
SC 10	0.085	0.602	-	10.8907
SC 11	0.089	0.859	-	11.9796
SC 12	0.233	0.73	-	11.1908
SC 13	0.235	-	-	6.01258
SC 14	0.094	0.886	-	10.796
SC 15	0.043	0.156	0.659	17.7222
SC 16	0.232	0.54	-	9.60974
SC 17	0.216	0.671	-	7.15722
SC 18	0.301	0.545	-	10.0593
SC 19	0.099	0.535	0.849	13.7826
SC 20	0.132	0.383	0.855	13.7189
SC 21	0.209	0.429	0.787	9.78166
SC 22	0.106	0.61	0.926	17.5214
SC 23	0.057	0.722	-	13.8159
SC 24	0.516	-	-	8.59579
SC 25	0.155	0.407	0.831	14.0957
SC 26	0.25	-	-	9.72342
SC 27	0.095	0.68	-	15.9879
SC 28	0.103	-	-	6.74975
SC 29	0.1	0.577	-	16.5436

Spermatocyte 6

	CO 1	CO 2	CO 3	SC Length
SC 1	0.172	0.476	0.667	14.224
SC 2	0.267	0.838	-	5.83891
SC 3	0.183	0.886	-	11.6087
SC 4	0.162	-	-	9.87189
SC 5	0.281	0.728	-	7.29274
SC 6	0.212	0.613	-	11.9374
SC 7	0.18	-	-	6.64174
SC 8	0.087	0.759	-	9.51643
SC 9	0.362	-	-	8.62099
SC 10	0.618	-	-	5.74434
SC 11	0.232	0.769	-	8.66649
SC 12	0.089	0.402	-	10.5965
SC 13	0.567	-	-	7.93303
SC 14	0.188	0.69	-	8.85563
SC 15	0.187	0.606	-	12.7588
SC 16	0.128	0.633	-	11.331
SC 17	0.218	-	-	9.99068
SC 18	0.425	-	-	5.64655
SC 19	0.204	0.634	-	12.518
SC 20	0.188	0.577	-	12.8895
SC 21	0.098	0.802	-	14.373
SC 22	0.129	0.597	-	9.07914
SC 23	0.151	-	-	9.24105
SC 24	0.152	-	-	7.4102
SC 25	0.527	-	-	6.90018
SC 26	0.299	-	-	5.64389
SC 27	0.153	0.636	-	20.3327
SC 28	0.108	-	-	12.2027
SC 29	0.157	0.466	-	14.3617

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.145	-	-	9.71943
SC 2	0.296	-	-	10.1995
SC 3	0.452	-	-	11.583
SC 4	0.268	-	-	9.69024
SC 5	0.375	-	-	11.4481
SC 6	0.335	-	-	10.1987
SC 7	0.356	-	-	9.20514
SC 8	0.48	-	-	14.0053
SC 9	0.115	0.721	-	17.1608
SC 10	0.389	-	-	11.994
SC 11	0.184	0.679	-	14.5323
SC 12	0.126	0.808	-	13.8011
SC 13	0.043	0.872	-	25.2774
SC 14	0.15	0.906	-	20.8346
SC 15	0.462	-	-	17.2962
SC 16	0.386	-	-	9.11442
SC 17	0.392	-	-	9.26352
SC 18	0.065	0.868	-	24.2119
SC 19	0.096	0.538	0.784	22.5126
SC 20	0.143	0.491	-	30.5386
SC 21	0.377	-	-	12.466
SC 22	0.525	-	-	17.1293
SC 23	0.103	-	-	16.9266
SC 24	0.135	-	-	15.2999
SC 25	0.076	-	-	15.4055
SC 26	0.108	0.662	0.87	29.3396
SC 27	0.101	0.553	-	23.9411
SC 28	0.192	0.854	-	25.8067
SC 29	0.19	0.87	-	14.951

Spermatocyte 8

	CO 1	CO 2	SC Length
SC 1	0.074	0.723	10.989
SC 2	0.442	-	10.0997
SC 3	0.168	-	7.56336
SC 4	0.431	-	8.31936
SC 5	0.164	0.818	13.6326
SC 6	0.113	0.364	12.6579
SC 7	0.443	-	7.30625
SC 8	0.177	0.746	18.5897
SC 9	0.142	0.686	12.2049
SC 10	0.162	0.725	12.1275
SC 11	0.082	0.766	16.8182
SC 12	0.264	-	12.5845
SC 13	0.075	0.767	19.2862
SC 14	0.139	0.82	23.4403
SC 15	0.155	0.541	19.0915
SC 16	0.299	-	11.759
SC 17	0.408	-	14.3628
SC 18	0.231	0.614	22.5433
SC 19	0.3	-	6.42019
SC 20	0.156	0.451	14.2467
SC 21	0.118	0.416	19.7121
SC 22	0.094	0.841	21.1745
SC 23	0.034	0.425	29.5981
SC 24	0.207	-	8.87474
SC 25	0.088	0.673	20.4522
SC 26	0.05	0.606	16.9648
SC 27	0.221	0.905	21.1501
SC 28	0.446	-	6.61927
SC 29	0.518	-	6.08874

Spermatocyte 9

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.209	0.733	-	-	10.6202
SC 2	0.064	0.33	0.648	0.962	22.1267
SC 3	0.159	0.603	0.889	-	33.1097
SC 4	0.526	-	-	-	4.88369
SC 5	0.122	0.601	-	-	13.228
SC 6	0.169	-	-	-	17.3844
SC 7	0.1	0.905	-	-	20.3383
SC 8	0.23	0.76	-	-	20.3867
SC 9	0.226	0.901	-	-	23.6589
SC 10	0.15	0.404	0.791	-	35.6483
SC 11	0.166	-	-	-	20.1612
SC 12	0.188	0.543	-	-	22.0471
SC 13	0.286	-	-	-	9.99236
SC 14	0.218	0.685	-	-	12.3257
SC 15	0.077	0.305	0.523	-	32.7826
SC 16	0.202	0.649	-	-	15.7812
SC 17	0.228	0.474	-	-	15.3751
SC 18	0.077	-	-	-	29.5303
SC 19	0.214	0.452	0.71	-	21.1891
SC 20	0.365	0.814	-	-	24.7908
SC 21	0.094	0.589	-	-	13.7324
SC 22	0.247	0.613	0.838	-	24.4199
SC 23	0.302	0.798	0.951	-	14.9514
SC 24	0.357	-	-	-	12.8652
SC 25	0.268	-	-	-	8.51613
SC 26	0.28	-	-	-	10.0962
SC 27	0.355	-	-	-	18.343
SC 28	0.217	-	-	-	8.95013
SC 29	0.489	-	-	-	14.3116

Spermatocyte 10

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.108	0.805	-	-	10.1825
SC 2	0.394	-	-	-	10.1134
SC 3	0.267	0.8	-	-	9.99292
SC 4	0.423	-	-	-	7.27363
SC 5	0.243	-	-	-	13.234
SC 6	0.49	-	-	-	14.1534
SC 7	0.141	-	-	-	13.1006
SC 8	0.263	0.834	-	-	11.378
SC 9	0.186	0.865	-	-	9.57019
SC 10	0.22	-	-	-	7.20328
SC 11	0.426	-	-	-	8.673
SC 12	0.24	-	-	-	11.718
SC 13	0.048	0.428	-	-	17.0342
SC 14	0.531	-	-	-	6.0151
SC 15	0.102	0.586	-	-	13.7598
SC 16	0.055	0.681	-	-	17.7973
SC 17	0.353	-	-	-	11.3821
SC 18	0.136	-	-	-	7.79009
SC 19	0.336	-	-	-	18.9955
SC 20	0.154	-	-	-	18.2853
SC 21	0.414	-	-	-	12.6588
SC 22	0.131	0.318	0.64	0.836	28.2246
SC 23	0.502	-	-	-	6.71594
SC 24	0.063	0.704	-	-	18.7933
SC 25	0.317	-	-	-	11.2983
SC 26	0.492	-	-	-	12.1677
SC 27	0.601	-	-	-	12.6179
SC 28	0.209	-	-	-	11.0582
SC 29	0.22	-	-	-	12.0353

Lowline

Spermatocyte 1

	CO 1	CO 2	SC Length
SC 1	0.252	-	8.061
SC 2	0.195	0.747	14.02
SC 3	0.203	-	7.317
SC 4	0.474	-	7.008
SC 5	0.235	-	9.891
SC 6	0.123	0.878	12.33
SC 7	0.164	0.424	15.08
SC 8	0.203	-	6.613
SC 9	0.476	-	10.3
SC 10	0.473	-	9.996
SC 11	0.401	-	9.654
SC 12	0.371	-	8.385
SC 13	0.415	-	14.81
SC 14	0.29	0.551	8.383
SC 15	0.085	0.816	14.84
SC 16	0.07	0.703	18.36
SC 17	0.255	0.937	22.18
SC 18	0.175	-	14.22
SC 19	0.116	0.704	16.92
SC 20	0.079	-	11.4
SC 21	0.213	-	12.62
SC 22	0.112	0.812	16.31
SC 23	0.09	0.747	18.44
SC 24	0.543	-	9.579
SC 25	0.155	0.618	17.94
SC 26	0.62	-	17.41
SC 27	0.562	-	10.36
SC 28	0.136	0.519	23.02
SC 29	0.229	0.723	20.66

Spermatocyte 2

	CO 1	CO 2	CO 3	SC Length
SC 1	0.334	-	-	7.693
SC 2	0.224	0.786	-	9.75058
SC 3	0.37	-	-	7.26607
SC 4	0.073	0.667	-	11.9887
SC 5	0.219	0.789	-	13.2628
SC 6	0.288	0.605	-	8.2439
SC 7	0.072	0.828	-	13.7913
SC 8	0.16	0.577	-	14.4556
SC 9	0.147	0.847	-	11.6143
SC 10	0.126	0.564	0.822	15.5828
SC 11	0.385	-	-	7.38766
SC 12	0.165	0.573	-	9.99005
SC 13	0.215	-	-	5.887
SC 14	0.416	-	-	11.4994
SC 15	0.261	0.85	-	11.0611
SC 16	0.121	0.789	-	17.1372
SC 17	0.092	0.65	-	16.0596
SC 18	0.175	-	-	6.88772
SC 19	0.422	-	-	7.6727
SC 20	0.335	0.83	-	10.8957
SC 21	0.153	0.459	-	14.3014
SC 22	0.144	0.672	-	10.3307
SC 23	0.464	-	-	6.92062
SC 24	0.181	0.744	-	13.3303
SC 25	0.313	0.736	-	10.946
SC 26	0.495	-	-	9.58384
SC 27	0.354	-	-	6.94519
SC 28	0.131	0.693	-	10.3389
SC 29	0.118	0.395	0.833	17.2273

Spermatocyte 3

	CO 1	CO 2	CO 3	SC Length
SC 1	0.094	0.614	-	9.61611
SC 2	0.283	-	-	10.513
SC 3	0.208	0.655	-	11.4066
SC 4	0.425	-	-	7.47649
SC 5	0.123	0.551	-	10.1044
SC 6	0.47	-	-	6.70264
SC 7	0.213	0.5	0.685	11.5037
SC 8	0.498	-	-	5.80748
SC 9	0.148	0.655	-	11.1539
SC 10	0.358	-	-	9.15397
SC 11	0.242	-	-	7.63791
SC 12	0.412	-	-	6.02105
SC 13	0.489	-	-	6.36468
SC 14	0.257	0.679	-	15.3507
SC 15	0.122	0.449	0.812	15.5549
SC 16	0.119	0.501	0.846	15.5686
SC 17	0.166	0.766	-	9.94406
SC 18	0.411	-	-	6.37455
SC 19	0.386	-	-	10.3112
SC 20	0.242	-	-	7.80136
SC 21	0.124	0.653	-	13.3083
SC 22	0.136	0.615	-	10.4155
SC 23	0.199	0.761	-	10.0253
SC 24	0.212	0.448	0.757	14
SC 25	0.098	0.89	-	17.9963
SC 26	0.137	0.788	-	12.3191
SC 27	0.076	0.523	-	10.6742
SC 28	0.113	0.813	-	13.8117
SC 29	0.273	0.687	-	12.2964

Spermatocyte 4

	CO 1	CO 2	SC Length
SC 1	0.373	-	7.71057
SC 2	0.085	0.555	12.7628
SC 3	0.422	-	10.3083
SC 4	0.128	0.865	10.8952
SC 5	0.19	0.653	14.6635
SC 6	0.103	0.704	10.1256
SC 7	0.416	0.723	13.7507
SC 8	0.183	0.65	12.5245
SC 9	0.114	0.66	13.6417
SC 10	0.431	-	10.2176
SC 11	0.17	-	6.62851
SC 12	0.271	-	9.6915
SC 13	0.219	0.782	11.6667
SC 14	0.381	-	11.4451
SC 15	0.099	0.765	7.05719
SC 16	0.144	0.643	12.6727
SC 17	0.12	-	7.19943
SC 18	0.535	-	8.80551
SC 19	0.435	-	8.51123
SC 20	0.302	-	7.83902
SC 21	0.367	0.875	13.5081
SC 22	0.199	0.766	21.5808
SC 23	0.129	0.748	14.6173
SC 24	0.465	-	14.5877
SC 25	0.237	-	10.1506
SC 26	0.287	0.804	13.4544
SC 27	0.542	-	11.2572
SC 28	0.374	-	15.2674
SC 29	0.174	0.86	20.1501

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.244	-	-	7.27944
SC 2	0.196	0.568	-	10.1655
SC 3	0.177	0.587	-	13.1919
SC 4	0.474	-	-	6.0879
SC 5	0.164	0.866	-	8.03754
SC 6	0.279	-	-	13.6106
SC 7	0.369	-	-	10.4873
SC 8	0.283	0.605	-	14.6077
SC 9	0.04	0.452	0.788	18.2106
SC 10	0.161	0.667	-	12.4621
SC 11	0.666	-	-	8.7325
SC 12	0.252	-	-	7.80234
SC 13	0.119	0.782	-	12.5332
SC 14	0.576	-	-	7.7896
SC 15	0.481	-	-	9.80042
SC 16	0.219	-	-	9.08544
SC 17	0.481	-	-	11.2266
SC 18	0.245	0.634	-	9.54723
SC 19	0.151	0.587	-	13.2731
SC 20	0.207	0.757	-	11.7606
SC 21	0.371	0.645	-	12.7402
SC 22	0.128	0.865	-	15.8972
SC 23	0.188	-	-	9.94707
SC 24	0.236	0.631	-	13.3723
SC 25	0.118	0.765	-	11.1293
SC 26	0.149	0.792	-	12.2335
SC 27	0.147	-	-	6.57363
SC 28	0.213	0.562	-	13.8121
SC 29	0.337	-	-	7.30331

Spermatocyte 6

	CO 1	CO 2	CO 3	SC Length
SC 1	0.377	0.602	-	9.04113
SC 2	0.418	-	-	6.23497
SC 3	0.262	-	-	7.34825
SC 4	0.112	0.763	-	9.89681
SC 5	0.212	0.652	-	9.33569
SC 6	0.505	-	-	8.23844
SC 7	0.159	0.439	0.826	13.0866
SC 8	0.416	0.636	-	9.36411
SC 9	0.598	-	-	6.10764
SC 10	0.251	0.765	-	8.624
SC 11	0.132	0.597	-	9.96611
SC 12	0.324	0.624	-	9.35858
SC 13	0.432	-	-	6.7928
SC 14	0.157	0.751	-	13.5031

SC 15	0.316	-	-	6.85363
SC 16	0.439	-	-	11.8428
SC 17	0.746	-	-	7.2884
SC 18	0.056	0.627	-	12.5506
SC 19	0.378	-	-	5.29228
SC 20	0.726	-	-	10.2479
SC 21	0.213	0.451	0.886	14.2024
SC 22	0.293	0.649	-	14.3181
SC 23	0.437	0.897	-	13.6774
SC 24	0.238	0.699	-	16.5461
SC 25	0.251	0.796	-	16.394
SC 26	0.214	0.85	-	11.4149
SC 27	0.083	0.425	-	22.557
SC 28	0.292	0.57	-	13.3926
SC 29	0.265	0.537	-	12.8765

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.177	-	-	6.98607
SC 2	0.184	-	-	10.6393
SC 3	0.178	0.794	-	11.9653
SC 4	0.178	-	-	8.9285
SC 5	0.284	-	-	13.3986
SC 6	0.336	-	-	6.60933
SC 7	0.366	-	-	9.11134
SC 8	0.246	-	-	8.36857
SC 9	0.312	0.692	-	10.4927
SC 10	0.121	-	-	9.42956
SC 11	0.192	0.731	-	13.6438
SC 12	0.293	-	-	8.30473
SC 13	0.122	0.659	-	15.248
SC 14	0.109	0.508	-	12.8262
SC 15	0.075	0.382	0.747	18.9746
SC 16	0.093	0.875	-	22.923
SC 17	0.077	0.727	0.922	16.1445
SC 18	0.252	0.607	-	14.6822
SC 19	0.155	0.489	-	16.7561
SC 20	0.089	0.597	-	11.678
SC 21	0.184	0.614	-	20.1265
SC 22	0.049	0.679	-	20.9701
SC 23	0.085	0.41	0.829	28.9531
SC 24	0.459	-	-	12.3953
SC 25	0.171	0.517	-	17.2969
SC 26	0.516	-	-	12.6055
SC 27	0.319	-	-	11.7677
SC 28	0.314	-	-	7.56651
SC 29	0.095	-	-	8.48897

Spermatocyte 8

	CO 1	CO 2	CO 3	SC Length
SC 1	0.432	-	-	5.70591
SC 2	0.149	0.659	0.832	15.2851
SC 3	0.211	0.61	-	9.30909
SC 4	0.16	0.767	-	9.75023
SC 5	0.132	0.565	-	10.7295
SC 6	0.467	-	-	9.36852
SC 7	0.234	-	-	8.72424
SC 8	0.109	0.759	-	13.6867
SC 9	0.296	0.541	-	8.96189
SC 10	0.322	0.714	-	16.9278
SC 11	0.282	0.542	-	11.3756
SC 12	0.563	-	-	6.78762
SC 13	0.185	0.881	-	15.3747
SC 14	0.171	0.674	-	10.8694
SC 15	0.104	0.385	0.737	17.519
SC 16	0.167	0.873	-	7.43281
SC 17	0.348	-	-	8.36654
SC 18	0.114	0.531	-	12.6237
SC 19	0.099	0.816	-	19.6225
SC 20	0.372	0.589	-	14.747
SC 21	0.446	-	-	6.23525
SC 22	0.074	0.416	-	12.6558
SC 23	0.104	0.808	-	7.19208
SC 24	0.312	0.705	-	13.9476
SC 25	0.257	0.734	-	9.08285
SC 26	0.395	-	-	6.76592
SC 27	0.166	0.575	-	16.2314
SC 28	0.44	-	-	9.73532
SC 29	0.092	0.631	0.852	18.0585

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.127	0.586	-	12.1656
SC 2	0.376	-	-	6.38855
SC 3	0.411	-	-	5.817
SC 4	0.34	-	-	5.96554
SC 5	0.148	0.864	-	8.84107
SC 6	0.296	-	-	7.10801
SC 7	0.141	0.689	-	9.50586
SC 8	0.365	-	-	7.58079
SC 9	0.173	0.564	-	9.42935
SC 10	0.285	-	-	6.47346
SC 11	0.225	0.885	-	14.328
SC 12	0.282	-	-	6.87456
SC 13	0.202	0.463	-	10.7332
SC 14	0.364	-	-	9.64481
SC 15	0.269	0.783	-	10.6528
SC 16	0.301	0.787	-	12.7813
SC 17	0.13	0.791	-	10.0389
SC 18	0.192	0.666	-	12.6111
SC 19	0.067	0.457	0.744	16.6636
SC 20	0.604	-	-	12.4026
SC 21	0.312	0.883	-	13.1864
SC 22	0.322	0.541	-	14.9636
SC 23	0.22	0.616	-	14.6969
SC 24	0.403	0.864	-	11.7627
SC 25	0.228	-	-	12.8646
SC 26	0.359	-	-	8.78325
SC 27	0.245	0.724	-	9.82919
SC 28	0.382	-	-	4.65745
SC 29	0.229	0.683	-	8.61847

Spermatocyte 10

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.192	-	-	-	7.27559
SC 2	0.228	-	-	-	6.53233
SC 3	0.119	0.671	-	-	13.435
SC 4	0.524	-	-	-	6.96647
SC 5	0.076	0.848	-	-	12.3458
SC 6	0.08	0.795	-	-	11.3241
SC 7	0.217	-	-	-	9.48283
SC 8	0.171	-	-	-	8.78108
SC 9	0.09	0.622	-	-	17.4528
SC 10	0.331	-	-	-	10.7526
SC 11	0.179	0.76	-	-	11.902
SC 12	0.12	0.672	-	-	17.9456
SC 13	0.197	0.635	-	-	16.2037
SC 14	0.119	0.697	-	-	14.7151
SC 15	0.279	0.69	-	-	10.1575
SC 16	0.129	0.867	-	-	8.09592
SC 17	0.319	-	-	-	11.0997
SC 18	0.215	0.871	-	-	13.3076
SC 19	0.581	-	-	-	14.4223
SC 20	0.303	0.682	-	-	13.0082
SC 21	0.535	-	-	-	8.0948
SC 22	0.125	0.273	0.433	0.753	18.7571
SC 23	0.445	-	-	-	14.6537
SC 24	0.42	-	-	-	6.20655
SC 25	0.3	0.494	0.829	-	15.5169
SC 26	0.235	0.803	-	-	8.43073
SC 27	0.289	-	-	-	11.4414
SC 28	0.231	-	-	-	6.58049
SC 29	0.258	-	-	-	15.1262

Angus 1

Spermatocyte 1

	CO 1	CO 2	CO 3	SC Length
SC 1	0.44104	-	-	10.6164
SC 2	0.41054	-	-	5.5209
SC 3	0.32531	-	-	9.17105
SC 4	0.4503	-	-	8.5659
SC 5	0.23631	-	-	15.6873
SC 6	0.46553	-	-	6.92503
SC 7	0.49054	-	-	8.9999
SC 8	0.42865	-	-	8.09739
SC 9	0.2069	-	-	14.7133
SC 10	0.49506	-	-	10.8519
SC 11	0.29485	0.51306	-	9.40548
SC 12	0.15084	0.92907	-	14.9218
SC 13	0.27588	0.80843	-	11.9049
SC 14	0.06595	0.74736	-	8.92829
SC 15	0.24548	0.75973	-	13.7025
SC 16	0.16325	0.83412	-	6.85027
SC 17	0.25176	0.71039	-	16.8486
SC 18	0.31529	0.9246	-	9.72181
SC 19	0.32245	0.88944	-	12.0987
SC 20	0.30459	0.73983	-	10.1917
SC 21	0.14907	0.86056	-	10.0351
SC 22	0.34654	0.90321	-	14.3233
SC 23	0.19804	0.51313	-	19.7621
SC 24	0.34888	0.60623	-	11.9935
SC 25	0.30217	0.61126	0.87611	20.1593
SC 26	0.04715	0.4051	0.89341	15.6689
SC 27	0.26023	-	-	7.01393
SC 28	0.33191	-	-	7.31234
SC 29	0.35809	0.88195	-	7.53557

Spermatocyte 2

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.27719	0.78592	-	-	14.7839
SC 2	0.19376	0.79649	-	-	10.3919
SC 3	0.14597	0.87528	-	-	14.3845
SC 4	0.09627	0.77143	-	-	9.06822
SC 5	0.5503	0.85978	-	-	18.1828
SC 6	0.50497	0.72169	-	-	7.58618
SC 7	0.29081	0.91479	-	-	15.1526
SC 8	0.24172	0.7682	-	-	12.2644
SC 9	0.25746	0.90014	-	-	7.71106
SC 10	0.24095	0.91584	-	-	13.5564
SC 11	0.26424	0.90498	-	-	12.2877
SC 12	0.33003	0.8213	-	-	17.7635
SC 13	0.27831	0.86357	-	-	18.6113
SC 14	0.39358	0.72655	-	-	13.6698
SC 15	0.42071	0.82823	-	-	16.8905
SC 16	0.40973	0.67894	-	-	13.3435
SC 17	0.10021	0.85272	-	-	18.6194
SC 18	0.18424	0.70841	-	-	16.66
SC 19	0.49073	-	-	-	10.2642
SC 20	0.21749	-	-	-	7.80087
SC 21	0.41026	-	-	-	13.3025
SC 22	0.13658	-	-	-	9.70732
SC 23	0.41993	-	-	-	13.4574
SC 24	0.29829	-	-	-	14.808
SC 25	0.53812	0.65667	-	-	17.7146
SC 26	0.18591	0.90834	-	-	13.8916
SC 27	0.42625	-	-	-	10.8984
SC 28	0.06674	0.39206	0.58582	0.83889	35.3883
SC 29	0.35875	-	-	-	9.35788

Spermatocyte 3

	CO 1	CO 2	CO 3	SC Length
SC 1	0.29046	-	-	7.42546
SC 2	0.48436	-	-	10.3982
SC 3	0.20463	-	-	8.84079
SC 4	0.19603	-	-	5.26778
SC 5	0.45183	-	-	7.80297
SC 6	0.31363	-	-	9.00025
SC 7	0.44482	-	-	6.92916
SC 8	0.42895	-	-	7.52353
SC 9	0.21526	-	-	10.2197
SC 10	0.28563	-	-	9.61632
SC 11	0.2485	-	-	6.51875
SC 12	0.1563	-	-	8.44186
SC 13	0.33602	0.86916	-	15.2138
SC 14	0.16332	0.86909	-	13.8229
SC 15	0.59022	0.89899	-	11.7302
SC 16	0.06665	0.44614	-	17.4519
SC 17	0.03448	0.89893	-	16.1641
SC 18	0.12867	0.71664	-	19.3892
SC 19	0.10749	0.69137	-	24.2892
SC 20	0.29752	0.77538	-	7.6489
SC 21	0.07609	0.81781	-	19.435
SC 22	0.38656	0.7756	-	14.2575
SC 23	0.1743	0.83265	-	17.45
SC 24	0.23399	0.53296	-	14.192
SC 25	0.17091	0.74125	-	19.1202
SC 26	0.16873	0.48154	-	15.4637
SC 27	0.07773	0.51554	0.73395	20.1899
SC 28	0.52615	0.63506	-	10.5749
SC 29	0.06729	0.50507	0.94379	18.3796

Spermatocyte 4

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.26491	-	-	-	7.32662
SC 2	0.43516	-	-	-	6.94211
SC 3	0.13132	-	-	-	8.63702
SC 4	0.27296	-	-	-	8.49478
SC 5	0.41604	-	-	-	8.12602
SC 6	0.3493	-	-	-	8.0983
SC 7	0.29413	-	-	-	11.2437
SC 8	0.15624	-	-	-	11.7944
SC 9	0.29712	-	-	-	11.3747
SC 10	0.3735	-	-	-	8.34743
SC 11	0.39119	-	-	-	15.6184
SC 12	0.42056	-	-	-	8.10887
SC 13	0.26027	-	-	-	10.4675
SC 14	0.21556	0.88407	-	-	13.8365
SC 15	0.31568	0.92121	-	-	9.23321
SC 16	0.41778	0.93532	-	-	8.61819
SC 17	0.2256	0.90616	-	-	13.9128
SC 18	0.07554	0.66956	-	-	18.4314
SC 19	0.32037	0.82221	-	-	15.9856
SC 20	0.17822	0.92186	-	-	15.7264
SC 21	0.23236	0.89242	-	-	15.9275
SC 22	0.24811	0.97153	-	-	16.9408
SC 23	0.26547	0.6414	-	-	17.0928
SC 24	0.15881	0.65089	-	-	15.3864
SC 25	0.3016	0.58407	-	-	15.669
SC 26	0.31632	0.81285	-	-	23.5987
SC 27	0.1344	0.72012	-	-	11.5865
SC 28	0.19554	0.30809	0.45839	0.97744	30.1256
SC 29	0.18947	0.54407	-	-	9.5851

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.4906	-	-	7.01792
SC 2	0.2624	-	-	6.10323
SC 3	0.30357	-	-	6.9867
SC 4	0.22739	-	-	9.28193
SC 5	0.4165	-	-	8.1809
SC 6	0.27032	-	-	6.19577
SC 7	0.20688	-	-	10.7401
SC 8	0.43898	-	-	7.48181
SC 9	0.2887	-	-	9.56431
SC 10	0.33863	-	-	5.70423
SC 11	0.48119	-	-	9.99992
SC 12	0.32756	0.90231	-	10.7726
SC 13	0.17462	0.782	-	11.2904
SC 14	0.13036	0.86136	-	12.4302
SC 15	0.2858	0.8338	-	9.40086
SC 16	0.35405	0.77539	-	13.826
SC 17	0.05499	0.90279	-	15.6157
SC 18	0.26579	0.8404	-	13.3303
SC 19	0.52842	0.92379	-	14.1441
SC 20	0.26868	0.86551	-	15.3497
SC 21	0.32203	0.73844	-	16.0587
SC 22	0.08936	0.79815	-	16.4029
SC 23	0.36239	0.49786	0.7342	16.6745
SC 24	0.10538	0.39794	0.79001	15.6769
SC 25	0.14763	0.5347	0.89067	12.9826
SC 26	0.19007	0.45536	0.74591	14.014
SC 27	0.17148	0.75007	0.92768	10.2475
SC 28	0.4632	0.80538	-	10.0035
SC 29	0.18803	-	-	7.03535

Spermatocyte 6

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.35044	-	-	-	10.8315
SC 2	0.46549	-	-	-	9.92453
SC 3	0.49206	-	-	-	7.69482
SC 4	0.37146	-	-	-	7.18277
SC 5	0.43566	-	-	-	10.1399
SC 6	0.45805	-	-	-	10.3844
SC 7	0.39022	-	-	-	7.50253
SC 8	0.47473	-	-	-	13.6312
SC 9	0.29336	-	-	-	8.37361
SC 10	0.25673	-	-	-	7.89285
SC 11	0.26807	0.94123	-	-	11.586
SC 12	0.22837	0.5598	-	-	12.8282
SC 13	0.332	0.75382	-	-	12.0851
SC 14	0.24596	0.6524	-	-	8.27533
SC 15	0.36468	0.74792	-	-	13.4602
SC 16	0.46632	0.85314	-	-	15.5724
SC 17	0.2345	0.87116	-	-	15.5786
SC 18	0.66675	0.85243	-	-	12.8979
SC 19	0.23889	0.92009	-	-	17.6486
SC 20	0.17326	0.87814	-	-	16.2721
SC 21	0.24958	0.48291	0.80088	-	18.4255
SC 22	0.32093	0.70322	0.90513	-	10.8343
SC 23	0.24126	0.50546	0.8584	-	8.30417
SC 24	0.33039	0.72689	0.92122	-	16.7366
SC 25	0.07959	0.48474	0.8923	-	17.897
SC 26	0.31664	-	-	-	4.93059
SC 27	0.22667	0.82737	-	-	17.0854
SC 28	0.25249	0.69746	0.92235	-	23.2155
SC 29	0.21475	0.5072	0.64545	2.03203	30.8629

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.2685	-	-	6.47395
SC 2	0.41268	-	-	8.53069
SC 3	0.2456	-	-	9.27297
SC 4	0.367	-	-	7.23842
SC 5	0.40061	-	-	5.99529
SC 6	0.49508	-	-	8.03908
SC 7	0.21872	-	-	10.8304
SC 8	0.45161	-	-	7.12943
SC 9	0.29995	-	-	6.11289
SC 10	0.46023	0.74126	-	20.8919
SC 11	0.14505	0.76341	-	15.0622
SC 12	0.07416	0.91665	-	15.7077
SC 13	0.3482	0.75629	-	13.8204
SC 14	0.10424	0.86004	-	12.8275
SC 15	0.11669	0.89812	-	9.51321
SC 16	0.2692	0.84205	-	9.43495
SC 17	0.09115	0.4749	-	14.5909
SC 18	0.22985	0.8386	-	12.2592
SC 19	0.136	0.76061	-	11.2758
SC 20	0.32284	0.72075	-	16.0752
SC 21	0.10138	0.81101	-	16.5717
SC 22	0.16681	0.41306	0.68023	14.0685
SC 23	0.20696	0.62312	0.893	16.4105
SC 24	0.37408	0.48665	0.73694	16.1317
SC 25	0.1127	0.51818	0.86627	12.7274
SC 26	0.46382	0.8353	-	11.0137
SC 27	0.18478	-	-	6.98803
SC 28	0.31815	-	-	9.33737
SC 29	0.41356	-	-	9.12016

Spermatocyte 8

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.26098	-	-	-	8.68931
SC 2	0.32156	-	-	-	14.1168
SC 3	0.31796	-	-	-	13.4012
SC 4	0.29633	-	-	-	8.1165
SC 5	0.49125	-	-	-	10.7898
SC 6	0.20894	-	-	-	6.01797
SC 7	0.29676	-	-	-	6.03876
SC 8	0.32029	-	-	-	6.98824
SC 9	0.21568	-	-	-	6.03435
SC 10	0.225	-	-	-	6.01216
SC 11	0.29644	-	-	-	5.51075
SC 12	0.10431	-	-	-	9.77648
SC 13	0.3911	-	-	-	10.3256
SC 14	0.25949	-	-	-	17.5404
SC 15	0.33317	0.89427	-	-	9.73735
SC 16	0.23138	0.62514	-	-	13.7122
SC 17	0.28909	0.6944	-	-	13.6469
SC 18	0.09024	0.83766	-	-	10.7556
SC 19	0.27501	0.85618	-	-	14.618
SC 20	0.37849	0.85017	-	-	7.80395
SC 21	0.11775	0.80452	-	-	10.1926
SC 22	0.19193	0.46587	-	-	8.92906
SC 23	0.37534	0.83668	-	-	18.0951
SC 24	0.55562	0.7014	-	-	13.9313
SC 25	0.38586	0.49502	-	-	12.3897
SC 26	0.18972	0.76907	-	-	9.8259
SC 27	0.07981	0.32503	0.68688	0.94332	22.7803
SC 28	0.08349	0.33192	0.43478	-	15.8074
SC 29	0.45972	0.92711	-	-	20.0164

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.46072	-	-	7.23933
SC 2	0.42368	-	-	9.26625
SC 3	0.44363	-	-	5.51551
SC 4	0.38676	-	-	5.47841
SC 5	0.18713	-	-	6.64265
SC 6	0.46651	-	-	6.22783
SC 7	0.38489	-	-	6.0403
SC 8	0.19894	-	-	6.03379
SC 9	0.20656	-	-	5.89603
SC 10	0.31328	0.8011	-	8.48407
SC 11	0.58763	0.92501	-	9.4696
SC 12	0.22825	0.84497	-	13.0091
SC 13	0.39051	0.73819	-	11.1021
SC 14	0.24744	0.91316	-	11.4968
SC 15	0.19875	0.92596	-	10.7435
SC 16	0.41036	0.90177	-	10.2733
SC 17	0.48681	0.71665	-	11.9303
SC 18	0.22187	0.75216	-	7.69244
SC 19	0.09358	0.70088	-	12.0077
SC 20	0.14474	0.90239	-	12.1348
SC 21	0.28711	0.89523	-	7.60347
SC 22	0.1875	0.92173	-	8.03208
SC 23	0.14776	0.93296	-	12.7978
SC 24	0.14661	0.70324	-	14.3413
SC 25	0.25138	0.69305	-	9.67169
SC 26	0.10727	0.51323	0.88999	12.778
SC 27	0.08719	0.65811	0.81125	12.0495
SC 28	0.19558	0.3709	0.8896	12.1379
SC 29	0.4585	-	-	10.3286

Spermatocyte 10

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.4897	-	-	-	9.79139
SC 2	0.36506	-	-	-	6.7445
SC 3	0.3805	-	-	-	10.3375
SC 4	0.32805	-	-	-	7.04102
SC 5	0.21099	-	-	-	6.34508
SC 6	0.40818	-	-	-	5.45937
SC 7	0.22889	-	-	-	8.06918
SC 8	0.48459	-	-	-	6.14033
SC 9	0.26172	-	-	-	5.94601
SC 10	0.21262	0.58449	-	-	9.40751
SC 11	0.32579	0.68795	-	-	15.1189
SC 12	0.28713	0.66436	-	-	10.7349
SC 13	0.23159	0.87834	-	-	9.74365
SC 14	0.26245	0.72884	-	-	7.85442
SC 15	0.125	0.86565	-	-	12.4368
SC 16	0.30838	0.83494	-	-	9.43166
SC 17	0.19	0.77706	-	-	12.9787
SC 18	0.32322	0.67422	-	-	11.4806
SC 19	0.22593	0.80297	-	-	15.6991
SC 20	0.37307	0.93831	-	-	17.2883
SC 21	0.12856	0.77155	-	-	18.337
SC 22	0.11655	0.27918	0.49161	0.94224	14.1471
SC 23	0.20773	0.37311	0.65472	-	21.149
SC 24	0.26194	0.40648	0.8018	-	12.9578
SC 25	0.29835	0.64031	-	-	17.8163
SC 26	0.44204	0.59675	-	-	18.0175
SC 27	0.068	0.3852	0.75749	-	22.9816
SC 28	0.12644	0.43872	-	-	13.264
SC 29	0.15635	-	-	-	12.9834

Angus 2

Spermatocyte 1

	CO 1	CO 2	CO 3	SC Length
SC 1	0.27609	-	-	6.21894
SC 2	0.45493	-	-	5.59762
SC 3	0.40699	-	-	6.75801
SC 4	0.38716	-	-	7.01974
SC 5	0.38859	-	-	11.5581
SC 6	0.19732	-	-	12.2294
SC 7	0.44079	-	-	8.96105
SC 8	0.41752	-	-	5.81196
SC 9	0.47811	-	-	6.7375
SC 10	0.44673	-	-	8.02648
SC 11	0.33397	-	-	7.18312
SC 12	0.41088	-	-	7.65184
SC 13	0.15593	0.58855	-	7.91882
SC 14	0.12439	0.43438	-	14.0978
SC 15	0.28571	0.95953	-	15.0637
SC 16	0.20614	0.88123	-	8.86074
SC 17	0.53147	0.65024	-	14.1548
SC 18	0.3607	0.87636	-	9.91823
SC 19	0.24661	0.85229	-	15.39
SC 20	0.4559	0.79984	-	9.41115
SC 21	0.14405	0.76909	-	14.1537
SC 22	0.09445	0.71193	-	9.72755
SC 23	0.19928	0.86047	-	9.9736
SC 24	0.05803	0.85586	-	15.8931
SC 25	0.15947	-	-	4.82097
SC 26	0.08907	-	-	8.83008
SC 27	0.24791	-	-	15.3266
SC 28	0.4803	-	-	7.69811
SC 29	0.31321	0.67383	0.73289	12.2694

Spermatocyte 2

	CO 1	CO 2	CO 3	CO 4
SC 1	0.39292	-	-	-
SC 2	0.31078	-	-	-
SC 3	0.23008	-	-	-
SC 4	0.494	-	-	-
SC 5	0.18785	-	-	-
SC 6	0.32019	-	-	-
SC 7	0.18386	-	-	-
SC 8	0.3388	-	-	-
SC 9	0.47648	-	-	-
SC 10	0.43916	-	-	-
SC 11	0.09545	-	-	-
SC 12	0.46521	0.92187	-	-
SC 13	0.30382	0.68235	-	-
SC 14	0.46052	0.8977	-	-
SC 15	0.51831	0.79841	-	-
SC 16	0.63837	0.90786	-	-
SC 17	0.22948	0.69235	-	-
SC 18	0.17456	0.55399	-	-
SC 19	0.18943	0.74967	-	-
SC 20	0.31109	0.7975	-	-
SC 21	0.16237	0.57445	-	-
SC 22	0.31088	-	-	-
SC 23	0.401	-	-	-
SC 24	0.08719	-	-	-
SC 25	0.32309	-	-	-
SC 26	0.15713	0.45802	-	-
SC 27	0.25609	0.95275	-	-
SC 28	0.32637	0.55151	-	-
SC 29	0.06106	0.33489	0.79121	0.88601

Spermatocyte 3

	CO 1	CO 2	SC Length
SC 1	0.49124	-	9.07823
SC 2	0.25209	-	5.16726
SC 3	0.35256	-	9.83955
SC 4	0.28616	-	4.94445
SC 5	0.44615	-	7.55391
SC 6	0.43049	-	5.72285
SC 7	0.44755	-	7.49231
SC 8	0.39227	-	11.6495
SC 9	0.40972	-	12.2098
SC 10	0.08013	-	11.3567
SC 11	0.41225	-	6.39779
SC 12	0.44964	-	5.7365
SC 13	0.31262	-	6.25086
SC 14	0.49081	0.71684	7.8582
SC 15	0.32474	0.83684	8.35408
SC 16	0.58889	0.96143	14.5193
SC 17	0.28019	0.7186	9.95029
SC 18	0.31069	0.65329	8.50661
SC 19	0.11536	0.89707	6.80085
SC 20	0.49328	0.92068	13.3798
SC 21	0.11469	0.819	10.4828
SC 22	0.23919	0.49981	13.4292
SC 23	0.22317	0.61891	13.3083
SC 24	0.22587	0.81314	13.0621
SC 25	0.27445	0.82297	5.01711
SC 26	0.50564	0.79108	7.57883
SC 27	0.33369	-	9.1896
SC 28	0.32331	-	8.94747
SC 29	0.30787	-	3.23071

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.30648	-	-	10.0705
SC 2	0.44746	-	-	13.0247
SC 3	0.44682	-	-	6.22223
SC 4	0.47342	-	-	9.15131
SC 5	0.30376	-	-	8.32048
SC 6	0.44928	-	-	5.7967
SC 7	0.32425	-	-	5.45132
SC 8	0.22061	-	-	8.36787
SC 9	0.16816	-	-	5.50977
SC 10	0.19986	-	-	5.30033
SC 11	0.32406	-	-	6.13725
SC 12	0.20624	0.74534	-	6.04716
SC 13	0.55369	0.7921	-	11.3638
SC 14	0.38368	0.94461	-	10.1108
SC 15	0.12271	0.9447	-	9.36432
SC 16	0.41807	0.81042	-	11.0377
SC 17	0.40811	0.82533	-	12.3463
SC 18	0.13245	0.75996	-	14.2893
SC 19	0.62417	0.87719	-	15.6589
SC 20	0.21295	0.66701	-	14.1397
SC 21	0.33036	0.92678	-	9.82954
SC 22	0.27698	0.91836	-	9.43152
SC 23	0.49439	0.91079	-	15.8892
SC 24	0.41182	0.89693	-	17.0677
SC 25	0.17485	0.47239	-	5.88147
SC 26	0.32281	0.77094	-	9.14452
SC 27	0.1261	0.84436	-	8.15206
SC 28	0.13208	0.66703	-	7.65478
SC 29	0.1065	0.43709	0.85889	14.2197

Spermatocyte 5

	CO 1	CO 2	CO 3	CO 4
SC 1	0.24347	-	-	-
SC 2	0.39131	-	-	-
SC 3	0.26761	-	-	-
SC 4	0.09196	-	-	-
SC 5	0.41621	-	-	-
SC 6	0.31836	-	-	-
SC 7	0.12791	-	-	-
SC 8	0.3657	-	-	-
SC 9	0.24325	-	-	-
SC 10	0.35564	0.89575	-	-
SC 11	0.3172	-	-	-
SC 12	0.41896	-	-	-
SC 13	0.41633	-	-	-
SC 14	0.32258	-	-	-
SC 15	0.19671	-	-	-
SC 16	0.06612	0.70662	-	-
SC 17	0.36206	0.86779	-	-
SC 18	0.11604	0.78265	-	-
SC 19	0.41834	0.71963	-	-
SC 20	0.43677	0.82057	-	-
SC 21	0.30572	0.70831	-	-
SC 22	0.12848	-	-	-
SC 23	0.40332	0.59055	-	-
SC 24	0.16162	0.48148	0.80658	-
SC 25	0.44432	-	-	-
SC 26	0.43382	0.59596	0.89028	-
SC 27	0.15629	0.85661	-	-
SC 28	0.11261	0.3461	0.52489	0.86674
SC 29	0.22082	0.79781	-	-

Spermatocyte 6

	CO 1	CO 2	SC Length
SC 1	0.2424	-	11.1567
SC 2	0.43217	-	11.57
SC 3	0.39184	-	10.4926
SC 4	0.34679	-	10.7882
SC 5	0.25634	-	7.15806
SC 6	0.17507	-	9.61751
SC 7	0.39271	-	7.40544
SC 8	0.42509	-	18.5195
SC 9	0.28201	-	9.91795
SC 10	0.26836	-	11.6051
SC 11	0.44363	-	7.86534
SC 12	0.45176	-	6.35803
SC 13	0.25127	-	11.2621
SC 14	0.34538	0.92194	12.9719
SC 15	0.18612	0.55966	8.47028
SC 16	0.45111	0.85363	13.9848
SC 17	0.18007	0.92156	12.479
SC 18	0.42944	0.91223	11.8313
SC 19	0.30839	0.8239	9.14151
SC 20	0.30164	0.80239	8.62435
SC 21	0.37619	0.89714	10.1703
SC 22	0.52884	0.87716	10.1018
SC 23	0.28211	0.80433	15.2834
SC 24	0.32548	0.90758	15.2564
SC 25	0.20615	0.87853	14.5187
SC 26	0.4948	0.82719	16.654
SC 27	0.50129	0.79889	24.9047
SC 28	0.28837	0.72416	20.1643
SC 29	0.31975	0.74682	13.5219

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.36118	-	-	7.23534
SC 2	0.49763	-	-	8.44837
SC 3	0.42199	-	-	11.1231
SC 4	0.38616	-	-	6.99083
SC 5	0.13405	-	-	8.73229
SC 6	0.33798	-	-	7.18389
SC 7	0.27337	-	-	11.4125
SC 8	0.22311	-	-	11.3212
SC 9	0.3127	0.6852	-	16.5603
SC 10	0.14337	0.91612	-	16.325
SC 11	0.35746	0.83346	-	10.6987
SC 12	0.20497	0.77014	-	11.8908
SC 13	0.24013	0.90216	-	16.8162
SC 14	0.13228	0.80211	-	12.0166
SC 15	0.18074	0.74651	-	12.9329
SC 16	0.31376	0.64495	-	13.0323
SC 17	0.43612	0.87647	-	18.6248
SC 18	0.38178	0.92298	-	12.0539
SC 19	0.18185	0.7611	-	17.9359
SC 20	0.32644	0.95929	-	17.5367
SC 21	0.15768	0.8336	-	15.1254
SC 22	0.42469	-	-	11.1616
SC 23	0.16618	-	-	9.3625
SC 24	0.30148	-	-	13.5677
SC 25	0.13266	0.82539	-	8.54469
SC 26	0.38486	0.91182	-	22.7341
SC 27	0.46136	0.63563	0.88245	16.9922
SC 28	0.42452	-	-	8.92073
SC 29	0.11292	0.69119	-	17.3779

Spermatocyte 8

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.23412	-	-	-	6.88926
SC 2	0.4884	-	-	-	12.3244
SC 3	0.39214	-	-	-	11.0965
SC 4	0.14137	-	-	-	6.77887
SC 5	0.29923	-	-	-	7.21931
SC 6	0.31616	-	-	-	8.13624
SC 7	0.22425	-	-	-	4.05804
SC 8	0.36157	-	-	-	6.42418
SC 9	0.36283	-	-	-	12.0272
SC 10	0.36727	-	-	-	5.50515
SC 11	0.24241	-	-	-	10.6939
SC 12	0.45854	-	-	-	9.95295
SC 13	0.44855	-	-	-	9.43985
SC 14	0.48302	-	-	-	7.54922
SC 15	0.22279	-	-	-	9.83794
SC 16	0.18581	0.85155	-	-	12.2511
SC 17	0.30169	0.84545	-	-	10.8945
SC 18	0.37674	0.73266	-	-	9.56956
SC 19	0.44089	0.83819	-	-	7.63742
SC 20	0.19018	0.64178	-	-	13.4933
SC 21	0.54735	0.75836	-	-	13.6177
SC 22	0.51606	0.85942	-	-	6.8166
SC 23	0.13494	0.64611	-	-	17.6265
SC 24	0.21095	-	-	-	8.59551
SC 25	0.31337	0.54364	-	-	26.845
SC 26	0.23728	0.73094	-	-	16.8808
SC 27	0.06754	0.39523	0.6274	0.86854	31.3956
SC 28	0.11211	0.39426	0.68776	-	16.9553
SC 29	0.11478	0.69273	-	-	21.756

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.41708	-	-	9.5018
SC 2	0.25665	-	-	5.78578
SC 3	0.33937	-	-	9.94448
SC 4	0.33252	-	-	11.0976
SC 5	0.20355	-	-	9.56396
SC 6	0.20403	-	-	7.41622
SC 7	0.18167	-	-	6.83634
SC 8	0.39639	-	-	9.48598
SC 9	0.36839	-	-	9.63816
SC 10	0.12636	-	-	7.77077
SC 11	0.20204	-	-	5.85641
SC 12	0.37618	-	-	12.5437
SC 13	0.35144	-	-	12.5584
SC 14	0.3289	-	-	5.95742
SC 15	0.29607	-	-	9.67652
SC 16	0.46654	0.77544	-	12.6248
SC 17	0.19877	0.8138	-	6.61801
SC 18	0.12916	0.77478	-	15.965
SC 19	0.04935	0.62122	-	17.0211
SC 20	0.1855	0.85684	-	9.26072
SC 21	0.17599	0.62033	-	16.0908
SC 22	0.3186	0.79543	-	17.5815
SC 23	0.34443	0.7258	-	14.1322
SC 24	0.26101	0.82545	-	11.0239
SC 25	0.26314	0.87589	-	17.5022
SC 26	0.20382	0.78694	-	13.1683
SC 27	0.04886	0.40747	0.75733	16.329
SC 28	0.22666	0.79969	-	18.5021
SC 29	0.31932	0.80024	-	19.6581

Spermatocyte 10

	CO 1	CO 2	CO 3	SC Length
SC 1	0.4281	-	-	7.9366
SC 2	0.49037	-	-	10.4577
SC 3	0.39964	-	-	11.7202
SC 4	0.32729	-	-	6.64958
SC 5	0.44226	-	-	6.44112
SC 6	0.30197	-	-	7.6335
SC 7	0.36758	-	-	14.7473
SC 8	0.44669	-	-	9.48087
SC 9	0.40619	-	-	8.20589
SC 10	0.44326	-	-	12.1248
SC 11	0.38	-	-	6.02343
SC 12	0.29704	-	-	11.8119
SC 13	0.46372	-	-	11.7466
SC 14	0.32201	0.66295	-	7.31402
SC 15	0.25134	0.68901	-	12.2786
SC 16	0.08892	0.65887	-	10.6145
SC 17	0.24198	0.63242	-	8.56065
SC 18	0.25691	0.84517	-	8.35527
SC 19	0.13554	0.87897	-	15.9823
SC 20	0.24643	0.69238	-	13.9071
SC 21	0.05799	0.49612	-	11.558
SC 22	0.21235	0.80647	-	10.1072
SC 23	0.24407	0.85945	-	10.4003
SC 24	0.42333	0.7494	-	16.673
SC 25	0.38153	0.81629	-	10.2444
SC 26	0.35494	0.65939	-	8.46594
SC 27	0.43264	0.64617	0.82209	15.966
SC 28	0.06064	0.59825	0.94041	21.7294
SC 29	0.15163	0.46823	0.89334	12.5855

Angus 3

Spermatocyte 1

	CO 1	CO 2	CO 3	SC Length
SC 1	0.161	-	-	8.41638
SC 2	0.123	0.595	-	15.6768
SC 3	0.132	0.761	-	12.9413
SC 4	0.442	-	-	6.55991
SC 5	0.066	0.687	-	13.3985
SC 6	0.064	-	-	7.83447
SC 7	0.259	-	-	6.86399
SC 8	0.371	0.644	-	9.42004
SC 9	0.045	0.597	-	9.47646
SC 10	0.149	0.514	-	15.0904
SC 11	0.089	0.294	0.719	15.4405
SC 12	0.253	0.639	-	11.5613
SC 13	0.209	0.888	-	14.1553
SC 14	0.3	0.603	-	14.2622
SC 15	0.318	-	-	14.4486
SC 16	0.425	-	-	9.36124
SC 17	0.233	0.797	-	12.7042
SC 18	0.195	-	-	8.27029
SC 19	0.406	-	-	9.66343
SC 20	0.293	-	-	9.93188
SC 21	0.181	-	-	19.8817
SC 22	0.06	0.78	-	15.4783
SC 23	0.474	-	-	7.11732
SC 24	0.169	0.667	-	9.68282
SC 25	0.045	0.816	-	15.8638
SC 26	0.147	-	-	6.05801
SC 27	0.14	0.782	-	8.65088
SC 28	0.145	0.473	-	9.74183
SC 29	0.371	-	-	6.98292

Spermatocyte 2

	CO 1	CO 2	SC Length
SC 1	0.089	0.786	13.4182
SC 2	0.403	-	10.7242
SC 3	0.182	0.701	10.0648
SC 4	0.419	-	7.23156
SC 5	0.419	-	12.5339
SC 6	0.477	-	6.1334
SC 7	0.221	0.893	12.8686
SC 8	0.162	0.905	10.4565
SC 9	0.148	-	7.19516
SC 10	0.108	-	6.3938
SC 11	0.522	-	12.2658
SC 12	0.324	-	5.66706
SC 13	0.359	0.73	10.4604
SC 14	0.415	-	10.1835
SC 15	0.263	-	13.1161
SC 16	0.16	0.862	18.4304
SC 17	0.112	0.753	14.4752
SC 18	0.374	-	7.75943
SC 19	0.303	-	8.88412
SC 20	0.133	-	18.5931
SC 21	0.279	-	8.50752
SC 22	0.095	0.912	14.1076
SC 23	0.401	-	14.4565
SC 24	0.091	0.464	11.248
SC 25	0.132	0.72	6.63201
SC 26	0.172	0.557	15.9366
SC 27	0.211	-	8.81664
SC 28	0.12	0.745	17.0392
SC 29	0.11	-	5.87475

Spermatocyte 3

	CO 1	CO 2	CO 3	SC Length
SC 1	0.337	-	-	7.93429
SC 2	0.415	-	-	7.62062
SC 3	0.318	-	-	8.39433
SC 4	0.512	-	-	6.7123
SC 5	0.241	-	-	5.57732
SC 6	0.304	-	-	5.85018
SC 7	0.162	-	-	6.25898
SC 8	0.105	0.465	0.86	10.692
SC 9	0.276	-	-	4.85254
SC 10	0.335	0.719	-	10.8462
SC 11	0.172	0.867	-	10.0743
SC 12	0.11	0.544	-	9.89555
SC 13	0.282	-	-	5.12855
SC 14	0.1	0.829	-	9.46344
SC 15	0.307	-	-	5.33015
SC 16	0.351	-	-	5.66636
SC 17	0.196	0.689	-	7.45892
SC 18	0.173	0.387	-	9.78446
SC 19	0.089	0.31	-	19.473
SC 20	0.05	0.25	0.865	8.09753
SC 21	0.388	-	-	6.89885
SC 22	0.173	-	-	12.0309
SC 23	0.133	0.575	-	8.1844
SC 24	0.12	0.569	-	10.5887
SC 25	0.443	-	-	4.92646
SC 26	0.23	0.66	-	7.3759
SC 27	0.072	0.549	-	6.25415
SC 28	0.282	-	-	8.43045
SC 29	0.097	0.507	0.909	9.63662

Spermatocyte 4

	CO 1	CO 2	SC Length
SC 1	0.318	0.658	14.4332
SC 2	0.536	-	13.129
SC 3	0.318	-	10.8852
SC 4	0.124	-	9.0083
SC 5	0.177	0.734	14.8963
SC 6	0.178	-	6.81275
SC 7	0.149	0.626	11.9435
SC 8	0.235	0.601	14.096
SC 9	0.306	-	7.315
SC 10	0.116	0.635	17.5107
SC 11	0.434	-	11.4434
SC 12	0.229	-	7.52416
SC 13	0.189	-	8.2166
SC 14	0.116	0.808	11.2331
SC 15	0.191	0.693	15.9207
SC 16	0.038	0.562	14.5165
SC 17	0.054	0.873	12.9208
SC 18	0.151	0.743	23.4079
SC 19	0.083	0.584	23.0481
SC 20	0.124	0.526	18.879
SC 21	0.348	-	14.2561
SC 22	0.072	0.748	23.5795
SC 23	0.357	-	16.1265
SC 24	0.074	0.821	15.557
SC 25	0.063	-	12.6227
SC 26	0.113	0.863	19.7675
SC 27	0.12	-	7.3822
SC 28	0.402	-	9.24861
SC 29	0.462	-	7.84805

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.202	-	-	5.40799
SC 2	0.238	-	-	6.44525
SC 3	0.1	0.574	-	8.67118
SC 4	0.192	0.607	-	7.86569
SC 5	0.303	-	-	5.80398
SC 6	0.425	-	-	6.30245
SC 7	0.26	0.598	-	11.0677
SC 8	0.153	0.719	-	8.45222
SC 9	0.212	0.653	-	12.2448
SC 10	0.353	-	-	6.16875
SC 11	0.334	-	-	10.2769
SC 12	0.304	-	-	6.09756
SC 13	0.066	0.863	-	13.7071
SC 14	0.177	-	-	9.73574
SC 15	0.388	0.721	0.829	11.2032
SC 16	0.199	-	-	10.5412
SC 17	0.464	-	-	9.31651
SC 18	0.212	0.644	-	9.31224
SC 19	0.15	-	-	10.0428
SC 20	0.198	0.712	-	12.5875
SC 21	0.214	-	-	8.24768
SC 22	0.219	0.466	-	17.3565
SC 23	0.419	-	-	8.1823
SC 24	0.138	0.731	-	8.90547
SC 25	0.141	-	-	5.67147
SC 26	0.388	-	-	11.9004
SC 27	0.232	-	-	12.5138
SC 28	0.296	-	-	5.54155
SC 29	0.123	0.707	-	21.9573

Spermatocyte 6

	CO 1	CO 2	SC Length
SC 1	0.26	-	6.50657
SC 2	0.434	-	7.35987
SC 3	0.32	-	6.76578
SC 4	0.327	-	12.9112
SC 5	0.128	0.788	11.3271
SC 6	0.068	0.829	10.7936
SC 7	0.251	-	7.93842
SC 8	0.437	-	10.8885
SC 9	0.31	0.703	15.4912
SC 10	0.179	0.721	12.5609
SC 11	0.183	0.771	14.3466
SC 12	0.149	-	7.36484
SC 13	0.421	-	9.83822
SC 14	0.264	-	6.62515
SC 15	0.294	0.686	17.4144
SC 16	0.139	0.65	16.3973
SC 17	0.42	-	9.5102
SC 18	0.258	0.622	16.0962
SC 19	0.283	0.507	19.8099
SC 20	0.156	0.797	11.6706
SC 21	0.176	0.692	16.601
SC 22	0.259	-	16.3681
SC 23	0.098	0.909	17.53
SC 24	0.042	0.359	15.1166
SC 25	0.16	-	9.17861
SC 26	0.076	0.65	9.0902
SC 27	0.167	0.695	16.6804
SC 28	0.061	0.676	11.4353
SC 29	0.392	-	5.88644

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.333	-	-	10.8538
SC 2	0.104	0.727	-	9.3492
SC 3	0.218	-	-	6.20683
SC 4	0.364	-	-	10.1322
SC 5	0.198	0.695	-	9.86517
SC 6	0.376	0.561	-	12.4674
SC 7	0.36	-	-	5.79705
SC 8	0.291	-	-	8.95538
SC 9	0.354	-	-	9.84032
SC 10	0.372	-	-	6.09637
SC 11	0.129	0.723	-	10.4436
SC 12	0.092	0.711	-	12.6496
SC 13	0.337	-	-	15.5139
SC 14	0.501	-	-	7.34671
SC 15	0.107	0.751	-	9.29418
SC 16	0.424	-	-	12.2606
SC 17	0.204	0.678	-	12.1754
SC 18	0.427	-	-	8.97225
SC 19	0.234	-	-	6.59792
SC 20	0.105	0.438	-	10.9362
SC 21	0.18	0.813	-	16.0623
SC 22	0.144	0.855	-	12.6116
SC 23	0.177	0.629	-	13.6691
SC 24	0.525	-	-	7.81431
SC 25	0.51	-	-	6.27599
SC 26	0.095	0.431	0.882	14.8919
SC 27	0.421	-	-	9.56508
SC 28	0.119	-	-	7.49063
SC 29	0.091	0.434	0.698	16.4443

Spermatocyte 8

	CO 1	CO 2	CO 3	SC Length
SC 1	0.174	0.359	-	13.3256
SC 2	0.082	0.573	0.782	10.3397
SC 3	0.11	0.795	-	9.50908
SC 4	0.351	-	-	8.13414
SC 5	0.221	0.594	-	17.0356
SC 6	0.167	0.705	-	9.69682
SC 7	0.21	0.794	-	9.11155
SC 8	0.497	-	-	5.93614
SC 9	0.384	-	-	13.4379
SC 10	0.327	-	-	10.7386
SC 11	0.267	0.657	-	8.35457
SC 12	0.167	-	-	6.21411
SC 13	0.065	-	-	8.25069
SC 14	0.257	0.741	-	9.29866
SC 15	0.192	-	-	8.50171
SC 16	0.426	-	-	15.9492
SC 17	0.087	-	-	6.86504
SC 18	0.194	0.724	-	11.3672
SC 19	0.22	0.62	-	14.0478
SC 20	0.09	0.172	0.357	19.0193
SC 21	0.308	-	-	21.3812
SC 22	0.08	0.602	-	13.0147
SC 23	0.167	0.697	-	15.7907
SC 24	0.22	-	-	12.4328
SC 25	0.328	-	-	5.52265
SC 26	0.243	-	-	8.80054
SC 27	0.434	-	-	12.0777
SC 28	0.368	-	-	9.09783
SC 29	0.39	-	-	6.2762

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.229	-	-	6.45841
SC 2	0.118	-	-	7.41937
SC 3	0.096	-	-	8.99346
SC 4	0.257	-	-	6.59806
SC 5	0.218	0.714	-	12.1293
SC 6	0.12	0.431	-	12.8073
SC 7	0.499	-	-	7.44611
SC 8	0.268	0.881	-	11.9486
SC 9	0.22	0.609	-	22.0638
SC 10	0.379	-	-	7.71134
SC 11	0.497	-	-	15.159
SC 12	0.43	-	-	16.2387
SC 13	0.058	0.587	-	7.80066
SC 14	0.104	0.915	-	10.0532
SC 15	0.049	0.596	-	13.399
SC 16	0.122	0.506	-	9.51923
SC 17	0.126	0.648	-	15.7144
SC 18	0.089	0.808	-	16.883
SC 19	0.144	0.347	-	8.19084
SC 20	0.334	-	-	7.77217
SC 21	0.374	-	-	12.905
SC 22	0.273	-	-	15.3145
SC 23	0.226	0.919	-	14.9542
SC 24	0.218	0.584	0.801	19.9424
SC 25	0.244	0.668	-	13.4877
SC 26	0.509	0.686	-	16.5592
SC 27	0.1	-	-	15.6458
SC 28	0.34	-	-	15.4361
SC 29	0.307	-	-	5.92543

Spermatocyte 10

	CO 1	CO 2	CO 3	SC Length
SC 1	0.212	-	-	6.50349
SC 2	0.189	-	-	7.47166
SC 3	0.547	-	-	10.6888
SC 4	0.156	0.827	-	16.9408
SC 5	0.062	0.853	-	14.701
SC 6	0.571	-	-	11.9982
SC 7	0.087	0.709	-	10.9587
SC 8	0.221	0.675	-	15.6476
SC 9	0.521	-	-	11.8156
SC 10	0.367	-	-	15.3413
SC 11	0.152	-	-	7.45563
SC 12	0.291	-	-	8.93431
SC 13	0.124	-	-	11.2571
SC 14	0.238	0.717	0.8	9.73588
SC 15	0.5	-	-	7.62713
SC 16	0.136	-	-	10.9166
SC 17	0.2	0.873	-	10.7781
SC 18	0.403	-	-	11.0381
SC 19	0.247	0.484	-	15.8778
SC 20	0.457	-	-	19.4721
SC 21	0.087	0.423	-	9.16671
SC 22	0.196	-	-	6.86826
SC 23	0.451	-	-	18.1553
SC 24	0.373	0.85	-	16.3941
SC 25	0.174	0.573	-	6.76767
SC 26	0.051	0.275	0.747	10.3798
SC 27	0.178	0.25	0.778	16.6165
SC 28	0.157	0.85	-	15.3855
SC 29	0.096	0.586	0.864	18.8283

Angus 4

Spermatocyte 1

	CO 1	CO 2	CO 3	SC Length
SC 1	0.136	0.795	-	178.7
SC 2	0.24	0.582	-	227.6
SC 3	0.093	0.645	-	206.4
SC 4	0.125	0.704	-	255
SC 5	0.052	0.754	-	115.7
SC 6	0.325	-	-	167.7
SC 7	0.484	-	-	104.7
SC 8	0.417	-	-	162
SC 9	0.224	0.619	-	232.5
SC 10	0.406	-	-	165.9
SC 11	0.508	-	-	129.7
SC 12	0.358	0.49	-	114
SC 13	0.316	-	-	107
SC 14	0.438	-	-	129.8
SC 15	0.39	-	-	127.9
SC 16	0.071	0.478	-	192.8
SC 17	0.272	0.519	0.691	189.5
SC 18	0.402	-	-	159.5
SC 19	0.541	-	-	118.9
SC 20	0.102	0.57	0.74	199.6
SC 21	0.201	0.396	0.774	270.9
SC 22	0.212	-	-	151.7
SC 23	0.278	0.636	-	219.2
SC 24	0.048	0.799	-	215
SC 25	0.165	0.698	-	252.8
SC 26	0.709	-	-	106.8
SC 27	0.441	0.599	0.675	273.5
SC 28	0.126	0.434	-	180.1
SC 29	0.428	-	-	102.3

Spermatocyte 2

	CO 1	CO 2	SC Length
SC 1	0.325	-	9.19149
SC 2	0.238	0.571	12.7417
SC 3	0.165	0.634	17.2668
SC 4	0.254	-	6.93448
SC 5	0.507	-	9.0755
SC 6	0.14	0.851	10.8229
SC 7	0.436	-	9.814
SC 8	0.405	0.754	10.2003
SC 9	0.228	0.817	11.1276
SC 10	0.214	0.517	10.9421
SC 11	0.373	-	7.36694
SC 12	0.329	-	9.01425
SC 13	0.522	-	6.04821
SC 14	0.132	-	14.7677
SC 15	0.329	0.59	14.6386
SC 16	0.066	0.424	10.9761
SC 17	0.436	-	13.7231
SC 18	0.474	-	13.977
SC 19	0.179	-	7.05187
SC 20	0.121	0.641	10.3242
SC 21	0.195	-	5.97065
SC 22	0.418	-	6.84047
SC 23	0.196	-	7.88235
SC 24	0.091	0.566	13.6466
SC 25	0.147	0.785	10.1451
SC 26	0.153	0.56	7.42049
SC 27	0.108	0.842	19.2408
SC 28	0.18	0.659	12.023
SC 29	0.411	-	5.4341

Spermatocyte 3

	CO 1	CO 2	CO 3	SC Length
SC 1	0.479	-	-	7.35427
SC 2	0.133	0.715	-	11.9826
SC 3	0.387	-	-	10.4175
SC 4	0.386	-	-	7.80668
SC 5	0.178	-	-	5.70668
SC 6	0.554	-	-	6.97151
SC 7	0.081	0.79	-	12.0577
SC 8	0.099	0.57	-	14.2391
SC 9	0.111	0.604	-	13.634
SC 10	0.171	0.756	-	14.2579
SC 11	0.165	-	-	6.44735
SC 12	0.11	0.75	-	14.4807
SC 13	0.236	0.73	-	10.4358
SC 14	0.373	-	-	10.5207
SC 15	0.276	-	-	7.67067
SC 16	0.17	0.797	-	10.0774
SC 17	0.303	0.572	-	14.0628
SC 18	0.336	-	-	12.2116
SC 19	0.237	-	-	7.72618
SC 20	0.139	0.488	-	14.334
SC 21	0.199	-	-	7.62958
SC 22	0.125	0.595	-	10.4837
SC 23	0.472	-	-	12.2187
SC 24	0.163	0.589	-	15.3714
SC 25	0.155	0.773	-	15.8444
SC 26	0.242	-	-	7.83636
SC 27	0.068	0.702	0.882	17.7235
SC 28	0.312	-	-	12.9231
SC 29	0.312	0.669	-	17.2453

Spermatocyte 4

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.234	-	-	-	6.7536
SC 2	0.086	0.852	-	-	10.6509
SC 3	0.176	0.553	-	-	8.16935
SC 4	0.459	-	-	-	11.665
SC 5	0.535	-	-	-	10.7578
SC 6	0.223	0.773	-	-	9.58594
SC 7	0.215	-	-	-	7.19544
SC 8	0.389	-	-	-	8.38817
SC 9	0.246	-	-	-	8.96203
SC 10	0.114	0.528	-	-	14.2328
SC 11	0.291	-	-	-	7.42679
SC 12	0.337	-	-	-	13.739
SC 13	0.163	0.727	-	-	13.3592
SC 14	0.267	-	-	-	6.49831
SC 15	0.064	0.224	0.658	-	10.8958
SC 16	0.374	-	-	-	6.13907
SC 17	0.17	-	-	-	6.14278
SC 18	0.247	0.798	-	-	12.9915
SC 19	0.18	-	-	-	9.88155
SC 20	0.302	-	-	-	7.25928
SC 21	0.169	0.686	-	-	15.7765
SC 22	0.089	0.269	0.567	0.651	17.6721
SC 23	0.333	-	-	-	16.659
SC 24	0.12	0.562	0.757	-	14.1328
SC 25	0.239	0.474	-	-	17.6026
SC 26	0.199	0.615	-	-	16.7355
SC 27	0.191	0.698	-	-	13.6403
SC 28	0.437	-	-	-	11.2004
SC 29	0.229	0.606	-	-	17.0789

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.435	-	-	8.69757
SC 2	0.29	-	-	7.59115
SC 3	0.11	-	-	7.84595
SC 4	0.389	-	-	8.85689
SC 5	0.11	-	-	13.3736
SC 6	0.378	0.689	-	11.2206
SC 7	0.115	0.68	-	11.7565
SC 8	0.442	-	-	12.4898
SC 9	0.457	-	-	8.14016
SC 10	0.162	-	-	11.9673
SC 11	0.147	0.39	-	10.157
SC 12	0.112	0.9	-	18.3834
SC 13	0.229	-	-	6.84117
SC 14	0.208	-	-	8.80628
SC 15	0.282	-	-	11.4486
SC 16	0.195	0.592	-	14.0609
SC 17	0.264	0.619	-	15.6799
SC 18	0.3	-	-	11.2911
SC 19	0.334	-	-	7.5635
SC 20	0.17	0.82	-	15.3546
SC 21	0.107	0.703	-	17.0995
SC 22	0.202	0.713	-	12.7455
SC 23	0.095	0.795	-	17.2855
SC 24	0.391	0.741	-	20.6888
SC 25	0.103	0.768	-	18.6609
SC 26	0.074	0.815	-	17.2354
SC 27	0.123	0.826	-	12.6059
SC 28	0.173	0.501	-	16.4065
SC 29	0.062	0.8	0.948	16.3036

Spermatocyte 6

	CO 1	CO 2	SC Length
SC 1	0.294	-	7.72016
SC 2	0.376	-	10.5841
SC 3	0.226	0.719	10.5371
SC 4	0.293	0.568	13.9679
SC 5	0.045	0.661	12.7411
SC 6	0.247	-	7.64932
SC 7	0.488	-	6.91824
SC 8	0.086	0.782	11.7328
SC 9	0.1	0.558	14.2638
SC 10	0.1	0.73	14.4528
SC 11	0.198	-	6.52883
SC 12	0.165	0.587	5.6091
SC 13	0.158	0.756	13.9306
SC 14	0.094	0.602	13.3839
SC 15	0.12	0.588	10.3344
SC 16	0.198	-	7.45269
SC 17	0.376	-	8.13155
SC 18	0.149	0.636	10.2427
SC 19	0.212	0.538	7.30919
SC 20	0.133	0.714	11.9008
SC 21	0.132	0.485	14.3499
SC 22	0.174	0.786	9.98116
SC 23	0.524	-	10.6499
SC 24	0.177	0.681	13.0223
SC 25	0.477	-	12.0957
SC 26	0.159	0.599	15.1683
SC 27	0.147	0.9	14.3627
SC 28	0.162	0.758	11.5159
SC 29	0.142	0.739	16.1621

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.153	0.679	-	8.82784
SC 2	0.152	-	-	6.21474
SC 3	0.242	-	-	5.39189
SC 4	0.193	0.614	-	11.6707
SC 5	0.181	-	-	7.11655
SC 6	0.176	-	-	5.6637
SC 7	0.173	0.922	-	12.9315
SC 8	0.081	0.91	-	17.7039
SC 9	0.263	-	-	11.0951
SC 10	0.242	-	-	9.26807
SC 11	0.122	0.811	-	8.77296
SC 12	0.425	-	-	6.52064
SC 13	0.127	0.576	-	10.9939
SC 14	0.486	-	-	7.35973
SC 15	0.199	-	-	8.5379
SC 16	0.193	-	-	4.89321
SC 17	0.163	-	-	8.1991
SC 18	0.112	0.724	-	11.8585
SC 19	0.411	-	-	6.28593
SC 20	0.107	0.772	-	12.6407
SC 21	0.162	0.622	0.813	23.0903
SC 22	0.22	0.874	-	12.3489
SC 23	0.24	0.637	-	9.93741
SC 24	0.232	0.771	-	12.4314
SC 25	0.338	-	-	8.97708
SC 26	0.413	-	-	7.44324
SC 27	0.374	0.663	-	10.9977
SC 28	0.235	0.573	0.801	23.6133
SC 29	0.273	-	-	12.2291

Spermatocyte 8

	CO 1	CO 2	CO 3	SC Length
SC 1	0.228	-	-	6.34627
SC 2	0.268	-	-	9.34059
SC 3	0.101	0.63	-	14.0443
SC 4	0.309	0.522	-	10.6223
SC 5	0.072	0.516	0.907	17.926
SC 6	0.154	0.834	-	10.9103
SC 7	0.435	-	-	12.0181
SC 8	0.133	0.77	-	15.082
SC 9	0.221	0.929	-	13.7856
SC 10	0.399	-	-	7.77406
SC 11	0.205	0.562	-	16.4877
SC 12	0.505	-	-	14.3651
SC 13	0.167	0.714	-	12.3108
SC 14	0.27	0.851	-	16.4382
SC 15	0.117	0.849	-	17.2461
SC 16	0.487	-	-	12.9863
SC 17	0.425	-	-	10.5598
SC 18	0.205	-	-	12.8564
SC 19	0.297	-	-	12.3047
SC 20	0.487	-	-	12.1758
SC 21	0.136	-	-	15.2126
SC 22	0.374	-	-	13.8244
SC 23	0.588	-	-	4.33699
SC 24	0.178	-	-	12.7779
SC 25	0.464	-	-	10.8708
SC 26	0.436	-	-	5.01284
SC 27	0.13	0.805	-	9.60323
SC 28	0.738	-	-	10.5979
SC 29	0.155	0.762	-	11.2769

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.283	-	-	9.22579
SC 2	0.183	-	-	11.4024
SC 3	0.485	-	-	15.0721
SC 4	0.326	-	-	13.1993
SC 5	0.114	0.852	-	12.0897
SC 6	0.165	0.747	-	15.5814
SC 7	0.304	-	-	15.9794
SC 8	0.108	0.655	-	23.3453
SC 9	0.208	0.753	-	15.8967
SC 10	0.08	0.59	-	15.1267
SC 11	0.349	-	-	7.65275
SC 12	0.398	-	-	9.33135
SC 13	0.525	-	-	6.84194
SC 14	0.248	-	-	16.0707
SC 15	0.436	-	-	16.5749
SC 16	0.267	-	-	7.07518
SC 17	0.267	-	-	7.98154
SC 18	0.205	-	-	10.2841
SC 19	0.112	0.732	-	13.6994
SC 20	0.192	-	-	8.87866
SC 21	0.135	0.711	-	20.9311
SC 22	0.085	0.788	-	17.5316
SC 23	0.066	0.913	-	20.1852
SC 24	0.169	0.701	-	10.8667
SC 25	0.745	-	-	10.2974
SC 26	0.317	0.443	0.918	35.5288
SC 27	0.152	0.607	-	20.0218
SC 28	0.19	0.506	0.84	32.5147
SC 29	0.422	-	-	26.2692

Spermatocyte 10

	CO 1	CO 2	CO 3	SC Length
SC 1	0.183	-	-	5.873
SC 2	0.146	0.747	-	8.79648
SC 3	0.225	0.516	-	11.5051
SC 4	0.246	0.598	-	11.576
SC 5	0.11	0.682	-	15.9394
SC 6	0.483	-	-	5.72691
SC 7	0.3	0.558	-	13.1897
SC 8	0.129	0.801	-	10.5183
SC 9	0.174	0.523	-	12.5403
SC 10	0.412	-	-	5.89393
SC 11	0.132	0.711	-	9.10966
SC 12	0.461	-	-	6.6647
SC 13	0.146	0.532	-	10.9911
SC 14	0.26	0.718	-	11.7858
SC 15	0.278	-	-	9.29257
SC 16	0.142	0.481	0.901	9.94973
SC 17	0.131	0.605	0.925	15.0655
SC 18	0.109	0.532	-	14.0662
SC 19	0.107	0.658	-	9.12163
SC 20	0.196	0.777	-	6.83368
SC 21	0.074	0.56	-	10.838
SC 22	0.271	-	-	7.64064
SC 23	0.138	-	-	5.28164
SC 24	0.216	0.725	-	11.225
SC 25	0.114	0.794	-	10.6578
SC 26	0.362	-	-	5.68421
SC 27	0.097	0.74	-	13.606
SC 28	0.139	-	-	11.6766
SC 29	0.384	-	-	8.0892

Angus 5

Spermatocyte 1

	CO 1	CO 2	CO 3	SC Length
SC 1	0.034	0.657	-	14.7843
SC 2	0.38	-	-	16.0005
SC 3	0.215	-	-	14.503
SC 4	0.162	-	-	10.0537
SC 5	0.027	0.734	-	14.9801
SC 6	0.164	-	-	9.16552
SC 7	0.193	0.566	-	10.1927
SC 8	0.082	0.67	-	20.1105
SC 9	0.109	-	-	8.28667
SC 10	0.13	0.65	-	12.5037
SC 11	0.172	0.686	-	14.6152
SC 12	0.157	0.559	0.854	19.3668
SC 13	0.296	0.579	-	19.1666
SC 14	0.126	-	-	12.6635
SC 15	0.25	-	-	8.28373
SC 16	0.418	-	-	12.1435
SC 17	0.436	-	-	17.8283
SC 18	0.178	0.64	-	21.6878
SC 19	0.194	-	-	10.0288
SC 20	0.483	-	-	20
SC 21	0.124	0.495	0.852	25.829
SC 22	0.075	0.413	-	13.8368
SC 23	0.097	0.818	-	19.9677
SC 24	0.052	0.62	-	21.709
SC 25	0.109	-	-	14.9411
SC 26	0.117	0.48	0.824	32.9601
SC 27	0.284	-	-	9.27227
SC 28	0.145	0.406	0.827	17.8183
SC 29	0.204	0.899	-	15.9345

Spermatocyte 2

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.303	-	-	-	8.48183
SC 2	0.447	-	-	-	6.04702
SC 3	0.264	-	-	-	7.18515
SC 4	0.299	-	-	-	6.06641
SC 5	0.341	-	-	-	8.99836
SC 6	0.14	0.835	-	-	6.11009
SC 7	0.347	-	-	-	9.61506
SC 8	0.543	-	-	-	9.91879
SC 9	0.216	-	-	-	10.0769
SC 10	0.207	-	-	-	13.3061
SC 11	0.433	-	-	-	6.82353
SC 12	0.165	-	-	-	8.20071
SC 13	0.099	0.871	-	-	12.8622
SC 14	0.353	-	-	-	6.04947
SC 15	0.407	-	-	-	6.17946
SC 16	0.199	0.624	-	-	10.7309
SC 17	0.128	0.917	-	-	12.6159
SC 18	0.093	0.756	-	-	10.8941
SC 19	0.29	0.634	-	-	12.7512
SC 20	0.063	0.796	-	-	15.0217
SC 21	0.366	-	-	-	3.53955
SC 22	0.126	0.785	-	-	8.87264
SC 23	0.215	-	-	-	7.18396
SC 24	0.078	0.607	-	-	16.6626
SC 25	0.317	0.749	-	-	9.57404
SC 26	0.145	0.31	0.573	0.758	20.9006
SC 27	0.184	0.68	-	-	13.0933
SC 28	0.273	-	-	-	10.1563
SC 29	0.12	0.48	-	-	12.4497

Spermatocyte 3

	CO 1	CO 2	SC Length
SC 1	0.218	-	5.35227
SC 2	0.296	-	8.58459
SC 3	0.249	-	6.87001
SC 4	0.419	-	6.51427
SC 5	0.128	-	9.75905
SC 6	0.323	-	5.78354
SC 7	0.264	-	8.28632
SC 8	0.115	-	6.16336
SC 9	0.261	-	7.9716
SC 10	0.214	-	5.35122
SC 11	0.378	-	14.1145
SC 12	0.183	-	6.89836
SC 13	0.353	-	7.35336
SC 14	0.367	-	10.6454
SC 15	0.178	0.724	10.0661
SC 16	0.349	0.517	8.46853
SC 17	0.156	0.713	6.78209
SC 18	0.266	0.572	11.3077
SC 19	0.246	0.856	11.9904
SC 20	0.278	-	9.6369
SC 21	0.074	0.714	11.517
SC 22	0.206	0.875	17.0671
SC 23	0.174	0.634	9.22537
SC 24	0.214	0.611	10.3279
SC 25	0.128	0.674	13.627
SC 26	0.089	-	13.3669
SC 27	0.211	0.653	21.2677
SC 28	0.145	0.718	16.2414
SC 29	0.357	-	8.98331

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.444	-	-	7.45199
SC 2	0.445	-	-	9.55129
SC 3	0.397	-	-	12.272
SC 4	0.16	0.681	-	14.8951
SC 5	0.08	0.528	0.843	20.4116
SC 6	0.171	-	-	7.99883
SC 7	0.169	-	-	11.5394
SC 8	0.167	0.685	-	8.34624
SC 9	0.288	0.599	-	17.4587
SC 10	0.352	-	-	19.5011
SC 11	0.24	0.548	-	12.5474
SC 12	0.48	-	-	9.01005
SC 13	0.042	0.494	-	14.9853
SC 14	0.147	0.722	-	12.1112
SC 15	0.44	-	-	9.5249
SC 16	0.181	0.668	-	20.913
SC 17	0.318	-	-	12.6326
SC 18	0.175	0.621	-	16.4518
SC 19	0.173	-	-	10.1655
SC 20	0.084	0.48	0.941	24.4222
SC 21	0.19	0.688	-	12.8767
SC 22	0.389	-	-	15.9227
SC 23	0.331	0.605	-	19.3198
SC 24	0.307	0.569	-	15.8109
SC 25	0.35	-	-	9.87371
SC 26	0.092	0.242	0.938	15.5016
SC 27	0.238	-	-	7.6552
SC 28	0.489	-	-	14.4001
SC 29	0.182	-	-	11.6159

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.517	-	-	10.4101
SC 2	0.474	-	-	8.96315
SC 3	0.115	-	-	8.73481
SC 4	0.453	-	-	6.05017
SC 5	0.28	-	-	7.49322
SC 6	0.398	-	-	8.70905
SC 7	0.224	-	-	5.72593
SC 8	0.355	-	-	11.4745
SC 9	0.08	0.588	-	11.5756
SC 10	0.256	0.808	-	10.2249
SC 11	0.285	0.53	-	12.0273
SC 12	0.175	0.667	-	12.6211
SC 13	0.367	-	-	11.52
SC 14	0.126	0.582	-	15.9119
SC 15	0.441	-	-	11.2062
SC 16	0.052	0.541	0.834	18.0988
SC 17	0.137	0.7	-	13.4078
SC 18	0.302	0.556	-	13.827
SC 19	0.304	0.722	-	14.8103
SC 20	0.197	-	-	8.79921
SC 21	0.468	-	-	18.0109
SC 22	0.098	0.736	-	14.9888
SC 23	0.226	0.75	-	11.0753
SC 24	0.09	0.49	0.839	15.7531
SC 25	0.478	-	-	10.3197
SC 26	0.077	0.833	-	15.7659
SC 27	0.25	-	-	7.55153
SC 28	0.343	-	-	6.92258
SC 29	0.114	0.396	0.923	14.884

Spermatocyte 6

	CO 1	CO 2	SC Length
SC 1	0.344	-	7.85764
SC 2	0.28	-	8.40798
SC 3	0.226	-	11.9731
SC 4	0.463	-	7.49854
SC 5	0.113	0.781	14.8751
SC 6	0.231	-	8.9922
SC 7	0.153	0.794	15.0523
SC 8	0.247	0.711	15.7166
SC 9	0.123	0.899	12.5708
SC 10	0.142	0.81	13.0077
SC 11	0.413	-	14.577
SC 12	0.298	0.671	15.8127
SC 13	0.203	0.721	12.6176
SC 14	0.146	0.754	19.6692
SC 15	0.383	-	18.4628
SC 16	0.161	0.639	18.4661
SC 17	0.073	0.66	9.71558
SC 18	0.129	0.646	15.6855
SC 19	0.374	-	7.35994
SC 20	0.331	-	9.85824
SC 21	0.262	-	11.7558
SC 22	0.137	0.726	19.9655
SC 23	0.548	-	7.26593
SC 24	0.083	0.651	16.276
SC 25	0.128	-	8.23921
SC 26	0.152	0.652	16.7572
SC 27	0.257	-	10.6283
SC 28	0.381	-	6.01734
SC 29	0.53	-	13.0514

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.303	-	-	11.8233
SC 2	0.399	-	-	12.2559
SC 3	0.466	-	-	9.95589
SC 4	0.436	-	-	14.1357
SC 5	0.344	-	-	9.32309
SC 6	0.337	-	-	7.99442
SC 7	0.232	-	-	7.93226
SC 8	0.118	-	-	7.41349
SC 9	0.403	-	-	6.29797
SC 10	0.176	-	-	10.1533
SC 11	0.513	-	-	5.9451
SC 12	0.072	0.619	-	11.5338
SC 13	0.107	0.523	-	17.3326
SC 14	0.202	0.821	-	9.9414
SC 15	0.196	0.854	-	10.8214
SC 16	0.096	0.895	-	10.2801
SC 17	0.429	-	-	15.1512
SC 18	0.335	-	-	16.0823
SC 19	0.207	0.78	-	18.4101
SC 20	0.194	0.759	-	9.9638
SC 21	0.093	0.857	-	18.6162
SC 22	0.141	0.701	-	18.168
SC 23	0.084	0.577	0.96	16.1261
SC 24	0.135	-	-	6.52547
SC 25	0.542	-	-	8.3216
SC 26	0.259	0.767	-	14.3304
SC 27	0.48	-	-	11.5765
SC 28	0.34	0.647	-	10.4674
SC 29	0.084	0.75	-	12.6325

Spermatocyte 8

	CO 1	CO 2	CO 3	SC Length
SC 1	0.456	-	-	10.2206
SC 2	0.284	-	-	6.46037
SC 3	0.128	-	-	7.26488
SC 4	0.465	-	-	9.73581
SC 5	0.163	-	-	7.27216
SC 6	0.435	-	-	6.26388
SC 7	0.248	-	-	10.1451
SC 8	0.339	-	-	7.01743
SC 9	0.305	-	-	12.9011
SC 10	0.117	0.752	-	7.59255
SC 11	0.125	0.728	-	9.14571
SC 12	0.129	-	-	13.2108
SC 13	0.259	-	-	8.1004
SC 14	0.266	0.517	-	9.81204
SC 15	0.214	0.71	-	12.3162
SC 16	0.055	0.735	-	13.2185
SC 17	0.186	-	-	10.9397
SC 18	0.209	0.661	-	13.1659
SC 19	0.113	0.636	0.882	15.2858
SC 20	0.167	0.756	-	10.8552
SC 21	0.159	0.714	-	14.4488
SC 22	0.434	-	-	12.7695
SC 23	0.093	0.637	-	14.9541
SC 24	0.074	0.386	0.853	15.2772
SC 25	0.161	0.651	-	16.2071
SC 26	0.157	-	-	13.3251
SC 27	0.122	0.336	0.761	25.876
SC 28	0.172	0.335	0.739	15.2195
SC 29	0.241	-	-	11.2745

Spermatocyte 9

	CO 1	CO 2	SC Length
SC 1	0.197	-	7.91567
SC 2	0.377	-	8.5652
SC 3	0.473	-	6.63089
SC 4	0.13	-	9.60799
SC 5	0.305	-	8.4308
SC 6	0.447	-	10.4124
SC 7	0.235	-	7.91518
SC 8	0.258	-	7.05558
SC 9	0.308	-	5.81518
SC 10	0.414	-	9.50138
SC 11	0.221	-	13.6442
SC 12	0.33	-	10.0344
SC 13	0.296	-	10.0104
SC 14	0.151	0.712	6.9524
SC 15	0.097	0.686	14.8219
SC 16	0.198	0.703	8.94579
SC 17	0.055	0.792	14.5628
SC 18	0.289	0.495	13.7551
SC 19	0.351	0.855	14.3458
SC 20	0.243	-	12.7219
SC 21	0.417	-	10.0156
SC 22	0.118	0.79	12.6146
SC 23	0.354	-	6.89458
SC 24	0.198	-	8.60097
SC 25	0.082	0.693	20.4773
SC 26	0.116	0.715	21.2806
SC 27	0.255	-	11.15
SC 28	0.211	0.522	15.0436
SC 29	0.324	0.654	12.5739

Spermatocyte 10

	CO 1	CO 2	CO 3	SC Length
SC 1	0.434	-	-	8.55722
SC 2	0.229	-	-	6.99937
SC 3	0.478	-	-	9.71663
SC 4	0.354	-	-	6.2398
SC 5	0.337	-	-	6.39548
SC 6	0.206	-	-	5.93208
SC 7	0.368	-	-	8.79284
SC 8	0.22	0.612	-	6.30441
SC 9	0.151	0.776	-	8.09886
SC 10	0.055	0.646	-	11.7946
SC 11	0.181	0.803	-	8.60139
SC 12	0.256	0.632	-	10.2646
SC 13	0.122	0.425	-	7.73122
SC 14	0.162	0.656	-	9.95372
SC 15	0.089	0.722	-	9.23384
SC 16	0.219	0.777	-	10.518
SC 17	0.132	0.798	-	12.6726
SC 18	0.163	0.686	-	15.3329
SC 19	0.236	-	-	13.6691
SC 20	0.228	0.482	0.708	12.9809
SC 21	0.128	0.272	0.8	14.0252
SC 22	0.153	0.479	0.909	20.0526
SC 23	0.169	0.608	-	9.74932
SC 24	0.197	0.674	-	9.02125
SC 25	0.259	0.81	-	11.8868
SC 26	0.241	0.788	-	16.2833
SC 27	0.088	0.509	0.684	12.7257
SC 28	0.19	-	-	7.91042
SC 29	0.292	-	-	8.68511

Angus 7

Spermatocyte 1

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.24	-	-	-	8.33777
SC 2	0.086	0.329	0.788	-	23.9061
SC 3	0.078	0.675	-	-	18.9585
SC 4	0.104	0.427	-	-	12.3881
SC 5	0.382	0.65	-	-	16.2527
SC 6	0.254	0.683	-	-	15.7637
SC 7	0.111	0.599	-	-	9.78306
SC 8	0.26	-	-	-	13.4462
SC 9	0.107	-	-	-	14.7314
SC 10	0.309	-	-	-	7.87962
SC 11	0.524	-	-	-	10.4684
SC 12	0.256	-	-	-	15.8452
SC 13	0.263	0.656	-	-	12.2931
SC 14	0.315	-	-	-	7.54089
SC 15	0.087	0.527	-	-	11.2316
SC 16	0.097	-	-	-	12.0797
SC 17	0.235	-	-	-	12.3224
SC 18	0.472	-	-	-	7.3059
SC 19	0.34	-	-	-	11.2839
SC 20	0.132	0.936	-	-	12.8768
SC 21	0.072	-	-	-	11.7223
SC 22	0.137	0.444	-	-	7.10311
SC 23	0.255	-	-	-	7.8358
SC 24	0.126	0.61	-	-	14.6246
SC 25	0.222	0.646	-	-	18.0452
SC 26	0.042	0.304	0.59	0.881	20.9951
SC 27	0.12	0.474	0.868	-	22.095
SC 28	0.309	0.964	-	-	13.7178
SC 29	0.506	-	-	-	6.49999

Spermatocyte 2

	CO 1	CO 2	SC Length
SC 1	0.32	-	6.06235
SC 2	0.505	-	7.54677
SC 3	0.454	-	6.80442
SC 4	0.218	-	9.19177
SC 5	0.68	-	11.3415
SC 6	0.169	0.742	9.48416
SC 7	0.341	-	6.99041
SC 8	0.256	-	12.3893
SC 9	0.151	0.567	11.8717
SC 10	0.146	-	14.8252
SC 11	0.186	0.851	13.2607
SC 12	0.12	-	14.2913
SC 13	0.196	0.746	11.5795
SC 14	0.113	0.772	13.3202
SC 15	0.295	-	17.3739
SC 16	0.723	-	9.54366
SC 17	0.106	0.882	6.79203
SC 18	0.022	0.335	7.24409
SC 19	0.123	0.79	8.53279
SC 20	0.22	0.806	10.4896
SC 21	0.125	0.475	16.189
SC 22	0.212	-	15.0345
SC 23	0.098	0.45	11.7086
SC 24	0.04	-	12.4071
SC 25	0.466	0.757	8.56464
SC 26	0.162	0.456	13.7135
SC 27	0.201	-	10.2634
SC 28	0.211	0.639	11.5329
SC 29	0.276	0.479	28.2265

Spermatocyte 3

	CO 1	CO 2	CO 3	SC Length
SC 1	0.434	-	-	8.69169
SC 2	0.241	-	-	5.07773
SC 3	0.112	0.656	-	12.6734
SC 4	0.453	-	-	8.64766
SC 5	0.531	-	-	8.90281
SC 6	0.132	0.588	-	14.3116
SC 7	0.312	-	-	7.59213
SC 8	0.345	-	-	7.5194
SC 9	0.297	-	-	6.20137
SC 10	0.242	0.744	-	7.58114
SC 11	0.401	-	-	5.16579
SC 12	0.463	-	-	6.0585
SC 13	0.083	-	-	5.16579
SC 14	0.569	-	-	7.69475
SC 15	0.243	-	-	7.45675
SC 16	0.172	-	-	7.00749
SC 17	0.048	0.718	-	9.72944
SC 18	0.373	-	-	4.87956
SC 19	0.069	0.621	-	9.10245
SC 20	0.255	-	-	11.2382
SC 21	0.06	0.712	-	11.4283
SC 22	0.145	0.809	-	12.1034
SC 23	0.079	0.398	-	9.88841
SC 24	0.218	-	-	5.87881
SC 25	0.308	0.664	-	15.4153
SC 26	0.595	-	-	4.13385
SC 27	0.167	0.828	-	16.5064
SC 28	0.191	0.581	-	16.0204
SC 29	0.1	0.627	0.854	12.6234

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.123	0.414	-	8.85983
SC 2	0.219	-	-	4.87459
SC 3	0.445	-	-	6.04177
SC 4	0.12	0.464	-	9.57614
SC 5	0.442	-	-	10.3361
SC 6	0.305	0.792	-	8.11741
SC 7	0.169	-	-	15.2587
SC 8	0.339	-	-	6.97844
SC 9	0.523	-	-	7.2037
SC 10	0.346	0.723	-	15.8307
SC 11	0.101	0.657	-	16.0824
SC 12	0.135	-	-	10.4411
SC 13	0.178	-	-	7.43659
SC 14	0.431	0.732	-	11.6386
SC 15	0.071	0.842	-	9.75933
SC 16	0.055	0.76	-	7.69069
SC 17	0.33	-	-	9.65153
SC 18	0.416	-	-	6.71972
SC 19	0.143	-	-	10.004
SC 20	0.191	0.409	0.863	15.2137
SC 21	0.191	0.576	-	15.5693
SC 22	0.149	0.389	0.945	18.8133
SC 23	0.043	-	-	9.44055
SC 24	0.275	0.689	-	10.0846
SC 25	0.076	0.489	-	19.617
SC 26	0.893	-	-	10.2047
SC 27	0.365	0.804	-	13.8449
SC 28	0.159	-	-	11.6478
SC 29	0.067	0.298	-	12.5579

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.697	-	-	5.72369
SC 2	0.219	-	-	11.5641
SC 3	0.119	0.755	-	10.407
SC 4	0.063	0.803	-	11.205
SC 5	0.412	-	-	9.45763
SC 6	0.115	0.4	-	9.1945
SC 7	0.16	0.375	-	9.95925
SC 8	0.125	-	-	6.39898
SC 9	0.078	0.858	-	7.34944
SC 10	0.537	-	-	9.03294
SC 11	0.34	0.908	-	7.70392
SC 12	0.212	-	-	14.0256
SC 13	0.393	-	-	11.745
SC 14	0.418	-	-	8.70408
SC 15	0.249	-	-	11.1648
SC 16	0.383	0.744	-	19.3768
SC 17	0.049	0.582	-	7.69258
SC 18	0.147	0.755	-	18.7945
SC 19	0.353	0.641	-	12.7392
SC 20	0.355	0.758	-	12.8689
SC 21	0.346	0.577	-	10.5865
SC 22	0.083	-	-	14.2015
SC 23	0.08	0.262	-	8.21331
SC 24	0.128	0.337	0.69	14.1117
SC 25	0.353	0.772	-	12.4391
SC 26	0.427	-	-	12.984
SC 27	0.137	-	-	9.4458
SC 28	0.088	0.717	-	15.6542
SC 29	0.238	0.761	-	13.8209

Spermatocyte 6

	CO 1	CO 2	CO 3	SC Length
SC 1	0.14	0.615	-	11.1616
SC 2	0.45	-	-	9.81078
SC 3	0.149	0.471	-	12.8381
SC 4	0.07	-	-	6.2468
SC 5	0.139	0.819	-	7.47229
SC 6	0.388	-	-	7.42252
SC 7	0.127	0.524	-	8.79914
SC 8	0.433	-	-	8.94187
SC 9	0.32	0.707	-	10.3249
SC 10	0.202	0.713	-	11.1497
SC 11	0.112	0.377	0.783	13.8199
SC 12	0.191	-	-	7.72898
SC 13	0.365	-	-	15.102
SC 14	0.138	0.27	-	13.6846
SC 15	0.084	0.348	0.744	15.1409
SC 16	0.401	-	-	8.98149
SC 17	0.088	-	-	7.37947
SC 18	0.209	-	-	5.53525
SC 19	0.369	-	-	10.2143
SC 20	0.018	0.625	-	12.4026
SC 21	0.283	-	-	13.0083
SC 22	0.138	0.424	-	13.8128
SC 23	0.114	0.794	-	11.9869
SC 24	0.082	0.515	0.834	19.1241
SC 25	0.078	0.536	-	11.2427
SC 26	0.291	0.61	-	10.8324
SC 27	0.132	0.786	-	13.575
SC 28	0.253	-	-	6.35859
SC 29	0.183	-	-	11.6188

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.23	0.802	-	14.0916
SC 2	0.172	0.762	-	14.5699
SC 3	0.257	-	-	9.46757
SC 4	0.219	-	-	10.6548
SC 5	0.17	-	-	8.19826
SC 6	0.223	0.601	-	14.9465
SC 7	0.359	-	-	6.92552
SC 8	0.483	-	-	11.3639
SC 9	0.297	-	-	8.27869
SC 10	0.05	0.7	-	15.6045
SC 11	0.177	0.659	-	18.0772
SC 12	0.359	0.859	-	14.9174
SC 13	0.152	-	-	15.0491
SC 14	0.088	0.721	-	19.4213
SC 15	0.244	0.49	-	10.0442
SC 16	0.115	0.542	-	15.048
SC 17	0.441	-	-	10.9179
SC 18	0.446	0.766	-	12.0863
SC 19	0.607	-	-	12.6895
SC 20	0.26	0.826	-	12.9183
SC 21	0.136	-	-	8.02704
SC 22	0.207	0.65	-	9.88484
SC 23	0.142	0.593	0.765	19.7735
SC 24	0.106	-	-	13.784
SC 25	0.348	0.464	0.887	10.8597
SC 26	0.257	-	-	12.6722
SC 27	0.376	-	-	5.3333
SC 28	0.349	0.797	-	10.5723
SC 29	0.545	-	-	2.94385

Spermatocyte 8

	CO 1	CO 2	CO 3	SC Length
SC 1	0.357	0.565	-	8.92871
SC 2	0.294	0.697	-	6.99636
SC 3	0.282	0.765	-	4.83763
SC 4	0.322	0.526	-	11.9016
SC 5	0.088	-	-	6.24862
SC 6	0.101	0.37	0.713	12.8423
SC 7	0.432	-	-	8.09494
SC 8	0.138	0.565	-	14.7377
SC 9	0.363	-	-	5.20807
SC 10	0.138	0.789	-	7.01631
SC 11	0.234	0.566	-	9.78068
SC 12	0.102	0.732	-	9.89317
SC 13	0.125	-	-	6.62144
SC 14	0.183	0.603	-	9.84333
SC 15	0.264	0.782	-	6.80183
SC 16	0.064	0.831	-	12.2322
SC 17	0.304	-	-	5.2073
SC 18	0.196	0.917	-	8.76365
SC 19	0.035	0.561	-	12.6946
SC 20	0.265	0.479	-	8.14877
SC 21	0.392	-	-	5.45944
SC 22	0.613	-	-	5.44397
SC 23	0.112	0.639	0.806	10.8611
SC 24	0.296	0.845	-	12.5829
SC 25	0.161	0.746	-	8.3797
SC 26	0.272	0.908	-	5.52594
SC 27	0.327	0.518	0.712	16.4046
SC 28	0.149	0.645	-	8.7423
SC 29	0.435	0.532	0.797	27.6627

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.145	0.739	-	11.278
SC 2	0.234	-	-	7.66101
SC 3	0.86	-	-	10.3965
SC 4	0.157	-	-	6.64461
SC 5	0.096	-	-	12.9297
SC 6	0.071	0.505	-	13.1657
SC 7	0.085	-	-	10.9241
SC 8	0.185	0.573	-	7.70315
SC 9	0.254	-	-	11.462
SC 10	0.15	-	-	5.64256
SC 11	0.248	-	-	16.3587
SC 12	0.607	-	-	6.45169
SC 13	0.143	0.556	-	13.232
SC 14	0.195	-	-	8.90169
SC 15	0.217	0.585	-	10.9962
SC 16	0.084	0.72	-	16.5597
SC 17	0.381	-	-	5.98437
SC 18	0.261	0.921	-	17.3531
SC 19	0.304	0.72	-	10.5289
SC 20	0.272	0.524	0.915	14.4796
SC 21	0.274	-	-	4.98442
SC 22	0.166	0.798	-	9.39785
SC 23	0.14	-	-	14.5149
SC 24	0.286	0.55	-	9.61436
SC 25	0.599	-	-	8.96343
SC 26	0.57	-	-	7.28917
SC 27	0.084	-	-	5.27107
SC 28	0.693	-	-	8.12084
SC 29	0.583	-	-	12.0812

Spermatocyte 10

	CO 1	CO 2	CO 3	SC Length
SC 1	0.319	-	-	7.01463
SC 2	0.456	-	-	7.70084
SC 3	0.579	-	-	5.93453
SC 4	0.156	0.408	0.798	11.3352
SC 5	0.268	-	-	5.33316
SC 6	0.15	0.543	-	7.84259
SC 7	0.122	0.709	-	12.2361
SC 8	0.184	0.626	-	11.8753
SC 9	0.187	0.601	-	8.73747
SC 10	0.169	0.844	-	10.9573
SC 11	0.572	-	-	6.7767
SC 12	0.231	-	-	6.24008
SC 13	0.094	0.403	0.942	13.6725
SC 14	0.065	0.437	-	14.0592
SC 15	0.172	0.893	-	7.1323
SC 16	0.547	-	-	6.80316
SC 17	0.4	-	-	6.27648
SC 18	0.277	-	-	7.97503
SC 19	0.118	0.717	-	7.91686
SC 20	0.192	0.635	0.936	10.8634
SC 21	0.206	0.742	0.941	10.1702
SC 22	0.093	0.853	-	13.791
SC 23	0.313	0.607	-	11.2699
SC 24	0.392	0.705	-	13.8287
SC 25	0.377	-	-	6.04527
SC 26	0.195	0.641	-	8.32678
SC 27	0.085	0.596	-	8.39944
SC 28	0.244	0.67	-	12.2443
SC 29	0.298	0.768	-	15.9699

APPENDIX C

Crossover Placement and Synaptonemal Complex Length in Beefalo

Beefalo 1

Spermatocyte 1

	CO 1	CO 2	SC Length
SC 1	0.212	-	7.19159
SC 2	0.559	-	6.89948
SC 3	0.501	-	6.69193
SC 4	0.167	-	6.79483
SC 5	0.429	-	6.91068
SC 6	0.293	-	10.8525
SC 7	0.087	-	11.5453
SC 8	0.172	0.757	10.6213
SC 9	0.128	0.845	8.26609
SC 10	0.178	-	13.7939
SC 11	0.312	-	7.53235
SC 12	0.166	0.391	11.5977
SC 13	0.108	0.909	10.2458
SC 14	0.195	0.821	8.1718
SC 15	0.107	0.485	14.2327
SC 16	0.301	-	7.25704
SC 17	0.221	0.536	14.8723
SC 18	0.127	0.679	12.4826
SC 19	0.084	-	8.65088
SC 20	0.136	-	10.1686
SC 21	0.238	-	9.19499
SC 22	0.217	-	11.1002
SC 23	0.264	-	6.89192
SC 24	0.452	-	8.03726
SC 25	0.329	-	14.2986
SC 26	0.168	0.714	15.1336
SC 27	0.117	-	11.674
SC 28	0.273	-	6.28901
SC 29	0.205	0.878	9.44874

Spermatocyte 2

	CO 1	CO 2	CO 3	SC Length
SC 1	0.443	-	-	8.25909
SC 2	0.144	-	-	10.0192
SC 3	0.383	-	-	6.70404
SC 4	0.316	-	-	5.46378
SC 5	0.273	-	-	9.60183
SC 6	0.495	-	-	7.00686
SC 7	0.4	-	-	7.93548
SC 8	0.265	-	-	8.80768
SC 9	0.113	0.589	-	6.75668
SC 10	0.127	0.588	-	11.317
SC 11	0.336	0.506	-	10.0834
SC 12	0.233	0.796	-	11.7272
SC 13	0.196	-	-	8.90687
SC 14	0.222	0.836	-	13.1025
SC 15	0.279	-	-	10.1253
SC 16	0.384	-	-	9.02258
SC 17	0.111	0.676	-	9.28487
SC 18	0.112	0.565	0.917	12.5292
SC 19	0.058	0.45	0.921	17.0153
SC 20	0.35	-	-	8.81839
SC 21	0.437	-	-	9.18624
SC 22	0.457	-	-	4.96363
SC 23	0.413	-	-	7.67907
SC 24	0.425	-	-	7.22918
SC 25	0.162	0.77	-	13.3181
SC 26	0.367	-	-	8.16151
SC 27	0.09	0.387	-	12.9091
SC 28	0.254	0.503	-	19.6222
SC 29	0.087	0.842	-	10.2706

Spermatocyte 3

	CO 1	CO 2	SC Length
SC 1	0.601	-	6.23378
SC 2	0.264	-	5.30474
SC 3	0.427	-	7.44338
SC 4	0.373	-	8.18223
SC 5	0.208	-	11.2123
SC 6	0.265	-	5.61526
SC 7	0.199	-	8.96588
SC 8	0.344	-	5.53623
SC 9	0.386	-	9.42669
SC 10	0.315	-	5.57753
SC 11	0.475	-	8.16718
SC 12	0.196	-	9.38385
SC 13	0.291	-	10.075
SC 14	0.224	0.822	9.99488
SC 15	0.178	0.693	11.046
SC 16	0.205	0.651	12.2063
SC 17	0.192	0.69	14.4137
SC 18	0.098	0.681	16.1179
SC 19	0.122	0.782	12.3086
SC 20	0.119	0.676	10.4862
SC 21	0.289	0.737	12.5626
SC 22	0.495	-	11.1146
SC 23	0.13	0.727	7.11774
SC 24	0.081	0.62	12.8936
SC 25	0.249	0.666	10.0508
SC 26	0.448	-	12.9962
SC 27	0.163	-	11.5602
SC 28	0.353	-	9.47709
SC 29	0.151	-	10.4988

Spermatocyte 4

	CO 1	CO 2	SC Length
SC 1	0.29	-	7.60711
SC 2	0.113	-	7.02527
SC 3	0.459	-	10.1463
SC 4	0.161	0.804	12.043
SC 5	0.521	-	7.26047
SC 6	0.161	0.719	10.5922
SC 7	0.329	-	6.6444
SC 8	0.11	0.812	15.0784
SC 9	0.127	-	11.5707
SC 10	0.217	0.758	9.69234
SC 11	0.386	-	5.63248
SC 12	0.141	0.527	13.0205
SC 13	0.171	-	17.2724
SC 14	0.272	-	7.99694
SC 15	0.237	0.734	17.1783
SC 16	0.087	0.423	17.2159
SC 17	0.285	0.715	12.2707
SC 18	0.092	0.821	9.30244
SC 19	0.393	-	7.35301
SC 20	0.109	-	14.5042
SC 21	0.556	-	10.1021
SC 22	0.174	0.57	13.1347
SC 23	0.061	-	17.545
SC 24	0.152	-	9.16965
SC 25	0.072	0.92	15.206
SC 26	0.453	-	16.5339
SC 27	0.142	0.873	15.1451
SC 28	0.174	0.829	8.61714
SC 29	0.226	-	12.604

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.397	-	-	9.94049
SC 2	0.336	-	-	5.45258
SC 3	0.411	-	-	6.21824
SC 4	0.261	-	-	7.34916
SC 5	0.246	-	-	7.35007
SC 6	0.189	-	-	8.76071
SC 7	0.205	-	-	8.77492
SC 8	0.137	-	-	7.26299
SC 9	0.162	-	-	7.91217
SC 10	0.067	-	-	9.93258
SC 11	0.133	0.659	-	12.647
SC 12	0.294	-	-	14.5017
SC 13	0.051	0.59	-	14.9667
SC 14	0.153	0.594	-	11.3522
SC 15	0.253	0.492	-	12.1483
SC 16	0.232	0.571	-	9.91998
SC 17	0.321	-	-	6.0753
SC 18	0.472	-	-	5.8975
SC 19	0.131	0.538	-	13.2423
SC 20	0.262	0.727	-	14.7914
SC 21	0.099	0.599	-	15.1934
SC 22	0.222	0.706	-	11.498
SC 23	0.45	-	-	8.14065
SC 24	0.277	-	-	8.81909
SC 25	0.128	0.631	-	11.9131
SC 26	0.123	0.681	-	8.9733
SC 27	0.16	0.422	0.743	14.8026
SC 28	0.491	-	-	14.9461
SC 29	0.031	0.581	-	8.09641

Spermatocyte 6

	CO 1	CO 2	SC Length
SC 1	0.212	-	7.19159
SC 2	0.559	-	6.89948
SC 3	0.501	-	6.69193
SC 4	0.167	-	6.79483
SC 5	0.429	-	6.91068
SC 6	0.293	-	10.8525
SC 7	0.087	-	11.5453
SC 8	0.172	0.757	10.6213
SC 9	0.128	0.845	8.26609
SC 10	0.178	-	13.7939
SC 11	0.312	-	7.53235
SC 12	0.166	0.391	11.5977
SC 13	0.108	0.909	10.2458
SC 14	0.195	0.821	8.1718
SC 15	0.107	0.485	14.2327
SC 16	0.301	-	7.25704
SC 17	0.221	0.536	14.8723
SC 18	0.127	0.679	12.4826
SC 19	0.084	-	8.65088
SC 20	0.136	-	10.1686
SC 21	0.238	-	9.19499
SC 22	0.217	-	11.1002
SC 23	0.264	-	6.89192
SC 24	0.452	-	8.03726
SC 25	0.329	-	14.2986
SC 26	0.168	0.714	15.1336
SC 27	0.117	-	11.674
SC 28	0.273	-	6.28901
SC 29	0.205	0.878	9.44874

Spermatocyte 7

	CO 1	CO 2	SC Length
SC 1	0.601	-	6.23378
SC 2	0.264	-	5.30474
SC 3	0.427	-	7.44338
SC 4	0.373	-	8.18223
SC 5	0.208	-	11.2123
SC 6	0.265	-	5.61526
SC 7	0.199	-	8.96588
SC 8	0.344	-	5.53623
SC 9	0.386	-	9.42669
SC 10	0.315	-	5.57753
SC 11	0.475	-	8.16718
SC 12	0.196	-	9.38385
SC 13	0.291	-	10.075
SC 14	0.224	0.822	9.99488
SC 15	0.178	0.693	11.046
SC 16	0.205	0.651	12.2063
SC 17	0.192	0.69	14.4137
SC 18	0.098	0.681	16.1179
SC 19	0.122	0.782	12.3086
SC 20	0.119	0.676	10.4862
SC 21	0.289	0.737	12.5626
SC 22	0.495	-	11.1146
SC 23	0.13	0.727	7.11774
SC 24	0.081	0.62	12.8936
SC 25	0.249	0.666	10.0508
SC 26	0.448	-	12.9962
SC 27	0.163	-	11.5602
SC 28	0.353	-	9.47709
SC 29	0.151	-	10.4988

Spermatocyte 8

	CO 1	CO 2	CO 3	SC Length
SC 1	0.443	-	-	8.25909
SC 2	0.144	-	-	10.0192
SC 3	0.383	-	-	6.70404
SC 4	0.316	-	-	5.46378
SC 5	0.273	-	-	9.60183
SC 6	0.495	-	-	7.00686
SC 7	0.4	-	-	7.93548
SC 8	0.265	-	-	8.80768
SC 9	0.113	0.589	-	6.75668
SC 10	0.127	0.588	-	11.317
SC 11	0.336	0.506	-	10.0834
SC 12	0.233	0.796	-	11.7272
SC 13	0.196	-	-	8.90687
SC 14	0.222	0.836	-	13.1025
SC 15	0.279	-	-	10.1253
SC 16	0.384	-	-	9.02258
SC 17	0.111	0.676	-	9.28487
SC 18	0.112	0.565	0.917	12.5292
SC 19	0.058	0.45	0.921	17.0153
SC 20	0.35	-	-	8.81839
SC 21	0.437	-	-	9.18624
SC 22	0.457	-	-	4.96363
SC 23	0.413	-	-	7.67907
SC 24	0.425	-	-	7.22918
SC 25	0.162	0.77	-	13.3181
SC 26	0.367	-	-	8.16151
SC 27	0.09	0.387	-	12.9091
SC 28	0.254	0.503	-	19.6222
SC 29	0.087	0.842	-	10.2706

Spermatocyte 9

	CO 1	CO 2	SC Length
SC 1	0.29	-	7.60711
SC 2	0.113	-	7.02527
SC 3	0.459	-	10.1463
SC 4	0.161	0.804	12.043
SC 5	0.521	-	7.26047
SC 6	0.161	0.719	10.5922
SC 7	0.329	-	6.6444
SC 8	0.11	0.812	15.0784
SC 9	0.127	-	11.5707
SC 10	0.217	0.758	9.69234
SC 11	0.386	-	5.63248
SC 12	0.141	0.527	13.0205
SC 13	0.171	-	17.2724
SC 14	0.272	-	7.99694
SC 15	0.237	0.734	17.1783
SC 16	0.087	0.423	17.2159
SC 17	0.285	0.715	12.2707
SC 18	0.092	0.821	9.30244
SC 19	0.393	-	7.35301
SC 20	0.109	-	14.5042
SC 21	0.556	-	10.1021
SC 22	0.174	0.57	13.1347
SC 23	0.061	-	17.545
SC 24	0.152	-	9.16965
SC 25	0.072	0.92	15.206
SC 26	0.453	-	16.5339
SC 27	0.142	0.873	15.1451
SC 28	0.174	0.829	8.61714
SC 29	0.226	-	12.604

Spermatocyte 10

	CO 1	CO 2	CO 3	SC Length
SC 1	0.397	-	-	9.94049
SC 2	0.336	-	-	5.45258
SC 3	0.411	-	-	6.21824
SC 4	0.261	-	-	7.34916
SC 5	0.246	-	-	7.35007
SC 6	0.189	-	-	8.76071
SC 7	0.205	-	-	8.77492
SC 8	0.137	-	-	7.26299
SC 9	0.162	-	-	7.91217
SC 10	0.067	-	-	9.93258
SC 11	0.133	0.659	-	12.647
SC 12	0.294	-	-	14.5017
SC 13	0.051	0.59	-	14.9667
SC 14	0.153	0.594	-	11.3522
SC 15	0.253	0.492	-	12.1483
SC 16	0.232	0.571	-	9.91998
SC 17	0.321	-	-	6.0753
SC 18	0.472	-	-	5.8975
SC 19	0.131	0.538	-	13.2423
SC 20	0.262	0.727	-	14.7914
SC 21	0.099	0.599	-	15.1934
SC 22	0.222	0.706	-	11.498
SC 23	0.45	-	-	8.14065
SC 24	0.277	-	-	8.81909
SC 25	0.128	0.631	-	11.9131
SC 26	0.123	0.681	-	8.9733
SC 27	0.16	0.422	0.743	14.8026
SC 28	0.491	-	-	14.9461
SC 29	0.031	0.581	-	8.09641

Beefalo 2

Spermatocyte 1

	1 CO	2 CO	SC Length
SC 1	0.101	0.709	9.34878
SC 2	0.455	-	6.34438
SC 3	0.496	-	6.76585
SC 4	0.228	-	6.10596
SC 5	0.319	-	5.51488
SC 6	0.345	-	6.02196
SC 7	0.493	-	5.7057
SC 8	0.605	-	8.42919
SC 9	0.396	-	7.29239
SC 10	0.192	-	8.0997
SC 11	0.242	-	12.993
SC 12	0.156	-	9.70669
SC 13	0.23	-	14.0279
SC 14	0.353	-	8.43836
SC 15	0.032	0.554	13.2609
SC 16	0.478	-	10.7067
SC 17	0.154	0.598	10.0237
SC 18	0.115	0.838	9.06577
SC 19	0.141	0.544	12.1981
SC 20	0.189	0.591	10.251
SC 21	0.242	0.411	6.7697
SC 22	0.302	-	9.15229
SC 23	0.458	-	15.6842
SC 24	0.133	-	13.3639
SC 25	0.403	0.654	14.5812
SC 26	0.082	0.618	12.3295
SC 27	0.109	0.591	13.409
SC 28	0.086	0.714	13.3258
SC 29	0.291	0.647	9.2806

Spermatocyte 2

	1 CO	2 CO	3 CO	4 CO	SC Length
SC 1	0.272	-	-	-	8.78983
SC 2	0.235	-	-	-	6.97473
SC 3	0.437	-	-	-	6.51707
SC 4	0.069	0.587	-	-	5.73328
SC 5	0.094	0.757	-	-	8.87075
SC 6	0.222	0.753	-	-	13.685
SC 7	0.319	0.6	-	-	10.0073
SC 8	0.143	0.747	-	-	9.72447
SC 9	0.422	0.705	-	-	6.90403
SC 10	0.343	0.682	-	-	8.33945
SC 11	0.14	0.587	0.735	-	14.1674
SC 12	0.055	0.45	0.807	-	12.8106
SC 13	0.064	0.537	-	-	11.72
SC 14	0.142	0.78	-	-	5.96638
SC 15	0.289	0.589	-	-	5.99844
SC 16	0.257	0.517	-	-	9.01572
SC 17	0.282	0.757	-	-	9.64089
SC 18	0.204	0.444	-	-	8.41547
SC 19	0.192	0.822	-	-	14.0384
SC 20	0.146	0.447	-	-	10.1271
SC 21	0.374	-	-	-	3.45506
SC 22	0.333	-	-	-	4.75909
SC 23	0.134	0.483	0.732	-	13.572
SC 24	0.093	0.87	-	-	18.1766
SC 25	0.253	0.814	-	-	12.6545
SC 26	0.194	0.634	-	-	9.15124
SC 27	0.192	-	-	-	7.79821
SC 28	0.148	0.74	-	-	13.1368
SC 29	0.142	0.373	0.523	0.882	23.8783

Spermatocyte 3

	1 CO	2 CO	SC Length
SC 1	0.241	-	10.5496
SC 2	0.413	-	14.49
SC 3	0.396	-	11.2599
SC 4	0.264	-	7.55727
SC 5	0.293	-	10.1742
SC 6	0.177	-	7.37793
SC 7	0.378	-	9.59651
SC 8	0.096	0.769	17.1951
SC 9	0.11	0.887	15.3145
SC 10	0.153	0.827	19.3104
SC 11	0.132	0.741	10.5298
SC 12	0.202	0.503	7.66563
SC 13	0.3	0.492	13.7227
SC 14	0.313	0.658	15.5299
SC 15	0.112	0.517	14.3607
SC 16	0.182	0.815	14.4332
SC 17	0.169	0.493	11.2506
SC 18	0.447	-	10.9474
SC 19	0.063	0.878	17.8079
SC 20	0.208	0.691	11.3449
SC 21	0.39	-	4.48637
SC 22	0.199	-	10.6796
SC 23	0.345	-	4.17277
SC 24	0.112	-	12.2491
SC 25	0.325	-	6.55382
SC 26	0.499	-	7.46781
SC 27	0.348	-	15.1482
SC 28	0.122	0.813	10.3683
SC 29	0.097	0.644	14.2768

Spermatocyte 4

	1 CO	2 CO	3 CO	SC Length
SC 1	0.318	-	-	7.52045
SC 2	0.153	-	-	5.47652
SC 3	0.286	-	-	8.56044
SC 4	0.259	-	-	10.0614
SC 5	0.097	-	-	12.8799
SC 6	0.435	-	-	6.6647
SC 7	0.068	-	-	20.2829
SC 8	0.143	-	-	7.4697
SC 9	0.488	-	-	6.30665
SC 10	0.542	-	-	7.32221
SC 11	0.094	0.634	-	6.36125
SC 12	0.154	0.859	-	9.19317
SC 13	0.183	0.748	-	14.7552
SC 14	0.255	0.672	-	12.8507
SC 15	0.323	0.518	-	11.9171
SC 16	0.315	0.514	-	13.3191
SC 17	0.306	0.618	-	13.0395
SC 18	0.205	-	-	7.51485
SC 19	0.104	0.36	0.778	9.1679
SC 20	0.233	-	-	12.6607
SC 21	0.228	0.839	-	8.58732
SC 22	0.097	0.778	-	12.7765
SC 23	0.514	-	-	7.07189
SC 24	0.196	0.675	-	8.21961
SC 25	0.294	-	-	5.93117
SC 26	0.07	0.689	-	12.1152
SC 27	0.509	-	-	8.69848
SC 28	0.498	-	-	5.3984
SC 29	0.233	-	-	9.88463

Spermatocyte 5

	1 CO	2 CO	3 CO	SC Length
SC 1	0.253	-	-	9.719
SC 2	0.31	-	-	6.418
SC 3	0.255	-	-	5.676
SC 4	0.069	0.491	-	9.373
SC 5	0.197	0.732	-	7.813
SC 6	0.432	-	-	6.537
SC 7	0.409	-	-	6.186
SC 8	0.47	-	-	7.233
SC 9	0.212	-	-	9.854
SC 10	0.457	-	-	6.377
SC 11	0.529	-	-	10.09
SC 12	0.117	0.83	-	7.818
SC 13	0.237	0.581	-	10.56
SC 14	0.125	0.529	-	9.301
SC 15	0.327	0.643	-	10.18
SC 16	0.186	0.778	-	6.618
SC 17	0.132	0.68	-	7.062
SC 18	0.234	0.841	-	12.8
SC 19	0.289	0.786	-	12.74
SC 20	0.407	0.655	-	10.85
SC 21	0.202	0.823	-	13.09
SC 22	0.065	0.269	0.75	15.65
SC 23	0.188	0.649	0.811	13.6
SC 24	0.059	0.599	-	11.95
SC 25	0.104	0.592	0.863	14.62
SC 26	0.133	0.481	-	16.76
SC 27	0.037	0.397	0.652	15.97
SC 28	0.147	0.535	0.846	13.08
SC 29	0.162	0.364	0.765	12.08

Spermatocyte 6

	1 CO	2 CO	3 CO	SC Length
SC 1	0.48	-	-	6.65854
SC 2	0.258	-	-	10.8438
SC 3	0.412	-	-	7.89292
SC 4	0.365	-	-	7.52451
SC 5	0.15	-	-	9.76864
SC 6	0.282	-	-	9.52763
SC 7	0.21	-	-	13.2416
SC 8	0.42	-	-	5.7925
SC 9	0.171	0.612	-	13.3821
SC 10	0.17	0.574	-	10.9419
SC 11	0.074	0.679	-	11.3755
SC 12	0.161	0.615	-	13.5019
SC 13	0.176	0.689	-	16.0957
SC 14	0.064	0.546	-	12.5721
SC 15	0.132	0.495	-	16.1183
SC 16	0.067	0.687	-	11.4776
SC 17	0.12	0.8	-	12.1995
SC 18	0.131	0.864	-	9.12261
SC 19	0.086	0.825	-	11.2595
SC 20	0.127	0.288	0.678	13.1977
SC 21	0.063	0.527	-	13.3068
SC 22	0.129	0.484	-	10.7621
SC 23	0.429	-	-	7.86849
SC 24	0.169	0.456	-	8.4469
SC 25	0.147	-	-	9.44076
SC 26	0.518	-	-	6.28537
SC 27	0.27	0.575	-	13.8646
SC 28	0.301	0.63	-	12.1316
SC 29	0.111	-	-	6.28663

Spermatocyte 7

	1 CO	2 CO	3 CO	SC Length
SC 1	0.29	-	-	6.443
SC 2	0.394	-	-	6.024
SC 3	0.464	-	-	9.102
SC 4	0.456	-	-	6.862
SC 5	0.208	-	-	6.755
SC 6	0.331	-	-	7.639
SC 7	0.191	0.79	-	9.431
SC 8	0.09	-	-	9.137
SC 9	0.15	0.667	-	6.699
SC 10	0.257	0.733	-	9.282
SC 11	0.217	0.723	-	8.479
SC 12	0.121	0.539	-	11.81
SC 13	0.138	0.659	-	8.805
SC 14	0.238	0.654	-	11.31
SC 15	0.157	0.798	-	12.43
SC 16	0.124	0.472	-	13.59
SC 17	0.121	-	-	15.55
SC 18	0.094	0.792	-	11.85
SC 19	0.202	0.56	-	7.685
SC 20	0.521	-	-	5.192
SC 21	0.207	0.603	-	12.22
SC 22	0.149	0.768	-	12.6
SC 23	0.456	-	-	6.002
SC 24	0.337	0.789	-	9.586
SC 25	0.32	-	-	6.625
SC 26	0.201	0.439	0.803	15.08
SC 27	0.182	0.407	0.78	12.18
SC 28	0.138	-	-	5.675
SC 29	0.206	0.711	-	8.96

Spermatocyte 8

	1 CO	2 CO	3 CO	SC Length
SC 1	0.511	-	-	10.2003
SC 2	0.433	-	-	6.39177
SC 3	0.364	-	-	5.985
SC 4	0.385	-	-	7.94437
SC 5	0.424	-	-	7.08897
SC 6	0.191	-	-	8.904
SC 7	0.188	0.767	-	8.0311
SC 8	0.308	0.707	-	9.17518
SC 9	0.059	0.411	-	9.94889
SC 10	0.056	0.735	-	10.1137
SC 11	0.212	0.635	-	15.2188
SC 12	0.125	0.606	-	11.272
SC 13	0.48	-	-	4.30591
SC 14	0.396	-	-	14.3557
SC 15	0.1	-	-	8.87677
SC 16	0.131	0.329	0.751	18.4049
SC 17	0.142	-	-	9.89149
SC 18	0.427	0.682	-	15.3096
SC 19	0.15	0.593	-	12.1173
SC 20	0.608	-	-	10.9377
SC 21	0.39	-	-	13.6373
SC 22	0.528	0.702	-	17.5464
SC 23	0.203	0.735	-	8.43857
SC 24	0.203	-	-	13.749
SC 25	0.197	-	-	6.84145
SC 26	0.116	-	-	14.0214
SC 27	0.289	0.929	-	19.5841
SC 28	0.092	0.366	0.727	15.5535
SC 29	0.172	-	-	10.2587

Spermatocyte 9

	1 CO	2 CO	3 CO	SC Length
SC 1	0.405	-	-	6.13802
SC 2	0.614	-	-	8.862
SC 3	0.263	-	-	10.0799
SC 4	0.131	0.516	0.903	16.4408
SC 5	0.241	-	-	13.2599
SC 6	0.319	0.515	-	17.2639
SC 7	0.173	-	-	13.5335
SC 8	0.203	0.524	0.848	24.2902
SC 9	0.11	0.557	-	14.1977
SC 10	0.143	0.52	0.805	17.5512
SC 11	0.239	0.769	-	9.94546
SC 12	0.213	0.658	-	14.4458
SC 13	0.161	-	-	12.8908
SC 14	0.42	-	-	11.2167
SC 15	0.339	-	-	9.97451
SC 16	0.332	-	-	13.4862
SC 17	0.099	-	-	12.2284
SC 18	0.215	0.593	-	11.8945
SC 19	0.517	-	-	7.02072
SC 20	0.171	-	-	8.05686
SC 21	0.513	-	-	7.64491
SC 22	0.085	-	-	9.42592
SC 23	0.372	-	-	8.00422
SC 24	0.147	0.871	-	7.82271
SC 25	0.121	0.814	-	15.7966
SC 26	0.38	-	-	10.5421
SC 27	0.36	-	-	10.6196
SC 28	0.282	0.557	-	13.9481
SC 29	0.465	-	-	20.9818

Spermatocyte 10

	CO 1	CO 2	CO 3	SC Length
SC 1	0.296	-	-	8.02025
SC 2	0.314	-	-	6.67898
SC 3	0.153	0.67	-	7.53431
SC 4	0.276	-	-	6.86707
SC 5	0.288	0.569	-	6.81072
SC 6	0.274	-	-	8.21219
SC 7	0.191	-	-	9.04512
SC 8	0.398	-	-	5.11119
SC 9	0.165	0.665	-	9.72783
SC 10	0.127	0.877	-	12.2096
SC 11	0.164	0.692	-	5.49276
SC 12	0.184	0.772	-	13.2173
SC 13	0.101	0.614	0.795	14.0561
SC 14	0.11	0.8	-	12.9273
SC 15	0.268	0.574	-	8.95447
SC 16	0.32	0.588	-	11.0519
SC 17	0.187	0.476	-	13.6255
SC 18	0.072	0.702	-	13.84
SC 19	0.197	0.67	-	9.56648
SC 20	0.337	-	-	10.5803
SC 21	0.21	-	-	13.568
SC 22	0.472	-	-	5.35612
SC 23	0.46	-	-	4.75405
SC 24	0.187	0.726	-	8.94145
SC 25	0.491	-	-	3.02288
SC 26	0.164	-	-	8.20022
SC 27	0.129	0.808	-	13.0483
SC 28	0.344	0.566	-	12.9514
SC 29	0.151	0.67	-	9.22019

Beefalo 3

Spermatocyte 1

	CO 1	CO 2	CO 3	SC Length
SC 1	0.41075	-	-	10.3844
SC 2	0.47162	-	-	6.94456
SC 3	0.44304	-	-	10.2164
SC 4	0.24337	-	-	6.30119
SC 5	0.41709	-	-	6.03799
SC 6	0.49476	-	-	7.20867
SC 7	0.46929	-	-	5.99319
SC 8	0.41622	-	-	10.0359
SC 9	0.46082	-	-	6.8257
SC 10	0.39553	0.77789	-	11.2149
SC 11	0.1518	0.74934	-	9.10973
SC 12	0.35559	0.94527	-	13.6726
SC 13	0.35177	0.82773	-	7.16527
SC 14	0.3909	0.83897	-	10.048
SC 15	0.28416	0.82354	-	14.6296
SC 16	0.3023	0.88902	-	15.6377
SC 17	0.26772	0.78997	-	29.1398
SC 18	0.16178	0.70042	-	12.627
SC 19	0.22751	0.81277	-	10.6181
SC 20	0.21665	0.84717	-	16.4961
SC 21	0.17388	0.47198	0.75948	18.2111
SC 22	0.14318	0.57675	0.88762	13.4497
SC 23	0.11869	0.69392	-	10.4174
SC 24	0.34964	0.84673	-	8.40847
SC 25	0.08092	0.9212	-	15.8409
SC 26	0.20125	0.69819	-	8.35338
SC 27	0.13106	0.84942	-	10.1654
SC 28	0.54368	0.72536	-	13.3803
SC 29	0.21024	-	-	7.50449

Spermatocyte 2

	CO 1	CO 2	SC Length
SC 1	0.25655	-	7.46032
SC 2	0.1962	-	8.97064
SC 3	0.44476	-	8.0542
SC 4	0.12178	-	12.3983
SC 5	0.10934	-	11.2578
SC 6	0.43626	-	14.8906
SC 7	0.32305	-	8.17915
SC 8	0.41117	-	9.3408
SC 9	0.26367	0.67999	14.9126
SC 10	0.55888	0.70831	11.0568
SC 11	0.17127	0.93837	24.0798
SC 12	0.23135	0.75365	17.51
SC 13	0.1065	0.73802	14.942
SC 14	0.22226	0.85564	15.089
SC 15	0.08584	0.69631	23.2212
SC 16	0.22495	0.898	11.2272
SC 17	0.06646	0.83462	18.6502
SC 18	0.31832	0.81695	15.0465
SC 19	0.14861	0.5052	14.8865
SC 20	0.17508	0.62839	18.101
SC 21	0.18465	0.52451	23.7442
SC 22	0.34384	-	15.4925
SC 23	0.17884	-	9.60967
SC 24	0.17402	-	7.6237
SC 25	0.16346	-	7.5628
SC 26	0.09448	-	15.7434
SC 27	0.22957	-	10.0218
SC 28	0.10392	-	14.5887
SC 29	0.2157	0.69566	13.811

Spermatocyte 3

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.20847	-	-	-	8.12805
SC 2	0.14434	-	-	-	8.58613
SC 3	0.14287	-	-	-	7.05292
SC 4	0.33411	-	-	-	6.73589
SC 5	0.14391	-	-	-	7.51877
SC 6	0.47107	-	-	-	14.3728
SC 7	0.63637	-	-	-	12.1915
SC 8	0.38581	-	-	-	7.34818
SC 9	0.31701	-	-	-	6.433
SC 10	0.17182	-	-	-	6.88121
SC 11	0.2284	0.7927	-	-	18.0114
SC 12	0.52238	0.94142	-	-	11.7838
SC 13	0.20037	0.56383	-	-	13.551
SC 14	0.22874	0.93943	-	-	12.3962
SC 15	0.05545	0.83235	-	-	11.9235
SC 16	0.42774	0.8297	-	-	11.5165
SC 17	0.2837	0.53447	-	-	12.0289
SC 18	0.42792	0.90976	-	-	14.9899
SC 19	0.6706	0.77591	-	-	18.2704
SC 20	0.10424	0.83134	-	-	15.1127
SC 21	0.51819	0.92931	-	-	17.7232
SC 22	0.01899	0.95488	-	-	25.8046
SC 23	0.26456	0.69031	-	-	23.043
SC 24	0.1917	-	-	-	9.4955
SC 25	0.31789	-	-	-	17.7394
SC 26	0.43194	0.94011	-	-	17.0308
SC 27	0.16237	0.72613	-	-	12.329
SC 28	0.09016	0.26502	0.5655	0.77777	28.9538
SC 29	0.20934	0.51226	0.76896	0.73875	18.3369

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.28561	-	-	10.1332
SC 2	0.36553	-	-	9.94714
SC 3	0.39723	-	-	9.98431
SC 4	0.46334	-	-	16.7635
SC 5	0.30885	-	-	14.6901
SC 6	0.40257	-	-	12.7388
SC 7	0.4115	-	-	11.2645
SC 8	0.2643	-	-	15.8517
SC 9	0.31393	-	-	17.6068
SC 10	0.30747	-	-	19.16
SC 11	0.34695	0.83617	-	17.9787
SC 12	0.1913	0.93	-	13.8514
SC 13	0.61719	0.86383	-	11.9518
SC 14	0.28046	0.79128	-	16.1649
SC 15	0.1267	0.75505	-	16.7247
SC 16	0.12552	0.43242	0.89449	17.9555
SC 17	0.08669	0.60591	0.86667	26.1589
SC 18	0.29219	0.63698	-	15.4701
SC 19	0.2188	0.86273	-	13.288
SC 20	0.08637	0.49488	0.84555	19.8631
SC 21	0.22843	0.72645	-	17.467
SC 22	0.2686	0.84632	-	14.5845
SC 23	0.12387	0.74617	-	18.681
SC 24	0.21499	0.53267	0.84992	20.3178
SC 25	0.37014	0.5445	0.96901	23.0663
SC 26	0.18883	-	-	11.275
SC 27	0.23753	0.52526	-	21.1704
SC 28	0.07328	-	-	13.8562
SC 29	0.22684	0.91772	-	17.2155

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.11022	-	-	8.08339
SC 2	0.32973	-	-	9.58874
SC 3	0.29815	-	-	5.86593
SC 4	0.34646	-	-	6.84117
SC 5	0.27106	-	-	6.38295
SC 6	0.27301	-	-	5.76842
SC 7	0.41933	-	-	9.40338
SC 8	0.26784	-	-	5.53049
SC 9	0.37208	-	-	9.34052
SC 10	0.31731	-	-	9.56865
SC 11	0.22138	-	-	7.4277
SC 12	0.26674	-	-	6.67905
SC 13	0.21604	-	-	8.57843
SC 14	0.30339	0.90531	-	14.0433
SC 15	0.2325	0.67479	-	12.4042
SC 16	0.13133	0.78692	-	9.3128
SC 17	0.57178	0.91221	-	11.4799
SC 18	0.11753	0.61841	-	15.4998
SC 19	0.10117	0.82764	-	16.7231
SC 20	0.17779	0.62992	-	9.5046
SC 21	0.22273	0.93733	-	13.6385
SC 22	0.25537	0.73624	-	13.8573
SC 23	0.45829	0.82069	-	10.3001
SC 24	0.15695	0.72344	-	11.8042
SC 25	0.18276	0.92648	-	14.0936
SC 26	0.11305	0.78534	-	14.4786
SC 27	0.50163	0.96473	-	9.92285
SC 28	0.40528	0.84009	-	10.012
SC 29	0.13011	0.29523	0.9241	16.7513

Spermatocyte 6

	CO 1	CO 2	CO 3	SC Length
SC 1	0.22529	-	-	5.49682
SC 2	0.13036	-	-	7.46564
SC 3	0.43426	-	-	5.70269
SC 4	0.3374	-	-	5.11301
SC 5	0.14026	-	-	5.2514
SC 6	0.28929	-	-	6.4043
SC 7	0.49452	-	-	7.62048
SC 8	0.16649	-	-	6.6787
SC 9	0.48151	-	-	14.7469
SC 10	0.37424	-	-	5.67588
SC 11	0.33478	0.76301	-	12.4186
SC 12	0.23431	0.91713	-	15.2049
SC 13	0.28066	0.54516	-	9.18519
SC 14	0.31955	0.77149	-	10.5372
SC 15	0.2827	0.93106	-	13.6792
SC 16	0.45652	0.87387	-	7.189
SC 17	0.3783	0.90817	-	11.6795
SC 18	0.39397	0.85871	-	9.8931
SC 19	0.12157	0.79598	-	9.11708
SC 20	0.21693	0.55049	-	13.0682
SC 21	0.55438	0.77398	-	15.1163
SC 22	0.55534	0.85446	-	11.1183
SC 23	0.20769	0.94552	-	10.2792
SC 24	0.09382	0.82784	-	9.25001
SC 25	0.13222	0.67603	-	10.0201
SC 26	0.14196	0.6899	-	15.936
SC 27	0.15853	0.55688	-	10.9999
SC 28	0.61619	0.7519	-	15.5937
SC 29	0.41612	0.63346	0.86702	25.5605

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.34377	-	-	7.06986
SC 2	0.39014	-	-	7.03409
SC 3	0.28779	-	-	7.64624
SC 4	0.28102	-	-	10.5193
SC 5	0.43382	-	-	7.60732
SC 6	0.47123	-	-	8.68497
SC 7	0.42662	-	-	14.1332
SC 8	0.3536	0.85187	-	7.88991
SC 9	0.11976	0.89528	-	12.0345
SC 10	0.18271	0.71696	-	14.6313
SC 11	0.12518	0.72548	-	11.0695
SC 12	0.35421	0.79106	-	9.79244
SC 13	0.09763	0.79435	-	10.4858
SC 14	0.08865	0.80676	-	13.9523
SC 15	0.26183	0.82945	-	9.71859
SC 16	0.18051	0.77114	-	8.55687
SC 17	0.36	0.939	-	11.7319
SC 18	0.11014	0.91342	-	15.5149
SC 19	0.24296	0.88481	-	20.7708
SC 20	0.11635	0.86625	-	18.7333
SC 21	0.29949	0.82396	-	14.069
SC 22	0.25076	0.56319	-	16.3934
SC 23	0.11197	0.36919	0.88869	15.4312
SC 24	0.26374	0.52016	0.86163	15.4589
SC 25	0.37703	0.94525	-	17.8957
SC 26	0.1378	0.81649	-	13.9184
SC 27	0.16871	-	-	7.30961
SC 28	0.35954	0.68879	-	14.7652
SC 29	0.26872	0.70506	-	11.1225

Spermatocyte 8

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.38758	-	-	-	6.96136
SC 2	0.48909	-	-	-	10.5629
SC 3	0.20871	-	-	-	6.53079
SC 4	0.27409	-	-	-	6.21691
SC 5	0.47475	-	-	-	5.27667
SC 6	0.28002	-	-	-	11.239
SC 7	0.47668	-	-	-	14.4436
SC 8	0.41281	-	-	-	9.31014
SC 9	0.22751	-	-	-	9.46351
SC 10	0.42945	-	-	-	11.0268
SC 11	0.49272	-	-	-	11.5387
SC 12	0.36497	-	-	-	6.57965
SC 13	0.3531	-	-	-	7.92316
SC 14	0.24377	-	-	-	6.19521
SC 15	0.14439	0.81228	-	-	13.6503
SC 16	0.46252	0.88093	-	-	10.9693
SC 17	0.13327	0.88972	-	-	13.8177
SC 18	0.14726	0.84424	-	-	12.6256
SC 19	0.16654	0.60828	0.95947	-	16.7665
SC 20	0.1594	0.68875	-	-	14.4996
SC 21	0.47003	0.85582	-	-	9.46309
SC 22	0.12688	0.8092	-	-	9.17686
SC 23	0.50595	0.91746	-	-	7.63224
SC 24	0.14161	0.90619	-	-	14.3634
SC 25	0.47601	0.94039	-	-	17.2953
SC 26	0.17658	0.54065	0.94023	-	14.0009
SC 27	0.19877	-	-	-	7.30177
SC 28	0.11521	0.91103	-	-	13.8173
SC 29	0.23611	0.61623	0.79891	0.91151	20.9562

Spermatocyte 9

	CO 1	CO 2	SC Length
SC 1	0.336	-	6.63404
SC 2	0.213	-	9.73588
SC 3	0.246	-	8.83008
SC 4	0.567	-	6.29286
SC 5	0.457	-	6.01951
SC 6	0.478	-	10.2387
SC 7	0.531	-	14.86
SC 8	0.158	0.674	6.2531
SC 9	0.08	0.643	9.13584
SC 10	0.216	0.724	12.4203
SC 11	0.154	0.674	10.1198
SC 12	0.098	0.635	10.1212
SC 13	0.263	0.796	6.48445
SC 14	0.173	0.68	7.10094
SC 15	0.162	0.806	13.4504
SC 16	0.543	-	9.00662
SC 17	0.049	0.786	11.6218
SC 18	0.238	0.846	15.0905
SC 19	0.099	0.889	16.3139
SC 20	0.141	0.645	16.0342
SC 21	0.089	0.532	8.90974
SC 22	0.105	0.721	15.1491
SC 23	0.13	0.548	17.7675
SC 24	0.218	0.504	10.1548
SC 25	0.095	0.499	13.383
SC 26	0.425	-	6.60198
SC 27	0.269	0.593	14.5146
SC 28	0.166	-	7.14147
SC 29	0.124	0.797	14.2369

Spermatocyte 10

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.38043	-	-	-	12.3107
SC 2	0.49696	-	-	-	6.6906
SC 3	0.4459	-	-	-	6.98859
SC 4	0.43464	-	-	-	7.11473
SC 5	0.23791	-	-	-	5.88861
SC 6	0.37092	-	-	-	7.65499
SC 7	0.25837	-	-	-	9.6831
SC 8	0.26304	0.78301	-	-	8.9586
SC 9	0.32588	0.70236	-	-	8.40861
SC 10	0.07514	0.87063	-	-	12.2046
SC 11	0.55467	0.92858	-	-	11.2624
SC 12	0.50104	0.8493	-	-	10.642
SC 13	0.17375	0.76591	-	-	8.73817
SC 14	0.26333	0.89283	-	-	15.1943
SC 15	0.28391	0.60848	-	-	13.8447
SC 16	0.31406	0.74611	-	-	11.0744
SC 17	0.45038	0.76127	-	-	10.5531
SC 18	0.36288	0.8254	-	-	9.85789
SC 19	0.4209	0.80266	-	-	9.68996
SC 20	0.42407	0.91388	-	-	10.1789
SC 21	0.38063	0.8997	-	-	9.38266
SC 22	0.29089	0.73982	-	-	14.9083
SC 23	0.19002	0.86655	-	-	7.38633
SC 24	0.11967	0.63309	-	-	16.2471
SC 25	0.31532	0.87372	-	-	18.3623
SC 26	0.18352	0.8552	-	-	12.7382
SC 27	0.11797	0.37721	0.89746	-	15.9001
SC 28	0.11485	0.38547	0.82876	-	13.4091
SC 29	0.19508	0.32648	0.54345	0.86936	16.5311

Beefalo 4

Spermatocyte 1

	CO 1	CO 2	CO 3	SC Length
SC 1	0.36867	-	-	8.46384
SC 2	0.43937	-	-	12.0039
SC 3	0.48378	-	-	16.211
SC 4	0.38656	-	-	10.1583
SC 5	0.45615	-	-	13.9372
SC 6	0.40814	-	-	11.4377
SC 7	0.24651	-	-	13.858
SC 8	0.23192	-	-	8.45411
SC 9	0.40363	-	-	9.76878
SC 10	0.45926	-	-	8.91429
SC 11	0.339	-	-	7.33467
SC 12	0.26455	-	-	8.99178
SC 13	0.26268	-	-	13.0451
SC 14	0.30054	-	-	17.92
SC 15	0.41736	-	-	16.9012
SC 16	0.19136	0.9151	-	14.6796
SC 17	0.24308	0.8743	-	11.0757
SC 18	0.38356	0.85034	-	15.4937
SC 19	0.18983	-	-	13.7866
SC 20	0.39524	0.75611	-	18.2132
SC 21	0.36839	0.93307	-	9.90584
SC 22	0.46185	0.83744	-	12.5577
SC 23	0.17873	0.65661	-	22.1361
SC 24	0.33037	0.71453	-	19.2616
SC 25	0.05005	0.71743	-	22.3301
SC 26	0.27901	0.44278	0.81072	32.7329
SC 27	0.24002	0.42396	0.5154	26.5034
SC 28	0.27485	0.6581	-	21.7079
SC 29	0.22933	0.91466	-	24.4671

Spermatocyte 2

	CO 1	CO 2	SC Length
SC 1	0.2571	-	7.49966
SC 2	0.45197	-	11.5564
SC 3	0.20869	-	8.16116
SC 4	0.41239	-	10.3098
SC 5	0.25762	-	6.40717
SC 6	0.42663	-	10.4683
SC 7	0.30402	-	6.73687
SC 8	0.17424	-	7.60718
SC 9	0.45527	-	8.33336
SC 10	0.29033	-	13.7407
SC 11	0.05093	0.82278	18.3041
SC 12	0.32263	0.62332	15.265
SC 13	0.21171	0.89126	13.5433
SC 14	0.25849	0.63959	16.0063
SC 15	0.22201	0.98011	11.4591
SC 16	0.27677	0.8356	15.5448
SC 17	0.26744	0.84234	9.39554
SC 18	0.47831	0.93253	10.2226
SC 19	0.38832	0.76512	10.246
SC 20	0.26453	0.9399	15.4921
SC 21	0.24898	0.49339	19.0073
SC 22	0.31774	0.8432	16.1173
SC 23	0.20272	0.54423	15.3457
SC 24	0.61247	0.82051	16.4337
SC 25	0.34792	0.67458	17.2777
SC 26	0.181	-	5.4824
SC 27	0.2472	-	6.78398
SC 28	0.31096	-	6.77845
SC 29	0.30543	-	7.56322

Spermatocyte 3

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.184	-	-	-	7.589
SC 2	0.259	-	-	-	6.366
SC 3	0.442	-	-	-	9.124
SC 4	0.457	-	-	-	9.709
SC 5	0.299	-	-	-	10.6
SC 6	0.386	-	-	-	10.76
SC 7	0.149	-	-	-	10.42
SC 8	0.361	-	-	-	7.08
SC 9	0.201	-	-	-	6.71
SC 10	0.447	-	-	-	7.521
SC 11	0.329	-	-	-	18.2
SC 12	0.286	-	-	-	7.032
SC 13	0.21	0.775	-	-	12.24
SC 14	0.329	0.753	-	-	16.24
SC 15	0.233	0.598	-	-	10.44
SC 16	0.241	0.743	-	-	8.057
SC 17	0.1	0.881	-	-	9.944
SC 18	0.52	0.827	-	-	7.649
SC 19	0.261	0.601	-	-	13.13
SC 20	0.439	0.891	-	-	10.59
SC 21	0.2	0.909	-	-	14.81
SC 22	0.071	0.93	-	-	11.11
SC 23	0.245	0.767	-	-	14.04
SC 24	0.271	0.87	-	-	16.46
SC 25	0.188	0.878	0.968	-	13.59
SC 26	0.138	0.561	0.906	-	15.39
SC 27	0.11	0.448	0.953	-	19.77
SC 28	0.056	0.399	0.7	0.918	20.21
SC 29	0.482	0.923	-	-	15.36

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.33512	-	-	6.86385
SC 2	0.44994	-	-	6.50307
SC 3	0.08234	-	-	8.45348
SC 4	0.34986	-	-	7.21301
SC 5	0.19542	-	-	8.67265
SC 6	0.36196	-	-	11.2566
SC 7	0.34257	-	-	13.3587
SC 8	0.36861	-	-	9.73105
SC 9	0.17831	-	-	11.2322
SC 10	0.35602	-	-	13.0848
SC 11	0.48415	-	-	7.89005
SC 12	0.07193	0.81166	-	12.9802
SC 13	0.18731	0.43684	-	12.4938
SC 14	0.30213	0.60476	-	13.1961
SC 15	0.28807	0.76332	-	19.4403
SC 16	0.47932	0.93158	-	18.416
SC 17	0.32789	0.72912	-	10.428
SC 18	0.53498	0.8445	-	7.09975
SC 19	0.20915	0.8146	-	10.0701
SC 20	0.14643	0.80125	-	7.4669
SC 21	0.32498	0.76743	-	6.41298
SC 22	0.37684	0.90934	-	16.2401
SC 23	0.31242	0.70492	-	14.1979
SC 24	0.46454	-	-	9.36012
SC 25	0.06524	-	-	14.2367
SC 26	0.34161	-	-	10.3275
SC 27	0.49401	-	-	4.34364
SC 28	0.32338	0.45687	0.85805	20.3952
SC 29	0.21348	-	-	12.0868

Spermatocyte 5

	CO 1	CO 2	SC Length
SC 1	0.3008	-	3.02267
SC 2	0.38641	-	2.69052
SC 3	0.3929	-	4.2784
SC 4	0.12041	-	2.4626
SC 5	0.34659	-	3.58589
SC 6	0.08551	-	4.09304
SC 7	0.30247	-	7.62433
SC 8	0.29948	-	2.96611
SC 9	0.38506	-	4.16479
SC 10	0.4142	-	4.21085
SC 11	0.39884	-	4.01513
SC 12	0.43463	-	6.50356
SC 13	0.19385	-	2.67645
SC 14	0.10113	-	3.20838
SC 15	0.23584	-	3.39402
SC 16	0.4982	-	6.11135
SC 17	0.36156	0.78979	6.61661
SC 18	0.23202	0.83799	7.21896
SC 19	0.13818	0.84307	4.82419
SC 20	0.24938	0.72842	6.35418
SC 21	0.31259	0.85213	7.10066
SC 22	0.23674	0.96275	7.51604
SC 23	0.55799	0.90849	5.35451
SC 24	0.60335	0.71833	4.40545
SC 25	0.39756	0.81183	6.55795
SC 26	0.23333	0.82244	3.89858
SC 27	0.25875	0.68817	3.03457
SC 28	0.20484	0.78938	6.06081
SC 29	0.16566	0.91396	9.19506

Spermatocyte 6

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.12052	-	-	-	6.80015
SC 2	0.43668	-	-	-	10.6227
SC 3	0.35074	-	-	-	5.85284
SC 4	0.20468	-	-	-	9.39533
SC 5	0.36471	-	-	-	7.00042
SC 6	0.19985	-	-	-	6.95982
SC 7	0.47064	-	-	-	7.02296
SC 8	0.3729	0.71793	-	-	9.50649
SC 9	0.1645	0.82207	-	-	14.4825
SC 10	0.34914	0.84621	-	-	12.1624
SC 11	0.20153	0.6175	-	-	9.60519
SC 12	0.27397	0.68997	-	-	13.7767
SC 13	0.51744	0.89544	-	-	8.12644
SC 14	0.22589	0.59879	-	-	9.56228
SC 15	0.16354	0.85362	-	-	6.96318
SC 16	0.23858	0.68001	-	-	13.2945
SC 17	0.1629	0.91437	-	-	10.3275
SC 18	0.29102	0.77946	-	-	7.3752
SC 19	0.29063	0.69625	-	-	14.9149
SC 20	0.52397	0.77971	-	-	11.5543
SC 21	0.31741	0.79458	-	-	10.7892
SC 22	0.34201	0.78613	-	-	17.705
SC 23	0.23344	0.50439	0.89462	-	11.7616
SC 24	0.33522	0.57567	0.91949	-	9.73392
SC 25	0.27212	0.71691	0.97053	-	17.6173
SC 26	0.32878	-	-	-	10.6022
SC 27	0.46966	-	-	-	9.13143
SC 28	0.20401	0.48875	0.89378	-	16.1266
SC 29	0.18234	0.30156	0.45514	0.86481	13.5962

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.25042	-	-	9.04323
SC 2	0.14835	-	-	10.1161
SC 3	0.20898	-	-	7.59941
SC 4	0.26548	-	-	7.87255
SC 5	0.21751	-	-	10.5904
SC 6	0.47952	-	-	11.1619
SC 7	0.21791	-	-	7.95809
SC 8	0.26712	-	-	6.45687
SC 9	0.49284	-	-	12.4849
SC 10	0.3426	-	-	18.3827
SC 11	0.41946	-	-	12.234
SC 12	0.38373	-	-	11.94
SC 13	0.17055	-	-	15.3847
SC 14	0.36787	-	-	8.08367
SC 15	0.19285	0.91203	-	17.7048
SC 16	0.24462	0.75287	-	10.4647
SC 17	0.53274	0.71931	-	16.1173
SC 18	0.14424	0.78636	-	9.95099
SC 19	0.2883	0.66978	-	11.8027
SC 20	0.25399	0.94818	-	11.1686
SC 21	0.19838	0.87061	-	11.3607
SC 22	0.22039	0.69172	-	18.9849
SC 23	0.21355	0.79533	-	14.3948
SC 24	0.49526	0.8927	-	12.3996
SC 25	0.19839	-	-	9.48388
SC 26	0.23787	-	-	6.63208
SC 27	0.18597	0.74843	-	16.2798
SC 28	0.36193	0.44273	0.59	27.577
SC 29	0.14257	0.50421	0.88158	24.1617

Spermatocyte 8

	CO 1	CO 2	SC Length
SC 1	0.21085	-	8.26637
SC 2	0.19848	-	7.77784
SC 3	0.42359	-	9.80672
SC 4	0.32799	-	9.64054
SC 5	0.33295	-	7.03759
SC 6	0.40547	-	10.3909
SC 7	0.45482	-	9.52
SC 8	0.21703	-	6.55851
SC 9	0.47755	-	8.87859
SC 10	0.33376	-	8.03775
SC 11	0.48286	-	10.05
SC 12	0.37155	-	6.545
SC 13	0.37387	-	7.77203
SC 14	0.42161	-	5.96029
SC 15	0.16409	0.91768	10.1728
SC 16	0.19582	0.718	11.3575
SC 17	0.11268	0.83866	12.8956
SC 18	0.37472	0.69088	15.4784
SC 19	0.2576	0.80024	11.0901
SC 20	0.11245	0.79071	13.078
SC 21	0.35439	0.68436	16.7399
SC 22	0.45072	0.83117	18.4719
SC 23	0.05092	0.84737	17.0449
SC 24	0.12351	0.90445	15.5308
SC 25	0.39055	0.76582	13.2769
SC 26	0.25774	0.75669	18.1668
SC 27	0.10212	0.73048	18.8312
SC 28	0.17278	0.79381	12.5593
SC 29	0.47172	-	7.14329

Spermatocyte 9

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.32024	-	-	-	7.95277
SC 2	0.37754	-	-	-	7.99344
SC 3	0.49452	-	-	-	8.31173
SC 4	0.39321	-	-	-	5.75141
SC 5	0.4564	-	-	-	9.53603
SC 6	0.17327	-	-	-	11.5049
SC 7	0.19838	-	-	-	13.6389
SC 8	0.3041	-	-	-	8.95132
SC 9	0.4916	-	-	-	12.5906
SC 10	0.35781	-	-	-	10.8076
SC 11	0.19556	-	-	-	15.6808
SC 12	0.49143	-	-	-	20.7706
SC 13	0.33636	-	-	-	8.87572
SC 14	0.42805	-	-	-	14.2314
SC 15	0.5006	0.94809	-	-	13.7043
SC 16	0.18352	0.8123	-	-	16.0333
SC 17	0.17392	0.74216	-	-	14.3749
SC 18	0.07973	0.71329	-	-	14.4813
SC 19	0.31793	0.64342	-	-	22.2762
SC 20	0.05469	0.77152	-	-	23.9138
SC 21	0.12244	0.83503	-	-	13.4795
SC 22	0.09046	0.37526	0.94703	-	23.3012
SC 23	0.14798	0.23937	0.6672	0.79973	29.9653
SC 24	0.17316	0.62103	0.80736	-	24.6574
SC 25	0.22109	0.69086	-	-	34.2217
SC 26	0.1059	0.58435	0.89109	-	20.6484
SC 27	0.29656	0.75405	-	-	26.2083
SC 28	0.4748	-	-	-	18.03
SC 29	0.32763	-	-	-	10.6895

Spermatocyte 10

	CO 1	CO 2	SC Length
SC 1	0.31528	-	9.53659
SC 2	0.40807	-	6.95513
SC 3	0.41881	-	10.4448
SC 4	0.26654	-	7.77014
SC 5	0.40501	-	7.69265
SC 6	0.34603	-	7.71463
SC 7	0.39513	-	6.35425
SC 8	0.14671	-	9.87721
SC 9	0.47522	-	11.636
SC 10	0.34908	-	13.1488
SC 11	0.2946	-	12.5301
SC 12	0.29694	-	11.2952
SC 13	0.16881	-	13.2696
SC 14	0.2595	-	12.7309
SC 15	0.10481	0.88354	12.0217
SC 16	0.39111	0.5219	14.3284
SC 17	0.22093	0.6725	17.0941
SC 18	0.24038	0.89062	18.9187
SC 19	0.14868	0.9035	17.5921
SC 20	0.22932	0.82627	19.1122
SC 21	0.11594	0.91604	19.8332
SC 22	0.36773	0.89659	21.826
SC 23	0.31567	0.92863	17.5358
SC 24	0.45638	-	16.7061
SC 25	0.07828	0.83153	14.5741
SC 26	0.35363	0.76555	19.6872
SC 27	0.08758	-	14.7636
SC 28	0.25152	0.62413	15.8947
SC 29	0.13958	-	8.01493

Beefalo 5

Spermatocyte 1

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.25079	-	-	-	9.45364
SC 2	0.27896	0.69607	-	-	9.54835
SC 3	0.15442	0.61293	-	-	11.8661
SC 4	0.38067	-	-	-	8.29717
SC 5	0.24449	-	-	-	8.61875
SC 6	0.17226	0.55806	-	-	9.50789
SC 7	0.04923	0.52827	-	-	16.2238
SC 8	0.0771	0.32246	-	-	19.6716
SC 9	0.06775	0.7271	-	-	8.77345
SC 10	0.12443	0.34014	0.81291	-	18.7071
SC 11	0.38389	-	-	-	14.2206
SC 12	0.38275	-	-	-	7.9751
SC 13	0.13127	-	-	-	17.7661
SC 14	0.09287	0.39849	0.76903	-	16.5561
SC 15	0.43307	-	-	-	7.05453
SC 16	0.16155	0.48036	-	-	11.0888
SC 17	0.31691	0.72693	-	-	18.7739
SC 18	0.21544	0.83233	-	-	14.9895
SC 19	0.18279	-	-	-	11.5082
SC 20	0.38717	-	-	-	12.8192
SC 21	0.10774	0.57986	-	-	15.0626
SC 22	0.10627	0.91413	-	-	14.3644
SC 23	0.08997	0.71909	-	-	9.84277
SC 24	0.09399	0.65384	-	-	15.3264
SC 25	0.40571	-	-	-	11.8406
SC 26	0.13703	0.72758	-	-	11.1277
SC 27	0.24717	0.74231	-	-	18.5243
SC 28	0.05875	0.89835	-	-	12.1527
SC 29	0.11356	0.25816	0.50569	0.83457	15.6388

Spermatocyte 2

	CO 1	CO 2	SC Length
SC 1	0.28891	-	7.52171
SC 2	0.09286	-	9.39456
SC 3	0.36552	-	14.1504
SC 4	0.22026	0.75864	15.9734
SC 5	0.06183	0.66586	13.494
SC 6	0.21009	0.71426	12.9837
SC 7	0.10225	-	9.58048
SC 8	0.334	0.62379	19.319
SC 9	0.47178	-	12.6567
SC 10	0.18566	-	27.0117
SC 11	0.12924	-	9.20773
SC 12	0.29354	-	13.163
SC 13	0.1043	0.66051	12.8142
SC 14	0.46822	-	16.5879
SC 15	0.2387	-	22.5254
SC 16	0.08205	0.69693	22.1822
SC 17	0.10332	0.88971	15.5451
SC 18	0.13117	0.51069	11.6682
SC 19	0.09284	0.56342	14.8121
SC 20	0.23419	-	10.9057
SC 21	0.17261	0.65392	24.7059
SC 22	0.48251	-	7.07399
SC 23	0.39277	-	9.15334
SC 24	0.32738	0.6968	21.5426
SC 25	0.10147	0.81815	13.3126
SC 26	0.40039	-	15.5157
SC 27	0.18891	0.39039	19.8295
SC 28	0.10479	0.82976	21.8182
SC 29	0.09631	0.73033	24.3216

Spermatocyte 3

	CO 1	CO 2	CO 3	SC Length
SC 1	0.36318	-	-	9.21018
SC 2	0.28242	0.73471	-	13.9057
SC 3	0.07903	0.64273	-	10.8386
SC 4	0.15262	0.74982	-	13.0715
SC 5	0.08481	0.72376	-	12.7696
SC 6	0.4796	-	-	13.68
SC 7	0.178	0.53471	-	12.7674
SC 8	0.06336	0.62726	-	12.1122
SC 9	0.10734	0.62525	-	8.70772
SC 10	0.33214	-	-	7.81025
SC 11	0.42784	-	-	7.02681
SC 12	0.13217	0.69536	-	9.93097
SC 13	0.33975	-	-	4.48889
SC 14	0.35422	-	-	7.38262
SC 15	0.15392	-	-	8.63926
SC 16	0.33095	-	-	6.0564
SC 17	0.46624	-	-	6.04065
SC 18	0.20462	0.6579	-	13.8477
SC 19	0.18965	0.61257	-	10.2234
SC 20	0.22739	0.67259	-	10.5992
SC 21	0.46307	-	-	9.35613
SC 22	0.35529	-	-	6.39352
SC 23	0.08191	0.70957	-	8.73096
SC 24	0.08662	0.62311	-	13.5181
SC 25	0.10646	0.73627	-	8.85248
SC 26	0.14271	0.38333	0.65746	13.5822
SC 27	0.40065	0.81013	-	7.48195
SC 28	0.23164	-	-	12.8013
SC 29	0.10293	0.48738	0.81177	13.7099

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.09038	0.81215	-	9.29047
SC 2	0.39292	-	-	5.69128
SC 3	0.08265	0.57912	-	12.6502
SC 4	0.20196	-	-	8.93494
SC 5	0.14447	0.7773	-	13.6047
SC 6	0.10992	0.73309	-	11.8782
SC 7	0.21586	0.52463	-	16.0667
SC 8	0.2305	0.57357	-	9.38623
SC 9	0.11727	0.7132	-	11.0265
SC 10	0.18614	0.3675	0.83153	17.9047
SC 11	0.2337	0.53019	-	15.4568
SC 12	0.40198	-	-	6.24897
SC 13	0.19217	0.67009	-	10.5349
SC 14	0.07562	0.50849	0.69955	16.6924
SC 15	0.04062	0.51961	-	18.063
SC 16	0.19009	-	-	6.66771
SC 17	0.06651	0.63613	0.99611	9.37902
SC 18	0.45654	-	-	7.98
SC 19	0.20394	-	-	11.0748
SC 20	0.10012	0.56069	-	22.7347
SC 21	0.44193	-	-	12.0633
SC 22	0.35217	-	-	10.4952
SC 23	0.3064	-	-	6.98313
SC 24	0.34002	-	-	13.9592
SC 25	0.0736	-	-	8.21142
SC 26	0.10622	0.81437	-	11.0438
SC 27	0.30544	-	-	4.71205
SC 28	0.36345	-	-	8.31152
SC 29	0.33454	-	-	6.56131

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.1687	-	-	7.22085
SC 2	0.44555	-	-	6.8887
SC 3	0.26944	-	-	9.88085
SC 4	0.11328	0.83443	-	15.153
SC 5	0.1329	-	-	8.24327
SC 6	0.21932	0.82495	-	13.2973
SC 7	0.20034	0.81587	-	8.54434
SC 8	0.28702	0.60261	-	12.495
SC 9	0.24737	-	-	6.18359
SC 10	0.20673	0.70886	-	7.259
SC 11	0.20052	0.75359	-	10.3285
SC 12	0.24288	0.73398	-	12.9658
SC 13	0.33497	0.64635	-	11.2449
SC 14	0.17592	0.45063	-	15.1489
SC 15	0.08187	0.66874	0.82217	16.095
SC 16	0.20943	0.62045	-	10.9961
SC 17	0.40556	-	-	10.6358
SC 18	0.22034	0.73864	-	17.1173
SC 19	0.34164	-	-	6.58196
SC 20	0.19643	0.6709	-	9.27087
SC 21	0.48996	-	-	7.48734
SC 22	0.22418	-	-	11.2188
SC 23	0.32286	-	-	10.5027
SC 24	0.23206	0.58844	-	15.2336
SC 25	0.19931	0.61888	-	14.5039
SC 26	0.1401	0.75331	-	12.1617
SC 27	0.19608	-	-	8.32258
SC 28	0.18499	0.73293	-	11.1476
SC 29	0.11515	0.33831	0.74885	11.5938

Spermatocyte 6

	CO 1	CO 2	CO 3	SC Length
SC 1	0.05559	0.4917	-	17.8333
SC 2	0.17231	0.74263	-	17.5005
SC 3	0.20186	-	-	8.28289
SC 4	0.12031	0.70132	-	16.9423
SC 5	0.17193	0.57706	-	12.6421
SC 6	0.163	0.83471	-	14.0659
SC 7	0.2807	-	-	8.31943
SC 8	0.36771	-	-	7.13412
SC 9	0.34221	-	-	14.8985
SC 10	0.26929	0.42124	0.74636	16.1617
SC 11	0.49486	-	-	14.6662
SC 12	0.12774	0.79633	-	12.6702
SC 13	0.19874	0.77226	-	12.796
SC 14	0.47895	-	-	10.6292
SC 15	0.12258	-	-	17.1555
SC 16	0.2166	0.49608	-	6.32772
SC 17	0.07304	0.58791	-	15.96
SC 18	0.08154	0.31455	0.632	22.3718
SC 19	0.33515	-	-	6.58035
SC 20	0.34506	-	-	14.1274
SC 21	0.16079	0.53653	-	11.1257
SC 22	0.06225	0.56689	0.81967	20.237
SC 23	0.21953	-	-	16.8995
SC 24	0.09222	0.32813	0.62712	33.5684
SC 25	0.17773	-	-	9.15166
SC 26	0.13324	-	-	11.0166
SC 27	0.19096	0.50669	-	17.8159
SC 28	0.3526	-	-	17.3382
SC 29	0.28763	-	-	8.78654

Spermatocyte 7

	CO 1	CO 2	SC Length
SC 1	0.14323	0.49287	6.07551
SC 2	0.11322	0.68702	8.87971
SC 3	0.47369	-	5.74119
SC 4	0.43524	-	6.93301
SC 5	0.24175	-	6.87015
SC 6	0.20612	-	12.012
SC 7	0.13531	-	11.0603
SC 8	0.30895	0.7378	14.7937
SC 9	0.47416	-	6.15125
SC 10	0.34954	-	9.0839
SC 11	0.25332	-	7.23961
SC 12	0.32368	0.59968	15.3917
SC 13	0.25012	0.69275	11.5115
SC 14	0.34897	-	6.51518
SC 15	0.14262	0.64969	13.2523
SC 16	0.08439	-	11.872
SC 17	0.23079	0.63268	12.4949
SC 18	0.21244	0.65739	14.9442
SC 19	0.17517	0.28334	15.0901
SC 20	0.13783	0.85913	11.7149
SC 21	0.13206	0.55762	13.7131
SC 22	0.15938	0.61387	14.7886
SC 23	0.44989	-	7.44065
SC 24	0.32448	-	12.5864
SC 25	0.42144	0.57038	13.2255
SC 26	0.18307	0.83319	10.6919
SC 27	0.24724	0.76586	8.56072
SC 28	0.47368	-	8.79858
SC 29	0.49729	-	11.0069

Spermatocyte 8

	CO 1	CO 2	CO 3	SC Length
SC 1	0.26118	-	-	7.60963
SC 2	0.27979	-	-	7.00882
SC 3	0.24537	-	-	9.70095
SC 4	0.29467	0.49965	-	9.53554
SC 5	0.23809	0.62733	-	14.9626
SC 6	0.12511	-	-	7.66976
SC 7	0.27105	-	-	15.293
SC 8	0.22165	-	-	14.4169
SC 9	0.22233	-	-	12.6152
SC 10	0.1463	0.70267	-	11.3774
SC 11	0.44574	-	-	11.1919
SC 12	0.10792	0.62773	-	15.3318
SC 13	0.31085	0.72835	-	9.85159
SC 14	0.14397	0.80144	-	18.7772
SC 15	0.06802	0.54995	-	19.0673
SC 16	0.25723	0.38124	0.72189	22.7024
SC 17	0.11467	0.5628	-	17.0387
SC 18	0.31446	-	-	11.3343
SC 19	0.46805	-	-	13.8291
SC 20	0.20363	-	-	10.415
SC 21	0.22632	-	-	7.95669
SC 22	0.08414	0.49971	-	15.7945
SC 23	0.49011	-	-	9.35795
SC 24	0.11792	0.56585	-	17.8028
SC 25	0.49284	-	-	16.3426
SC 26	0.30102	-	-	19.111
SC 27	0.19185	-	-	10.0905
SC 28	0.47576	-	-	15.3878
SC 29	0.3365	0.46338	-	19.6841

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.10132	0.49507	0.79452	12.8927
SC 2	0.11046	0.75873	-	12.4883
SC 3	0.16527	-	-	9.06297
SC 4	0.44268	-	-	7.00742
SC 5	0.4617	-	-	6.40213
SC 6	0.19597	0.65906	-	14.2139
SC 7	0.3614	-	-	6.20088
SC 8	0.08701	0.62845	-	13.6437
SC 9	0.22632	0.65079	-	10.6282
SC 10	0.11946	0.74633	-	9.1882
SC 11	0.17598	0.40024	0.65883	13.1937
SC 12	0.32142	-	-	6.27585
SC 13	0.47089	-	-	9.81666
SC 14	0.34768	-	-	9.10539
SC 15	0.08541	0.65604	-	10.8144
SC 16	0.41864	-	-	10.8214
SC 17	0.16087	0.76758	-	13.6186
SC 18	0.08974	0.72688	-	12.9751
SC 19	0.08532	0.38779	0.6509	14.7743
SC 20	0.28403	0.72475	-	13.4987
SC 21	0.21317	0.60774	-	10.8959
SC 22	0.47783	-	-	13.5981
SC 23	0.09884	0.70262	-	9.38392
SC 24	0.06778	0.52491	0.84831	14.6259
SC 25	0.34457	-	-	8.10558
SC 26	0.16619	0.76712	-	13.2418
SC 27	0.17604	0.56889	-	7.12544
SC 28	0.29288	-	-	4.49687
SC 29	0.39033	-	-	5.15179

Spermatocyte 10

	CO 1	CO 2	CO 3	SC Length
SC 1	0.07551	-	-	9.16776
SC 2	0.2326	-	-	7.18333
SC 3	0.10394	0.70644	-	13.5806
SC 4	0.17046	0.60939	-	13.8069
SC 5	0.18344	0.62263	-	17.6156
SC 6	0.13584	0.76682	-	13.7911
SC 7	0.07078	0.57463	-	12.1017
SC 8	0.18527	-	-	6.49684
SC 9	0.41351	0.73303	-	15.2149
SC 10	0.4884	-	-	6.5828
SC 11	0.15703	-	-	7.36561
SC 12	0.41923	-	-	10.2104
SC 13	0.3096	-	-	10.3412
SC 14	0.28708	-	-	9.91256
SC 15	0.32324	-	-	7.86394
SC 16	0.04621	0.92251	-	18.0933
SC 17	0.1276	0.73639	-	11.4541
SC 18	0.07528	0.71212	-	13.574
SC 19	0.10351	0.7738	-	11.2528
SC 20	0.0772	0.62161	-	13.184
SC 21	0.43594	-	-	17.0009
SC 22	0.14491	0.43399	-	7.88578
SC 23	0.22574	-	-	6.69949
SC 24	0.41369	-	-	7.05866
SC 25	0.09764	-	-	8.44403
SC 26	0.11497	0.31593	-	12.5733
SC 27	0.235	0.46012	-	7.70462
SC 28	0.19407	0.6632	0.91927	15.6533
SC 29	0.25164	0.66276	-	9.38077

Beefalo 6

Spermatocyte 1

	CO 1	CO 2	SC Length
SC 1	0.453	-	6.55417
SC 2	0.153	-	8.8956
SC 3	0.607	-	6.36188
SC 4	0.152	-	10.2481
SC 5	0.439	-	5.52545
SC 6	0.119	-	9.59161
SC 7	0.569	-	11.7853
SC 8	0.55	-	8.15059
SC 9	0.161	0.879	11.851
SC 10	0.455	-	6.6689
SC 11	0.315	-	10.3032
SC 12	0.262	-	9.9624
SC 13	0.152	0.653	17.9309
SC 14	0.101	0.733	15.0315
SC 15	0.204	0.764	7.63294
SC 16	0.316	-	10.2487
SC 17	0.058	0.737	18.5326
SC 18	0.126	-	13.0201
SC 19	0.196	0.515	13.498
SC 20	0.093	0.82	10.7482
SC 21	0.148	0.778	19.1304
SC 22	0.276	0.604	15.768
SC 23	0.113	0.647	15.1336
SC 24	0.183	-	15.2903
SC 25	0.174	-	13.4012
SC 26	0.317	-	7.81585
SC 27	0.19	0.628	13.4149
SC 28	0.158	0.723	13.8521
SC 29	0.271	-	4.91386

Spermatocyte 2

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.328	0.66	-	-	7.62664
SC 2	0.065	0.731	-	-	11.9907
SC 3	0.147	0.71	-	-	12.8999
SC 4	0.225	0.619	-	-	7.69349
SC 5	0.454	-	-	-	15.4162
SC 6	0.151	0.825	-	-	20.9238
SC 7	0.421	-	-	-	8.33154
SC 8	0.362	-	-	-	18.817
SC 9	0.664	-	-	-	13.7717
SC 10	0.276	-	-	-	8.92381
SC 11	0.134	0.648	-	-	12.588
SC 12	0.126	0.803	-	-	18.5885
SC 13	0.199	0.802	-	-	11.6454
SC 14	0.102	0.696	-	-	17.4521
SC 15	0.247	-	-	-	7.4165
SC 16	0.28	-	-	-	9.59245
SC 17	0.15	0.685	-	-	22.7648
SC 18	0.497	-	-	-	14.5549
SC 19	0.409	-	-	-	11.7384
SC 20	0.288	-	-	-	15.1537
SC 21	0.323	-	-	-	7.71974
SC 22	0.371	-	-	-	17.0706
SC 23	0.325	0.873	-	-	30.1043
SC 24	0.179	0.308	0.436	0.796	37.4704
SC 25	0.258	0.847	-		18.4316
SC 26	0.402	-	-	-	12.3379
SC 27	0.307	0.64	-	-	7.91518
SC 28	0.161	0.49	0.812	-	20.8552
SC 29	0.136	0.489	0.655	-	54.6772

Spermatocyte 3

	CO 1	CO 2	SC Length
SC 1	0.271	0.536	12.8885
SC 2	0.085	0.564	9.44209
SC 3	0.477	-	5.38433
SC 4	0.226	-	5.4978
SC 5	0.113	-	8.89287
SC 6	0.227	0.652	16.778
SC 7	0.434	-	9.42543
SC 8	0.3	-	8.59558
SC 9	0.504	-	5.10622
SC 10	0.244	-	8.82672
SC 11	0.377	-	7.95872
SC 12	0.171	-	9.52154
SC 13	0.384	-	11.9084
SC 14	0.166	0.887	13.9429
SC 15	0.254	-	9.62045
SC 16	0.17	0.882	15.2694
SC 17	0.277	-	14.6344
SC 18	0.411	-	7.96999
SC 19	0.352	-	6.99062
SC 20	0.305	-	9.68478
SC 21	0.265	0.813	13.0509
SC 22	0.464	-	5.29221
SC 23	0.338	-	14.9506
SC 24	0.142	0.673	11.2561
SC 25	0.049	0.701	12.3332
SC 26	0.342	-	7.04235
SC 27	0.455	-	6.78727
SC 28	0.543	-	6.21558
SC 29	0.327	0.777	13.1591

Spermatocyte 4

	CO 1	CO 2	CO 3	SC Length
SC 1	0.128	0.697	-	10.3613
SC 2	0.389	-	-	9.47597
SC 3	0.551	-	-	11.6357
SC 4	0.468	-	-	9.9253
SC 5	0.313	0.696	-	19.5614
SC 6	0.237	-	-	9.87868
SC 7	0.338	-	-	10.6079
SC 8	0.099	0.511	-	8.23501
SC 9	0.071	0.904	-	14.8527
SC 10	0.116	0.675	-	16.6337
SC 11	0.27	-	-	11.1119
SC 12	0.185	-	-	6.96836
SC 13	0.08	0.468	0.85	14.0716
SC 14	0.124	0.525	-	15.7681
SC 15	0.148	0.736	-	12.9128
SC 16	0.113	0.949	-	20.5165
SC 17	0.146	0.588	-	7.46592
SC 18	0.356	-	-	11.8463
SC 19	0.179	-	-	6.58287
SC 20	0.185	-	-	11.5218
SC 21	0.78	-	-	13.1586
SC 22	0.088	0.408	-	28.1337
SC 23	0.221	-	-	7.9618
SC 24	0.34	-	-	7.31577
SC 25	0.185	0.398	0.677	14.9836
SC 26	0.069	0.421	0.756	32.8241
SC 27	0.12	0.817	-	24.3975
SC 28	0.119	0.661	-	22.7987
SC 29	0.162	-	-	19.4736

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.461	-	-	9.62626
SC 2	0.402	-	-	7.39739
SC 3	0.3	-	-	8.17516
SC 4	0.177	0.873	-	18.3839
SC 5	0.214	-	-	6.03218
SC 6	0.342	-	-	6.32534
SC 7	0.501	-	-	13.3627
SC 8	0.088	0.743	-	9.04176
SC 9	0.075	0.79	-	10.8837
SC 10	0.212	0.823	-	14.9865
SC 11	0.511	-	-	12.171
SC 12	0.088	0.663	-	24.751
SC 13	0.387	-	-	14.4204
SC 14	0.276	-	-	6.96094
SC 15	0.117	-	-	16.3141
SC 16	0.056	-	-	7.67228
SC 17	0.173	0.577	-	18.1455
SC 18	0.251	0.779	-	15.6591
SC 19	0.034	0.401	0.823	24.687
SC 20	0.571	-	-	17.2379
SC 21	0.078	0.948	-	18.795
SC 22	0.656	-	-	18.339
SC 23	0.126	0.55	-	23.117
SC 24	0.194	0.796	-	18.5022
SC 25	0.118	0.774	-	21.0022
SC 26	0.091	-	-	15.1731
SC 27	0.371	-	-	13.5111
SC 28	0.451	-	-	2.69213
SC 29	0.221	-	-	11.3717

Spermatocyte 6

	CO 1	CO 2	CO 3	SC Length
SC 1	0.108	0.943	-	10.0743
SC 2	0.504	-	-	7.46977
SC 3	0.267	-	-	13.7838
SC 4	0.191	0.569	-	10.2213
SC 5	0.26	-	-	8.30347
SC 6	0.378	0.534	-	17.131
SC 7	0.273	0.642	-	15.7245
SC 8	0.608	-	-	11.4401
SC 9	0.18	0.697	-	16.3487
SC 10	0.053	0.762	-	11.7891
SC 11	0.163	0.84	-	12.9618
SC 12	0.325	0.683	-	19.2483
SC 13	0.14	0.732	-	16.9819
SC 14	0.4	-	-	7.83944
SC 15	0.167	0.681	-	18.8502
SC 16	0.136	0.821	-	17.4966
SC 17	0.143	0.717	-	7.75614
SC 18	0.205	-	-	9.54898
SC 19	0.108	0.838	-	13.7726
SC 20	0.23	-	-	7.43442
SC 21	0.226	-	-	7.30751
SC 22	0.159	0.528	0.728	22.2331
SC 23	0.092	0.56	-	19.7763
SC 24	0.092	0.786	-	19.3507
SC 25	0.389	-	-	13.5424
SC 26	0.504	-	-	13.3921
SC 27	0.422	-	-	10.0024
SC 28	0.304	-	-	9.03567
SC 29	0.097	-	-	9.66329

Spermatocyte 7

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.153	0.709	-	-	8.7584
SC 2	0.16	0.917	-	-	20.1876
SC 3	0.071	0.819	-	-	21.0719
SC 4	0.532	-	-	-	7.65023
SC 5	0.187	0.58	-	-	21.6968
SC 6	0.321	-	-	-	6.97151
SC 7	0.195	-	-	-	7.71505
SC 8	0.258	0.729	-	-	15.5661
SC 9	0.428	-	-	-	10.1216
SC 10	0.226	-	-	-	11.9688
SC 11	0.239	-	-	-	6.59288
SC 12	0.221	0.848	-	-	18.1214
SC 13	0.108	0.445	0.787	-	27.7722
SC 14	0.51	-	-	-	10.183
SC 15	0.176	-	-	-	12.5485
SC 16	0.216	0.502	0.778	-	14.5991
SC 17	0.453	-	-	-	8.17635
SC 18	0.222	0.421	-	-	13.229
SC 19	0.199	0.882	-	-	12.7546
SC 20	0.129	-	-	-	11.3189
SC 21	0.326	-	-	-	9.63858
SC 22	0.165	-	-	-	11.7607
SC 23	0.631	-	-	-	10.4045
SC 24	0.229	0.758	-	-	20.0007
SC 25	0.208	0.802	-	-	20.8572
SC 26	0.139	0.9	-	-	15.4543
SC 27	0.2	0.557	-	-	21.6605
SC 28	0.107	0.514	0.678	0.925	28.9083
SC 29	0.316	0.723	-	-	22.4744

Spermatocyte 8

	CO 1	CO 2	CO 3	SC Length
SC 1	0.228		-	7.51611
SC 2	0.259	0.918	-	9.81785
SC 3	0.263	0.751	-	11.65
SC 4	0.371	0.739	-	7.67284
SC 5	0.082	0.45	-	14.4715
SC 6	0.427	-	-	10.432
SC 7	0.284	-	-	5.66692
SC 8	0.462	-	-	5.02229
SC 9	0.297	-	-	6.97578
SC 10	0.058	0.406	-	13.9901
SC 11	0.101	-	-	6.95786
SC 12	0.1	0.869	-	13.4116
SC 13	0.258	0.688	-	10.6705
SC 14	0.034	0.898	-	13.422
SC 15	0.319	-	-	5.32602
SC 16	0.086	0.802	-	18.8142
SC 17	0.328	-	-	13.4234
SC 18	0.081	0.581	-	17.1143
SC 19	0.071	0.795	-	12.9381
SC 20	0.067	0.76	-	18.7054
SC 21	0.287	0.736	-	17.177
SC 22	0.131	0.493	0.893	15.9474
SC 23	0.164	0.796	-	8.02179
SC 24	0.48	-	-	12.8357
SC 25	0.262	0.764	-	18.7055
SC 26	0.458	0.848	-	10.1727
SC 27	0.174	0.768	-	13.993
SC 28	0.084	0.823	-	10.0505
SC 29	0.432	-	-	9.83745

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.159	-	-	6.01594
SC 2	0.156	0.669	-	13.3809
SC 3	0.428	-	-	6.27746
SC 4	0.312	-	-	5.94622
SC 5	0.439	-	-	10.541
SC 6	0.199	-	-	7.01722
SC 7	0.475	-	-	7.58779
SC 8	0.279	0.703	-	15.0083
SC 9	0.102	0.896	-	16.9887
SC 10	0.084	0.824	-	14.3057
SC 11	0.485	-	-	10.3957
SC 12	0.321	0.681	-	9.7734
SC 13	0.117	0.808	-	16.161
SC 14	0.151	0.83	-	9.23496
SC 15	0.277	0.434	-	14.3816
SC 16	0.221	0.626	-	11.4183
SC 17	0.205	-	-	6.6087
SC 18	0.328	-	-	8.58844
SC 19	0.267	-	-	14.0457
SC 20	0.307	-	-	10.4535
SC 21	0.097	0.9	-	11.3084
SC 22	0.335	-	-	5.8926
SC 23	0.188	0.704	-	8.98478
SC 24	0.299	0.803	-	9.82191
SC 25	0.147	-	-	7.77924
SC 26	0.142	-	-	7.14105
SC 27	0.217	0.468	-	9.09426
SC 28	0.112	0.435	0.694	15.6401
SC 29	0.116	0.478	-	17.7155

Spermatocyte 10

	CO 1	CO 2	SC Length
SC 1	0.431	-	9.77137
SC 2	0.104	-	6.50748
SC 3	0.3	-	6.37833
SC 4	0.125	0.865	12.141
SC 5	0.396	-	5.70318
SC 6	0.339	-	10.1108
SC 7	0.446	-	7.27216
SC 8	0.158	-	9.36516
SC 9	0.191	-	7.37597
SC 10	0.384	-	6.87498
SC 11	0.249	-	6.63677
SC 12	0.453	-	9.34465
SC 13	0.095	0.485	15.9309
SC 14	0.201	0.666	13.3538
SC 15	0.473	-	11.1884
SC 16	0.19	0.802	12.8487
SC 17	0.317	-	8.38978
SC 18	0.161	-	8.93032
SC 19	0.512	-	13.768
SC 20	0.379	-	10.4617
SC 21	0.088	0.569	14.4844
SC 22	0.374	-	9.35613
SC 23	0.29	0.647	15.6495
SC 24	0.148	0.852	18.5689
SC 25	0.097	0.842	20.0971
SC 26	0.148	-	6.47626
SC 27	0.333	-	10.8669
SC 28	0.473	-	9.04057
SC 29	0.102	0.621	14.3907

Beefalo 7

Spermatocyte 1

	CO 1	CO 2	SC Length
SC 1	0.406	-	7.18676
SC 2	0.32	-	12.5971
SC 3	0.227	-	10.9379
SC 4	0.173	-	6.91264
SC 5	0.36	-	8.11412
SC 6	0.337	-	16.827
SC 7	0.496	-	8.80936
SC 8	0.203	-	13.0005
SC 9	0.197	-	7.5131
SC 10	0.092	-	9.94434
SC 11	0.307	-	14.6254
SC 12	0.566	-	8.6429
SC 13	0.321	-	6.96143
SC 14	0.354	-	15.0013
SC 15	0.11	0.853	16.4322
SC 16	0.17	0.687	18.1717
SC 17	0.199	-	11.8416
SC 18	0.309	0.547	20.8897
SC 19	0.237	-	10.4556
SC 20	0.29	0.842	15.4095
SC 21	0.204	-	17.8891
SC 22	0.072	0.843	16.7024
SC 23	0.367	0.724	19.6282
SC 24	0.683	-	24.0605
SC 25	0.217	0.574	17.9358
SC 26	0.248	-	18.8395
SC 27	0.271	-	20.5897
SC 28	0.125	0.415	19.1944
SC 29	0.683	-	17.8893

Spermatocyte 2

	CO 1	CO 2	CO 3	CO 4	SC Length
SC 1	0.535	-	-	-	10.2613
SC 2	0.339	-	-	-	11.7668
SC 3	0.387	0.888	-	-	17.4846
SC 4	0.022	0.653	-	-	11.5882
SC 5	0.242	-	-	-	5.91927
SC 6	0.058	0.795	-	-	14.6563
SC 7	0.152	0.316	0.924	-	16.368
SC 8	0.251	-	-	-	5.79894
SC 9	0.148	0.607	-	-	18.7065
SC 10	0.138	0.887	-	-	16.2962
SC 11	0.765	-	-	-	6.21341
SC 12	0.104	0.597	-	-	8.80768
SC 13	0.125	0.942	-	-	21.839
SC 14	0.3	-	-	-	12.1378
SC 15	0.24	0.899	-	-	14.7781
SC 16	0.184	0.838	-	-	10.5624
SC 17	0.344	-	-	-	11.8597
SC 18	0.166	-	-	-	6.36853
SC 19	0.649	-	-	-	9.53099
SC 20	0.128	0.802	-	-	15.5555
SC 21	0.036	0.419	0.478	0.816	28.0169
SC 22	0.43	-	-	-	5.92018
SC 23	0.137	0.607	-	-	16.658
SC 24	0.165	-	-	-	9.78439
SC 25	0.108	0.916	-	-	17.5845
SC 26	0.196	0.633	-	-	11.73
SC 27	0.425	-	-	-	6.95968
SC 28	0.231	-	-	-	13.4266
SC 29	0.275	-	-	-	9.03175

Spermatocyte 3

	CO 1	CO 2	SC Length
SC 1	0.071	0.472	10.9254
SC 2	0.044	0.513	15.0865
SC 3	0.125	-	8.68245
SC 4	0.238	-	8.22563
SC 5	0.345	-	5.36305
SC 6	0.196	-	6.39387
SC 7	0.464	-	6.16056
SC 8	0.261	0.727	13.8753
SC 9	0.069	-	9.45357
SC 10	0.228	0.722	15.4696
SC 11	0.181	0.786	15.0955
SC 12	0.167	-	9.42123
SC 13	0.354	-	5.8912
SC 14	0.21	-	12.0327
SC 15	0.211	-	9.92278
SC 16	0.091	0.926	9.58062
SC 17	0.41	-	8.26231
SC 18	0.151	0.811	13.8344
SC 19	0.032	0.842	11.1108
SC 20	0.043	0.738	13.2237
SC 21	0.142	0.779	15.3517
SC 22	0.416	-	16.6772
SC 23	0.118	0.747	14.0372
SC 24	0.329	-	7.19278
SC 25	0.143	-	8.26224
SC 26	0.173	-	6.41872
SC 27	0.195	-	10.6755
SC 28	0.086	0.506	9.91494
SC 29	0.223	-	15.2965

Spermatocyte 4

	CO 1	CO 2	SC Length
SC 1	0.101	-	5.55569
SC 2	0.302	-	7.29939
SC 3	0.408	-	6.20592
SC 4	0.25	-	7.25564
SC 5	0.324	-	4.56127
SC 6	0.213	0.846	8.40623
SC 7	0.224	-	5.53378
SC 8	0.512	-	6.24295
SC 9	0.431	-	12.3044
SC 10	0.425	-	9.19226
SC 11	0.08	0.715	8.80075
SC 12	0.195	-	9.3184
SC 13	0.259	-	6.79308
SC 14	0.073	0.593	10.1846
SC 15	0.243	-	7.42014
SC 16	0.17	0.836	10.9476
SC 17	0.147	0.638	12.1419
SC 18	0.208	0.741	13.6536
SC 19	0.282	-	8.3489
SC 20	0.268	-	5.17468
SC 21	0.202	0.592	11.332
SC 22	0.136	0.694	12.3289
SC 23	0.471	-	11.8808
SC 24	0.131	0.748	10.3422
SC 25	0.125	0.845	9.63018
SC 26	0.4	-	5.54246
SC 27	0.605	-	8.34491
SC 28	0.136	0.668	13.1736
SC 29	0.38	-	11.8594

Spermatocyte 5

	CO 1	CO 2	CO 3	SC Length
SC 1	0.493	-	-	7.06909
SC 2	0.135	0.664	-	8.84219
SC 3	0.468	0.768	-	6.70467
SC 4	0.282	-	-	8.1949
SC 5	0.192	0.787	-	9.48374
SC 6	0.229	0.835	-	9.20199
SC 7	0.128	0.835	-	8.27554
SC 8	0.117	0.666	-	7.86163
SC 9	0.49	-	-	5.23236
SC 10	0.075	0.858	-	8.876
SC 11	0.111	-	-	9.44083
SC 12	0.111	0.707	-	12.7713
SC 13	0.42	-	-	13.7515
SC 14	0.222	-	-	10.5226
SC 15	0.166	-	-	5.89708
SC 16	0.331	0.749	0.886	15.5045
SC 17	0.216	-	-	11.9957
SC 18	0.064	0.701	-	14.496
SC 19	0.463	-	-	5.06331
SC 20	0.677	-	-	6.71132
SC 21	0.176	-	-	8.52607
SC 22	0.548	-	-	8.58438
SC 23	0.073	0.559	-	14.6267
SC 24	0.072	0.786	-	15.1507
SC 25	0.394	0.738	-	13.6202
SC 26	0.143	0.849	-	10.7682
SC 27	0.217	0.582	-	9.16251
SC 28	0.464	-	-	6.10862
SC 29	0.436	-	-	11.3413

Spermatocyte 6

	CO 1	CO 2	SC Length
SC 1	0.239	-	6.62249
SC 2	0.614	-	5.49143
SC 3	0.498	-	7.34181
SC 4	0.374	-	6.82038
SC 5	0.118	-	7.13923
SC 6	0.161	0.772	13.9481
SC 7	0.056	-	16.4336
SC 8	0.305	0.835	12.241
SC 9	0.169	-	5.42444
SC 10	0.124	-	5.36648
SC 11	0.142	0.236	16.9311
SC 12	0.14	0.832	14.1012
SC 13	0.134	0.767	14.2225
SC 14	0.348	-	11.0597
SC 15	0.362	-	11.2645
SC 16	0.292	-	7.01442
SC 17	0.238	-	7.2513
SC 18	0.128	-	8.45026
SC 19	0.127	-	10.4812
SC 20	0.379	-	15.1486
SC 21	0.353	0.659	18.1512
SC 22	0.129	-	10.0159
SC 23	0.258	-	7.6769
SC 24	0.518	-	11.0404
SC 25	0.186	-	13.3277
SC 26	0.692	-	12.6593
SC 27	0.163	0.791	14.7276
SC 28	0.196	-	8.79781
SC 29	0.2	0.377	13.5556

Spermatocyte 7

	CO 1	CO 2	CO 3	SC Length
SC 1	0.331	-	-	8.38565
SC 2	0.181	0.745	-	16.7101
SC 3	0.331	-	-	8.98912
SC 4	0.489	-	-	8.65774
SC 5	0.51	-	-	8.34463
SC 6	0.201	-	-	16.1843
SC 7	0.505	-	-	7.02856
SC 8	0.141	-	-	8.7654
SC 9	0.227	0.885	-	16.3687
SC 10	0.538	-	-	10.0761
SC 11	0.21	-	-	13.9662
SC 12	0.04	0.85	-	18.5819
SC 13	0.104	0.524	0.858	18.3581
SC 14	0.438	-	-	17.7493
SC 15	0.096	0.673	-	21.4271
SC 16	0.314	0.901	-	10.7164
SC 17	0.354	-	-	11.2066
SC 18	0.135	0.359	0.74	31.9339
SC 19	0.595	-	-	10.622
SC 20	0.525	-	-	10.7415
SC 21	0.153	0.669	-	21.245
SC 22	0.417	0.737	-	19.9083
SC 23	0.389	-	-	9.45336
SC 24	0.044	0.647	-	15.3061
SC 25	0.434	-	-	15.4363
SC 26	0.352	-	-	17.8082
SC 27	0.407	-	-	12.9404
SC 28	0.969	-	-	11.5441
SC 29	0.417	0.792	-	16.6835

Spermatocyte 8

	CO 1	CO 2	SC Length
SC 1	0.42	-	8.5281
SC 2	0.194	0.744	11.8028
SC 3	0.474	-	7.45605
SC 4	0.202	0.597	11.4381
SC 5	0.212	0.623	12.6513
SC 6	0.22	-	7.76209
SC 7	0.064	0.747	11.8054
SC 8	0.438	0.686	13.3363
SC 9	0.214	0.836	9.57481
SC 10	0.074	-	4.80578
SC 11	0.258	0.8	8.54686
SC 12	0.246	0.803	12.5819
SC 13	0.496	-	5.58747
SC 14	0.123	-	4.69413
SC 15	0.594	-	5.24545
SC 16	0.275	-	10.439
SC 17	0.261	-	9.45294
SC 18	0.255	-	9.2575
SC 19	0.281	-	9.23083
SC 20	0.496	-	6.03113
SC 21	0.141	-	5.65306
SC 22	0.154	-	7.79121
SC 23	0.096	0.84	12.7547
SC 24	0.119	0.76	14.9285
SC 25	0.6	-	12.6915
SC 26	0.265	-	5.94069
SC 27	0.368	-	13.6289
SC 28	0.302	0.744	9.90164
SC 29	0.202	-	7.00532

Spermatocyte 9

	CO 1	CO 2	CO 3	SC Length
SC 1	0.224	-	-	7.2394
SC 2	0.192	0.515	-	14.3805
SC 3	0.642	-	-	9.81848
SC 4	0.488	-	-	7.42784
SC 5	0.495	-	-	8.26406
SC 6	0.618	-	-	12.4776
SC 7	0.421	-	-	7.86177
SC 8	0.078	0.609	-	10.8639
SC 9	0.385	0.828	-	11.4849
SC 10	0.509	-	-	15.8022
SC 11	0.07	0.259	-	11.7657
SC 12	0.204	0.866	-	17.9486
SC 13	0.358	-	-	12.9956
SC 14	0.208	-	-	14.4133
SC 15	0.394	-	-	16.6554
SC 16	0.203	0.878	-	15.9593
SC 17	0.224	-	-	22.5217
SC 18	0.072	0.595	-	18.4025
SC 19	0.281	-	-	7.36813
SC 20	0.467	-	-	6.40325
SC 21	0.326	-	-	22.1002
SC 22	0.776	-	-	13.075
SC 23	0.447	-	-	7.48482
SC 24	0.312	-	-	6.80449
SC 25	0.184	0.42	0.782	17.0122
SC 26	0.27	0.619	0.882	25.5463
SC 27	0.469	-	-	21.6756
SC 28	0.707	-	-	8.99619
SC 29	0.078	0.138	0.611	25.2522

Spermatocyte 10

	CO 1	CO 2	SC Length
SC 1	0.266	-	20.0768
SC 2	0.204	-	10.3879
SC 3	0.185	0.638	15.574
SC 4	0.376	-	9.77977
SC 5	0.234	-	8.31572
SC 6	0.151	0.621	15.2564
SC 7	0.366	-	13.6677
SC 8	0.156	0.538	10.549
SC 9	0.371	-	14.975
SC 10	0.321	-	9.06654
SC 11	0.176	-	12.5463
SC 12	0.236	-	8.94852
SC 13	0.496	-	20.3851
SC 14	0.357	0.593	15.4158
SC 15	0.326	-	15.4734
SC 16	0.196	0.905	26.0923
SC 17	0.503	-	17.7071
SC 18	0.106	0.619	21.015
SC 19	0.102	-	22.8395
SC 20	0.328	-	18.032
SC 21	0.127	-	17.7195
SC 22	0.122	-	38.546
SC 23	0.142	-	21.2146
SC 24	0.272	-	12.1647
SC 25	0.164	-	17.4924
SC 26	0.616	-	7.63889
SC 27	0.074	0.557	22.3976
SC 28	0.217	0.657	11.8283
SC 29	0.547	-	8.09312

APPENDIX D

Defect Score Data

Beefalo

	Beefalo 1	Beefalo 2	Beefalo 3	Beefalo 4	Beefalo 5	Beefalo 6	Beefalo 7
Normal	36	39	40	34	37	40	35
Rings	7	5	4	5	6	6	3
No CO	5	5	2	9	2	4	4
Gaps	2	1	4	2	5	0	8

Cattle

	Charolais	Gelbvieh	Jersey	Lowline
Normal	40	45	44	36
Rings	1	0	0	3
No CO	4	2	4	9
Gaps	5	3	2	2

	Angus 1	Angus 2	Angus 3	Angus 4	Angus 5	Angus 6	Angus 7
Normal	43	48	42	41	36	39	40
Rings	2	2	1	1	4	5	3
No CO	1	0	4		5	5	3
Gaps	4	0	2	0	5	6	4

Statistical analysis results

Defect	Variance test P value	TTest P value
Normal	0.6235	0.00052
Rings	0.5577	0.1607
No CO	0.4414	0.9727
Gaps	0.4294	0.00602

APPENDIX E

Gastrointestinal Nematode Resistance in Katahdin Sheep

Project overview

Internal parasites create great challenges for organic and conventional livestock producers. Because of the health detriment to our livestock caused by these parasites and their new resistance, new methods of keeping our animals healthy are necessary. While methods like changing lambing season are being tested, other options should be explored to reduce seasonal parasites. It is known that some breeds of sheep are resistant or less susceptible to Gastrointestinal Nematodes (GIN). An option for less GIN is to select for genetically resistant sheep. In the past, estimated breeding values (EBV) have been used to select for GIN resistant sheep but has taken 10-20 years of selection (Albers and Gray, 1987). Therefore, one of the key objectives of this project is to utilize genomics to identify genetic loci associated with nematode resistance and/or resilience.

Worms such as *Haemonchus contortus* threaten the health of livestock. Besier et al., (2016) outlines the risks *H. contortus* has, such as the blood sucking aspect to their life cycle, which can lead to anemia and death if left untreated in livestock. Worms like *H. contortus* are becoming resistant to antihelmmithics, and are therefore leaving limited treatment options (Besier et al., 2016). Using selective breeding to select for animals that are less susceptible to GIN, may be a possible solution to the problem livestock producers are facing.

Katahdin sheep are a hair breed of sheep that were developed in the US in the 1950s by producer Michael Piel (Katahdin Hair Sheep International (KHSI), 2016). He was selecting for hair coat, meat-type conformation, high fertility, and flocking instinct. It is believed that one of the sheep in his original flock came from St. Croix, and is where their

reduction in GIN susceptibility is hypothesized to have come from (KHSI, 2016). Studies have shown that Katahdin sheep are less susceptible to GIN (Vanimisetti et al., 2004). Due to the known resistance in some animals from this breed, these sheep will be used in this study (Vanimisetti et al., 2004). The study is a collaboration between many scientists and producers. To find genetic loci associated with resistance, a genome wide analysis will be conducted. To do this, fecal worm egg counts (FWEC) need to be taken at weaning and post weaning along with other phenotypic data. Genotypes of animals are determined by SNP. The phenotype data will be evaluated against the genotype data to identify SNP associated with high and low FEC scores. This can provide insight into what genes to select for, to create sheep that are less susceptible to GIN.

This study will use sheep from various locations and farms in the US. Blood will be collected from sheep in the study and FWEC will be collected at weaning (60-120 days), and again 30 days after the first collection. Genotypes will be determined by collecting approximately 54,000 SNP across the genome via OvineSNP50 BeadChip. A whole genome association analysis will be conducted after genotyping control measures are taken. Genotyping control measures include removal of SNP probes with low genotype quality scores, minor allele frequency below 0.05, as well as samples not in Hardy Weinberg equilibrium.

Data are still being collected at this time. There are a total of 14 flocks participating in the study, with a total of 1,779 blood samples collected. From the 1,779 samples collected, 1,357 are from the year 2017 and 422 are from what has been collected as of spring 2018.

APPENDIX F

Published Conference Abstracts

Plant and Animal Genome XXV San Diego, California, United States, January 14-18, 2017

Understanding Chromosome Pairing and Crossovers in Beefalo Spermatocytes

Anna M. Rodriguez, Kimberly M. Davenport, Brenda M. Murdoch, University of Idaho, Moscow, ID

With the demand of an increasing population and changing climate, there is a need to produce efficient and adaptable livestock. In an effort to achieve this, hybrid mating of Bos taurus to Bos indicus and Bos taurus to Bison bison have been used. However, producing viable and fertile offspring from hybrid crosses is a major concern. To better understand how chromosomes pair and crossover in hybrid animals, 700 spermatocytes from *B. taurus* x *B. bison* (Beefalo) were examined and compared to 500 spermatocytes from B. taurus (cattle). Immunofluorescent staining was used to identify chromosome synapsis (SYCP3) and crossovers (MLH1) in pachytene stage spermatocytes. Despite both species having 30 chromosomes, Beefalo exhibit on average ~15% fewer crossovers per cell when compared to cattle (41 MLH1, 49 MLH1), respectively. Importantly, one crossover per chromosome arm is required to ensure proper chromosome segregation and ~12% of Beefalo spermatocytes had at least one pair of chromosomes fail to crossover. Furthermore, ~12% of cells exhibited the structural defect of a circular/fused chromosome. The consequence of improper chromosome segregation in spermatocytes is ultimately cell death; as defective spermatocytes will not develop into mature spermatozoa. Hybrid animals may provide specific attributes and adaptability to ensure sustainability and profitability in a changing industry. However, the effective use of hybrid animals requires a greater understanding of chromosomal compatibility to improve fertility and offspring viability. This research will provide valuable insight relating to chromosome pairing, synapsis, and crossovers in spermatocytes of Beefalo, an important strategy towards progress of livestock production.

International Society for Animal Genetics Conference 2017 Dublin, Ireland, July 16-21, 2017

Differences in Meiotic Chromosome Pairing Characteristics in Spermatocytes of Hybrid Beefalo

Anna M. Rodriguez, Kimberly M. Davenport, Hannah K. Jaeger, Rebekka J. Sawyer, Megan A. Follett, Taylor M. Badigian, and Brenda M. Murdoch

As livestock were domesticated for food, they were selectively bred and evolved from their wild counterparts. In an effort to optimize hybrid mating, mating between cattle (*Bos taurus*) and bison (*Bison bison*), to produce Beefalo (*Bison bison* x *Bos taurus*) has been used. However, mating of two different species can lead to reduced viable and fertile offspring from hybrid crosses. Chromosome pairing and crossovers (CO) during spermatogenesis creates an exchange of genetic material. The synaptonemal complex (SC) forms with synapsis and anchors homologous chromosomes together. There is a positive correlation between number of CO and the length of a chromosome, which can be determined measuring SC length. Immunofluorescent staining was used to identify chromosome synapsis (SYCP3) and CO (MLH1) in pachytene stage spermatocytes. Despite both species having 30 chromosomes, previous data (Murdoch lab, unpublished), show Beefalo exhibit on average ~10% fewer CO per spermatocyte when compared to cattle. To evaluate why fewer overall CO occur, the number of CO per SC were examined in each spermatocyte. For a subset of corresponding spermatocytes, SC measurements from Beefalo were examined and compared to cattle. Overall, cattle exhibited a higher occurrence of 3, 4, and as many as 5 CO per SC, whereas the maximum number of CO in Beefalo was 4. Importantly, when compared to cattle, ~10% more Beefalo spermatocytes exhibited the structural defect of a circular/fused chromosome, and ~5% more Beefalo spermatocytes were lacking a CO, both of which may lead to improper chromosome segregation. The consequence of improper chromosome segregation in spermatocytes is ultimately cell death; as defective spermatocytes will not develop into mature spermatozoa. Hybrid animals may provide insight into how speciation occurs in larger animals, and the difficulties in breeding to create new species. In addition, the use of hybrid cattle to understand differences may provide insight into breeding of other hybrids, by using chromosome characteristics. This

research will provide valuable insight relating to chromosome pairing, synapsis, and crossovers in hybrid spermatocytes.

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World Congress on Genetics Applied to Livestock Production, Auckland, New Zealand, February 7-16, 2018

Meiotic Recombination in Ruminant Livestock Species

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Homologous recombination is an important component of gametogenesis that contributes to genetic variation, and ensures proper chromosome segregation. Despite the importance of this process, we know very little about the factors that control and/or influence global meiotic recombination/crossover (CO) in livestock. Previous research recognizes that a least one CO per chromosome arm is required to ensure proper chromosome segregation. Even though cattle and sheep are different species and Beefalo are a cattle hybrid, they have the same number of chromosome arms. This study uses a direct cytological approach to quantify, and characterize the number of COs in Beefalo, cattle, and sheep spermatocytes. Here we report that Beefalo exhibit on average 5% fewer COs per spermatocyte compared to cattle, and cattle exhibit 28% fewer COs compared to sheep. Further, we examined the number of COs for each homologous chromosome pair in a subset of spermatocytes for each species. We found a positive correlation between the numbers of COs and the length of a chromosome. Overall, sheep exhibited as many as 9 COs per chromosome; whereas the maximum number observed in cattle and Beefalo was 5 and 4, respectively. Importantly, when compared to cattle, 11% of Beefalo spermatocytes exhibited chromosomes with structural defects and 9% were lacking a CO, both of which lead to improper chromosome segregation, and ultimately apoptosis and reduced fertility. While hybrid species and subspecies crosses have the potential to provide valuable phenotypic traits, understanding chromosomal differences will help resolve breeding difficulties. This research contributes valuable information towards understanding meiotic recombination in livestock, for use in both genetic predictions and selection strategies.

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Chromosomal Defects and Meiotic Recombination in Ruminant Livestock and Hybrid Beefalo Spermatocytes

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Understanding chromosomal characteristics is valuable information for learning how traits are passed on in livestock. Homologous recombination is an important component of gametogenesis that contributes to genetic variation, and ensures proper chromosome segregation. Despite the importance of this process, we know very little about the factors that control and/or influence global meiotic recombination/crossover (CO) in livestock. Previous research recognizes that a least one CO per chromosome arm is required to ensure proper chromosome segregation. Even though cattle and sheep are different species and Beefalo are a cattle hybrid, they have the same number of chromosome arms. This study uses a direct cytological approach to quantify, and characterize the number of COs in Beefalo, cattle, and sheep spermatocytes. Here we report that Beefalo exhibit on average 5% fewer COs per spermatocyte compared to cattle, and cattle exhibit 28% fewer COs compared to sheep. Further, we examined the number and location of COs for each homologous chromosome pair in a subset of Beefalo, cattle, and sheep spermatocytes. We found a positive correlation between the numbers of COs and the length of a chromosome. Overall, sheep exhibited as many as 9 COs per chromosome; whereas the maximum number observed in cattle and Beefalo was 5 and 4, respectively. Importantly, when compared to cattle, 9% more Beefalo spermatocytes exhibited chromosomes with structural defects and 2% more were lacking a CO, both of which can lead to improper chromosome segregation, apoptosis and reduced fertility. While hybrid species and subspecies crosses have the potential to provide valuable phenotypic traits, understanding chromosomal differences will help resolve breeding difficulties. This research contributes valuable information towards understanding chromosome structure in pachynema spermatocytes by visualizing meiotic recombination in livestock.

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A Comparison of Meiotic Recombination in Spermatocytes of Cattle and Sheep from the United States and Czech Republic

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Understanding meiotic recombination is valuable for learning how traits are inherited in livestock. Homologous recombination is an important component of gametogenesis that contributes to genetic variation and ensures proper chromosome segregation. Despite the importance of this process, little is known about the factors that control and/or influence global meiotic recombination/crossover (CO) in livestock. Previous research recognizes that a least one CO per chromosome arm is required to ensure proper chromosome segregation. Even though cattle and sheep are different species, they have the same number of chromosome arms. This study uses a direct cytological approach to quantify and characterize the number of COs in spermatocytes from U.S. Angus and Czech Spotted cattle, and diverse breeds of sheep from the United States and Czech Republic. Here we report that Angus exhibit on average 43.1 COs per spermatocyte, which are significantly fewer than 47.5 in Czech spotted cattle. US sheep in this study (Suffolk = 61.1, Icelandic = 63.5, and Targhee = 65.9), on average exhibit 62.5 COs per spermatocyte, which is similar to 62.9 observed in Czech sheep. Cattle have more than the one required CO per chromosome arm. Interestingly, sheep have approximately 28% more COs per spermatocyte than cattle. Further, we examined the number and location of COs for each homologous chromosome pair in a subset of cattle and sheep spermatocytes to better understand regions and frequency of the COs on individual chromosomes. Overall, this research contributes valuable information towards understanding meiotic recombination, and ultimately how traits are inherited in livestock.

APPENDIX G

Meiotic Recombination in Ruminant Livestock Species Permission

RE: Thesis Permission to use publication

Rachel Cook <Rachel@conference.nz>

Wed 7/25/2018 5:38 PM

To:Rodriguez, Anna (amrodriguez@uidaho.edu) <amrodriguez@uidaho.edu>;

Hi Anna,

I have sent your email to the programme convenors and they have responded with the following:

'Yes no problem, as long as the MS references it's source'

I think you are good to go!

Kind regards,

Rachel Cook
Director / Event Manager

Conference Innovators

Auckland
Christchurch
Wellington

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m — +64 21 918 524
rachel@

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conference.nz

From: Rodriguez, Anna (amrodriguez@uidaho.edu) [mailto:amrodriguez@uidaho.edu]
Sent: Wednesday, 25 July 2018 2:10 p.m.
To: Rachel Cook <Rachel@conference.nz>
Subject: Thesis Permission to use publication

Hello Ms. Cook,

I reached out once before in June. I am submitting my thesis and need written permission to use my publication at WCGALP in my thesis. I am hoping you can help me acquire this permission so that I can submit my Master of Science thesis. I need to have the permission by July 30th at the very latest. I hope you can help.

Thank you,

Anna