Semen, also known as seminal fluid, is an organic fluid that contains spermatozoa. It is secreted by the gonads (sexual glands) and can fertilize the ovum.

**Composition of Semen (Abstract)**

Semen is a substance produced by the male reproductive organs. It is composed of spermatozoa in a semi-viscous fluid. Structures within the male reproductive tract that are involved in the production of semen include:

- Testes and epididymis
- Prostate
- Seminal vesicles
- Bulbourethral gland

Semen is produced as a combination of secretions from the different regions of the male reproductive tract. Each fraction differs in chemical composition and function. The combination of these fractions during ejaculation results in the optimal environment for transporting sperm to the endocervical mucus in the female.

- Spermatozoa are produced in the testes. They mature in the epididymis. The testes also produce testosterone and inhibin.
- Fluid from the seminal vesicles accounts for approximately 70% of semen volume. The seminal vesicles are the source of fructose in semen. Fructose is used by the spermatozoa as an energy source.
- The prostate gland supplies about 20% of the volume of semen. Its fluids include acid phosphatase and proteolytic enzymes that lead to coagulation and subsequent liquefaction of semen. The prostate also contains most of the IgA found in semen.
- The bulbourethral gland produces mucoproteins that make up about 5% of the volume of semen.

**Composition of Semen (Details)**

**Spermatozoa**

- The fraction of the semen made up by spermatozoa is known as the spermatocrit, and ranges from more than 30% in sheep to less than 2% in pigs.
- In brief, the spermatozoa of the domestic mammals have spatulate heads containing the nuclear DNA, with an acrosome covering the anterior pole, attached by a specialized neck structure to a midpiece and tail. The midpiece consists of a helix of mitochondria surrounding the central two and surrounding nine fibres, which extend into the tail. The sperm of the domestic mammals are relatively small, at least when compared with those of most rodents, and are similar in size and structure to human sperm. The sperm of most murid rodents are much larger and quite different in shape, being falciform or hook shaped, with the acrosome over one side of the head.

**Other cells**

- As well as spermatozoa, white blood cells (WBC) are often found in semen. In domestic mammals, WBC are often present in small numbers in semen.
Table 1.1. Some details of the composition of the semen of the domestic animals. Based on data from Mann, 1964; Mann and Lutwak-Mann, 1981. Reproduced from Setchell, 1991, with permission from Elsevier.

<table>
<thead>
<tr>
<th></th>
<th>Bull</th>
<th>Ram</th>
<th>Goat</th>
<th>Boar</th>
<th>Stallion</th>
</tr>
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<tbody>
<tr>
<td><strong>Semen</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry weight (%)</td>
<td>9.5</td>
<td>14.8</td>
<td>–</td>
<td>4.6</td>
<td>4.3</td>
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<tr>
<td>pH</td>
<td>6.48–6.99</td>
<td>5.9–7.3</td>
<td>–</td>
<td>6.85–7.9</td>
<td>6.2–7.8</td>
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<tr>
<td>Specific gravity</td>
<td>1.035</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>1.013</td>
</tr>
<tr>
<td>Spermatoct (%)</td>
<td>10</td>
<td>33</td>
<td>–</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Volume (ml)</td>
<td>2–10</td>
<td>0.5–2</td>
<td>0.5–2.5</td>
<td>150–500</td>
<td>20–300</td>
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<tr>
<td><strong>Seminal plasma</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetylglosaminidase (units/ml)</td>
<td>15,000</td>
<td>16,000</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Ascorbic acid (mg/100 ml)</td>
<td>8.7</td>
<td>5</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>Bicarbonate (mmol/l)</td>
<td>7.1^a</td>
<td>7.1^a</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Calcium (mmol/l)</td>
<td>9.3</td>
<td>1.9</td>
<td>–</td>
<td>–</td>
<td>6.5</td>
</tr>
<tr>
<td>Chloride (mmol/l)</td>
<td>49</td>
<td>18</td>
<td>–</td>
<td>96</td>
<td>–</td>
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<tr>
<td>Citric acid (mg/100 ml)</td>
<td>357–1000</td>
<td>137</td>
<td>–</td>
<td>36–325</td>
<td>8–53</td>
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<tr>
<td>Ergothioneine (mg/100 ml)</td>
<td>Trace</td>
<td>Trace</td>
<td>Absent</td>
<td>6–30</td>
<td>3.5–13.7</td>
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<tr>
<td>Fructose (mg/100 ml)</td>
<td>120–540</td>
<td>150–600</td>
<td>20–40</td>
<td>&lt;1</td>
<td></td>
</tr>
<tr>
<td>Glutamic acid (mg/100 ml)</td>
<td>35–41</td>
<td>76</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>Glycerylphosphorylcholine (mg/100 ml)</td>
<td>110–500</td>
<td>1600–2000</td>
<td>1400–1630^a</td>
<td>110–240</td>
<td>40–110^a</td>
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<tr>
<td>Inositol (mg/100 ml)</td>
<td>25–46</td>
<td>10–15</td>
<td>–</td>
<td>380–610</td>
<td>19–47</td>
</tr>
<tr>
<td>Magnesium (mmol/l)</td>
<td>3.4</td>
<td>2.4</td>
<td>–</td>
<td>–</td>
<td>3.8</td>
</tr>
<tr>
<td>Mannosidase (units/ml)</td>
<td>400</td>
<td>50</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Potassium (mmol/l)</td>
<td>44</td>
<td>23</td>
<td>–</td>
<td>16</td>
<td>26</td>
</tr>
<tr>
<td>Protein (g/100 ml)</td>
<td>3–9</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Sodium (mmol/l)</td>
<td>117</td>
<td>76</td>
<td>–</td>
<td>122</td>
<td>114</td>
</tr>
<tr>
<td>Sorbitol (mg/100 ml)</td>
<td>10–136</td>
<td>26–120</td>
<td>–</td>
<td>6–18</td>
<td>20–60</td>
</tr>
</tbody>
</table>

*Whole semen*.

**Carbohydrates**

- One of the most remarkable features of semen is that the predominant reducing sugar is not glucose, as in blood, but fructose a sugar more usually found in plants. Small amounts of glucose are also present, and boar semen in particular contain large concentrations of inositol, but less fructose than semen from bulls or rams (Mann, 1951). Stallion semen also contains inositol and lower concentrations of fructose (Baronos, 1951; Mann *et al.*, 1963), and other compounds of inositol are also present in some species (Seamark *et al.*, 1968). Fructose in bulls and rams originates in the seminal vesicles, with some from the ampulla, but in the stallion, most comes from the ampulla. Inositol is secreted in the seminal vesicles (Mann and Lutwak-Mann, 1981).

- Both glucose and fructose can be utilized by sperm, either by oxidation or glycolysis. The mitochondria, in which oxidative phosphorylation occurs, are arranged as a helix around the midpiece of the sperm, whereas the glycolytic enzymes are concentrated in the principal piece of the tail, while some are bound to the fibrous sheath of the flagellum. However, it is unlikely that glycolysis alone could generate enough ATP for full motility, and while diffusion from the mitochondria may be sufficient in smaller sperm, in larger sperm it is likely that an adenylate kinase shuttle is involved in moving ATP from the mitochondria to the flagellum (Ford, 2006; Miki, 2007; Storey, 2008; Cummins, 2009). There is evidence for the occurrence in sperm of specific
glucose transporters that can transport both glucose and fructose (Purcell and Moley, 2009).

**Proteins, amino acids and other nitrogen-containing compounds**

- Seminal plasma contains a variety of proteins and peptides, the total concentration being somewhat less than that in blood plasma. Seminal plasma proteins are derived from the epididymis and the accessory glands, and are involved in several essential steps preceding fertilization, including capacitation, establishment of the oviductal sperm reservoir, modulation of the uterine immune response, sperm transport in the female tract and gamete interaction and fusion.

- Seminal plasma also contains considerable concentrations of free amino acids, particularly glutamic acid in rams and bulls (Setchell et al., 1967; Brown-Woodman and White, 1974) and hypotaurine in boars (Van der Horst and Grooten, 1966; Johnson et al., 1972). Hypotaurine may be important in preventing damage to sperm by reactive oxygen species (Alvarez and Storey, 1983; Bucak et al., 2009).

- There are also appreciable concentrations of carnitine in the seminal plasma of rams (Brooks, 1979), bulls (Carter et al., 1980) and stallions (Stradaioi et al., 2004). This substance is involved in fatty acid transport in other tissues, but that present in semen is largely derived from the epididymis (Hinton et al., 1979). Boar semen also contains ergothioneine, the betaine of thiolhistidine, a sulfur-containing reducing base, which comes mainly from the seminal vesicle (Mann and Leone, 1953); it is also present in stallion semen, but in this species, it originates largely from the ampulla (Mann and Lutwak-Mann, 1963).

- Semen and seminal plasma from rams, bulls, goats, boars and stallions were found to contain considerable amounts of glycerophosphorylcholine, which originates largely from the epididymis (Dawson et al., 1957; Brooks 1970), as well as glycerylphosphorylinositol.

**Lipids**

Semen contains considerable amounts of lipid, both neutral lipids and phospholipids, most of which is in the spermatozoa (Hartree and Mann, 1959). In ram semen, the most abundant phospholipid is choline plasmalogen (also known as phosphatidalcholine), whereas in boars, it is lecithin (also known as phosphatidylcholine) and in bull sperm, the two phospholipids are present in approximately equal amounts (see Mann and Lutwak-Mann, 1981). One remarkable feature of these phospholipids is their high concentration of highly unsaturated fatty acids, 22 carbons in length, with six double bonds (22:6) in rams and bulls and five double bonds (22:5) in boars (Johnson et al., 1969; Poulos et al., 1973; Evans and Setchell, 1978). These constituent fatty acids are particularly susceptible to damage from reactive oxygen species. The phospholipids may also be important precursors of platelet activating factor (PAF), which is probably involved in sperm motility, the acrosome reaction and fertilization, and which is found in bull and boar sperm (Parks et al., 1990; Roudebush and Diehl, 2001). Seminal plasma from bulls and stallions contains an acetylhydrolase, which may play a role in regulating autocrine or paracrine functions of PAF (Parks and Hough, 1993; Hough and Parks, 1994).
Semen also contains appreciable concentrations of steroids. In bull semen, the concentrations of several steroids, including progesterone, dihydrotestosterone, androstanediols and oestrogens are much higher than in blood plasma. The oestrogens appear to come from the prostate, whereas the other steroids originate from the epididymis. Testosterone is present in seminal plasma at about the same concentration as in blood plasma, much less than in the rete testis fluid leaving the testis (Ganjam and Amann, 1976).

**Structure of spermatozoa**

The spermatozoa of different groups of animals exhibit great variety of form. The spermatozoon, which performs the function of carrying genetic material from the male to the oocyte, consists of two principal parts= head and tail.

The tail consists of four components—neck, mid-piece, principal piece and end piece (Phillips, 1975).

Both of these parts of spermatozoon i.e. head and tail are contained as in living cells, in a continuous plasma membrane. The whole cell of sperm is streamlined and paired down for action of a special sort and of limited duration, namely, to swim and to meet an egg, to fuse with the cortex of an egg, and to introduce sperms nucleus and Centriole in the egg interior.

**Structure of head of sperm:**

The sperm head consists of mainly the nucleus and acrosome. Its shape, size and structure vary greatly in different groups of vertebrates. The head of sperm performs two functions—genetic and activation.

The genetic function is embodied in the sperm nucleus which consists almost entirely of DNA plus nuclear proteins and thus is responsible for the transmission of hereditary characters from the male. The nucleus of the sperm occupies major part of the head and its shape, ultimately, determines the shape of the head of sperm. At the anterior end of the sperm nucleus occurs a cap-like structure called acrosome.

The shape and size of the acrosome vary among different species. The acrosome is bounded by an acrosomal membrane and it contains certain acrosomal polysaccharides like galactose, mannose, fructose, and hexosamine (Kopency, 1976). A large number of enzymes especially hydrolases are also present in the acrosome. It also contains two most important enzymes such as hyaluronidase and zona lysin or acrosin which functions during sperm entry into the ovum (Nelson, 1985).

In the sperm of some animals such as fowl, there occurs a cone-shaped structure called axial body or acrosomal cone in between acrosome and nucleus. The acrosomal cone develops into an acrosomal filament at the time of fertilization. Very little cytoplasm occurs in between
nucleus and plasma membrane of sperm head. The cytoplasm in between the membrane of acrosomal vesicle and sperm plasma membrane is called periacrosomal cytoplasm.

**Structure of Tail of Spermatozoan:**

The motor apparatus of the spermatozoon tail is the axoneme or axial filament complex which consists of the usual central pair or axial fibril (or microtubules) surrounded by an inner row of nine evenly spaced doublet microtubules, each with two rows of arms that project towards the adjacent double tubule, one row of radial spokes that radiate inwards towards the central pair of microtubules, with outer ring of nine coarse longitudinal fibres (Guraya, 1987).

Actually, all the structural components of the flagellum, which include the connecting piece, 9 + 2 axoneme, fibrous sheath and outer dense fibres, are structurally interlocked into one functional unit.

A central sheath, made up of projections has been described surrounding the two central tubules. It is connected by nine spokes, radial links to the nine doublets, which are also connected to each other by inter doublet links.

*From morphological point of view tail consists of the following sub divisions:*

1. **Neck:**

The neck is a short, slightly constricted segment made up of projections located between the base of the head and the first gyre of the mitochondrial helix of the middle piece. The neck differs clearly from the head and also from the rest part of the tail (i.e. midpiece, principal piece and end piece.) in certain morphological features of plasmalemma, a sharp demarcation of its upper limit by the posterior ring, and lack of continuity between the segmented columns and the outer dense's fibres of the. The two Centrioles lie at right angles to each other are proximal and distal Centriole.
The distal Centriole forms and gives attachment to the axial filament of the sperm tail; the proximal Centriole has no active function in the spermatozoon but is a potential activist within an egg during first cleavage division of the fertilized egg. Two or three mitochondria are also present in the neck. These generally establish close relationship with either end of the proximal Centriole by wrapping around the lateral surface of the latter. These mitochondria are continuous with the uppermost mitochondria of the mid piece helix.

2. Middle piece:
Anatomically, the mitochondrial sheath and the outer ring of coarse fibres characterize the mammalian sperm mid piece. It is that part of the flagellum which lies between the neck and annulus and forms the most important site for various metabolic activities of the sperm. The axoneme of the mammalian sperm is surrounded by nine outer dense fibers which are also called the coarse or accessory fibres. These run for the major part of its length, thus constituting a 9+9+2 cross-sectional pattern. The mitochondria of the mid piece arranged end to end constitute a helix around the longitudinal fibrous elements of the tail. The end on junctions of mitochondria are generally seen at random along the course of the helix. The mitochondrial sheath is believed to be the source of energy (ATP) for sperm motility. However, this energy is limited and once utilized cannot be renewed, except in mammals and in those animals where spermatozoa remain alive within maternal body because there are energy sources available to the spermatozoon. At the junction of mid piece and principal piece is present the annulus which is also known as the ring Centriole or Jensen’s ring. The annulus is composed of the closely packed filamentous subunits, 3 to 4 nm in diameter. It develops in close association with the plasma membrane and remains firmly adhered to it. The functional significance of annulus is still not clear but according to some scientists the function of the annulus could be to prevent displacement of the mitochondria.

3. Principal piece:
The main piece or principal piece of mammalian spermatozoa is surrounded by a fibrous sheath which shows a similar basic organization in different species of mammals. Fibrous sheath is composed of a series of circumferentially oriented ribs that extend half way around the tail end in two longitudinal columns which run along opposite sides of the sheath for its whole length. The sheath is not attached to the plasma membrane. The longitudinal columns extend in the principal piece along the whole length of the fibrous sheath in its dorsal and ventral surfaces. These are composed of 15 to 20 nm thick longitudinal subunits attached to the axoneme during sperm movement. The plasma membrane is independent of this complex. Towards the end of the piece, the longitudinal columns progressively reduces in size. Meanwhile the ribs become slender. The abrupt ending of the fibrous sheath marks the junction of the principal and end piece.

4. End piece:
The end piece consists of a central pair of axial fibrils and ring of nine doublet fibres, which are surrounded by the plasma membrane. The 9+2 pattern of axial filament complex extends through most part of the tail including the end piece, but the arrangements of the fibres in the tip of the end piece is changed and decreasing number of fibres suggests a successive termination of the single subfibres.
Functions of the spermatozoon:
The main function of the spermatozoon is to carry the paternal genetic dowry and to activate the ovum.

Types of sperm:
The type of the sperm produced varies from species to species. The size of the sperm may be as little as 0.018 mm in Amphioxus or as large as 2.25 mm or more in toad. The sperm head is, however, species specific. It may be spheroidal (teleosts), rod or lance-shaped (amphibians), spoon-shaped (man and many other mammals), or hooked (mouse and rat). The sperm types are again divided into two main types found in animals—flagellate spermatozoa, which possess a flagellum or tail like biflagellate (in Opsanus, a toad fish) spermatozoa. The non-flagellate spermatozoa lack flagella and are found in Ascaris, crab etc.

Semen evaluation (See practical notebook)
Suggested Books-
1. Reproduction in Farm Animals by E.S.E. Hafeez
2. Duke’s Physiology of Domestic Animals