Sex Chromosomes

Williams, 1964; Ming et al, 2011; Charlesworth, 2016

- Found in ~40 spp from 21 genera in 15 plant families
- Cannabidaceae only family with all species having sex chromosomes

Classification according to shape

Heteromorphic = X and Y chromosomes are physically different

Species	2n	♀	♂
Cannabis sativa	20	XX	XY
Humulus lupulus	20	$X_1X_1X_2X_2$	$X_1X_2Y_1Y_2$
Humulus japonicus	16 ♀, 17 ♂	XX	XY_1Y_2
Melandrium album	22	XX	XY

Figure 1 Rumex acetosa with 2n = 12 + XX (indicated by arrows). Parker & Clark, 1991

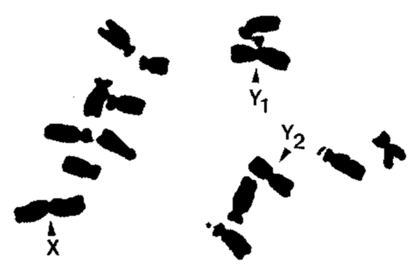
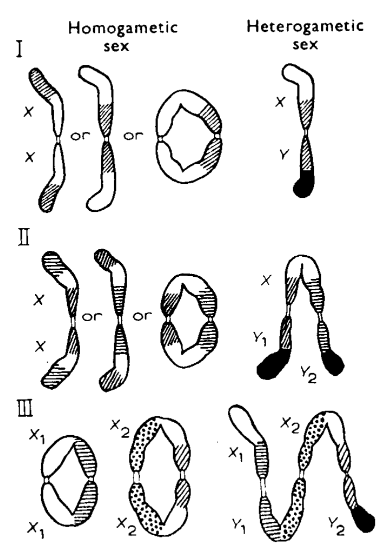


Figure 2 Rumex acetosa with 2n = 12 + XY_1Y_2 (indicated by arrows). Parker & Clark, 1991

Heteromorphic pairs are distinguishable at meiosis according to their pairing:

I. *Melandrium*
II. *Humulus japonicum*
III. *Humulus lupulus*

- notice only the heterogametic sex forms rings ▸



Rumex acetosa with 2n = 12 + XY_1Y_2 forming a trivalent Parker & Clark.

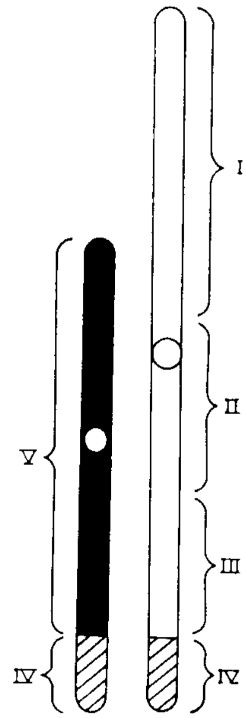
Homomorphic = X and Y chromosomes not visibly different

- includes papaya, asparagus, & wild grapes

Classification according to mode of action

Active Y

E.g., *Melandrium album* (= *Silene alba, Lychnis alba*; Caryophyllaceae; white campion or evening lychnis)



X (left) and Y (right) chromosomes of Melandrium

Composition of sex chromosomes determined by studying plants with fragmented Y chromosomes of *Melandrium*:

- Absence of section I permits the development of hermaphroditic flowers. ∴ Its function must be to suppress the ♀ parts (carpels). Also involved in anther development.
- When III and IV are missing, male sterility results. ∴ III plays a role in normal pollen development.
- Section IV is the only homologous part between the X & Y chromosomes. Necessary to permit pairing
- By the process of elimination, section V involved in ♀ determination.
- Only ♀ plants are recovered from anther culture, so conclude that lack of an X chromosome is lethal in the sporophyte

X:A ratio, as with *Drosophila*

In some polyploid species, ratio of X:Y chromosomes determines sex:

Ploidy	Chromosomes	X:A ratio	Sex	
			Melandrium	*Rumex*
2x	XY or YY	1:2 = 0.5; 0:2 = 0	♂	♂
	XXY	2:2 = 1.0	♂	♀
	XXXY	3:2 = 1.5	-	♀
3x	XY	1:3 = 0.3	♂	♂
	XXY	2:3 = 0.7	♂	H
	XXXY	3:3 = 1.0	♂	♀
4x	XY	1:4 = 0.25	♂	♀
	XXY or XXYY	2:4 = 0.5	♂	♂
	XXXY or XXXYY	3:4 = 0.75	♂	H
	XXXXYY	4:4 = 1.0	♂	♀
	XXXXY	4:4 = 1.0	♂ + H	-

- For *Rumex*, XXY goes from ♀ → H → ♂ as ploidy goes from 2x →3x → 4x
  - also, XY is ♂ @ 2x and 3x, but ♀ @ 4x

In general: X:A > 1.0 = ♀
0.5 ≤ X:A ≤ 1.0 = ♂ or H or ♀
X:A < 0.5 = ♂

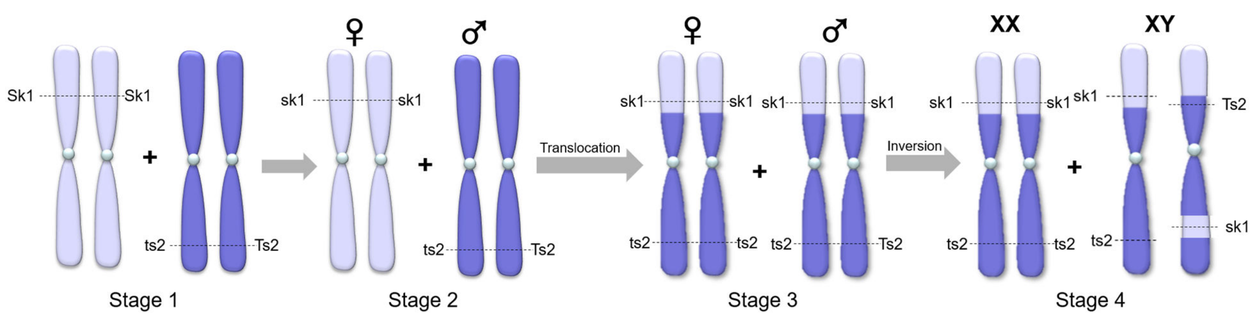
Identifying the heterogametic sex

- Meiotic pairing (heteromorphic chromosomes only)
- Sex-linked inheritance
- ⊗ of rare hermaphrodites
- Haldane's rule (1922. Genetics 128:841-858)
  - Originally for animals
  - When in the F1 offspring of an interspecific cross, one sex is absent, rare, or sterile, that sex is the heterogametic sex.
  - One exception found so far: *Fragaria orientalis*

Evolution of a sex chromosome

Normal, silkless & tassel-seeded maize plants

E.g., maize (start with a monoecious species)



Stage 1: = original monoecious condition
Stage 2: Need a mutation for ♀ sterility, e.g., silkless (*sk*) mutation

- Mutation for ♂ sterility: eg, Tassel seed 2 (*ts2*), converts tassels to ♀ flowers
- *sk sk* is ineffective in the presence of *ts2 ts2*
- Synthesize the following genotypes:
  - ♀: sk sk ts2 ts2 = ♀ fertile in ear and tassel
  - ♂: sk sk Ts2 ts2 = ♀ sterile, ♂ fertile

Stage 3: - Induce a translocation to link *sk* and *ts2*
Stage 4: - Induce an inversion to prevent recombination between *sk* and *ts2*

Stage 5: - Loss of genes on Y chromosome

Stage 6: Suppression of recombination along Y chromosome

The following graph depicts the evolutionary stages of sex chromosomes in some species (Ming et al, 2011):