Silverudd's Multiple Cock Shift System (SMCSS)

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Silverudd's Multiple Cock Shift System (SMCSS) is based on definite colour genotypes of the strains. The variations of colour of chicks after different cocks will indicate the male progenitor of all female chicks (in many cases also of male chicks). When shifting cocks in the pens, SMCSS will safeguard full pedigree for all female chicks, even when several cocks are kept in one pen, provided the shifting is done in accordance with the rules governing SMCSS.

Starting with only 4 groups, 144 sexable combinations can be made for as many RRS-tests in less than a one year. SMCSS may very well be utilized in such a way that, at the same time, complete sexing automation is achieved. Through the medium of SMCSS entirely new possibilities have been created for a time-saving and more comprehensive RRS and for obtaining a combination of strain breeding and RRS.

1. Reasons for experiments with crossings

Some twenty years ago, when studying the genetic background for producing the so-called autosexing breeds (the first one produced by PUNNETT and PEASE 1930), my interest was soon aroused to attempt producing an autosexing type of White Leghorn. It is true that something had earlier been published about a technique of conveying WL genes to an autosexing breed and also something of utilizing WL (PEASE 1951) for the actual production of an autosexing breed. I found that, for producing autosexing breeds, I required a technique that allowed for more than 90% WL-genes at the outset. My attention had been drawn to colour mutations, suppressed by dominant white (I) in White Leghorn. In 1956, an experiment was started with a double end in view, i.e. to produce an "autosexing White Leghorn" with predominant WL-blood, and, also, to get an idea of the colour mutations of the laboratory fowls. In order to eliminate dominant white from WL I had to cross in another breed of some kind. Through crossing with Brown Leghorn and recrossing to White Leghorn, dominant white was, by way of selection, eliminated from the stock. The colour factor for wild-type (e+) with Brown Leghorn, producing striped down, was cultivated in isolation within the stock, and, as expected, produced sexability in combination with barring, B (PUNNETT 1940). Out of the experiment emerged Fiftyfive Flowerly (FF), 1958 (SILVERUDD 1967). The experiment also indicated that, in WL, there exist colour genes, which, in combination with B, can give autosexing. Thus it had been proved that, in order to change it to an autosexing breed, it will not be necessary to add a single gene to WL from another breed. In 1960, the gene for silver (S) was bred into FF to make FF ideal as hen strain, with a view to produce sex-linked crossbreeds. Silver strains of FF are called SFF and gold strains GFF. Having been bred for more than ten generations since 1960 without the supply of new blood, FF is now very homogeneous and is raised in Sweden for commercial purpose. While producing FF the desirability was kept in mind of retaining a number of genes from old Swedish strains that had been raised in Sweden for several decades.

The basic condition for an ideal sexing automation has been studied (especially with regard to WL) in connection with many different crosses,
comparing their particular genotypes and phenotypes (Silverudd 1968). This gave impulses for studies of the genetics of autosexing in relation to the great problems of breeding techniques, caused by the fact that, after shifting cocks in pens, pedigree accuracy on the paternal side is lost for a period of about three weeks. I found that, in shifting cocks in pens, the colour genes may be adapted in a fascinating way, due to the fact that by the colour of the female chicks (whether dayold or feathered) it will be indicated without fail, which cock is the actual progenitor, in each case. Silverudd's multiple cock shift system (SMCSS) admits of continuous changes of cocks without jeopardizing the pedigree accuracy (Silverudd 1970). The fact that, (as hen strain) SFF has a genotype that makes the breed more suitable for SMCSS than practically all other breeds has had as a result that, as far as hen strains are concerned, the interest in SMCSS has especially been coupled with SFF.

Abbreviations for names of breeds:

AL = Automatic Leghorn
AuO = Black Australorps
BIL = Black Leghorn
BrL = Brown Leghorn
BR = Barred Plym. Rock
FF = Fiftyfive Flowery
HBAR = Hampbar (gold)
LS = Light Sussex
NH = New Hampshire
NJ = Norwegian Jaerhons
RIR = Rhode Island Red
RBAR = Rhodebar (barred RIR)
SBNH = Silver Barred NH
SFF = Fiftyfive Flowery in silver
SRB = Swedish Reddish Brown
WL = White Leghorn

Designations of genes

A great variety of genes may have reference to SMCSS. Here below are specified primarily the genes included in the tables, and then those that are mentioned in the text only.

Genes with Z-loci

K = slow feathering
k^+ = rapid feathering
Id = inhibitor of dermal melanin
s^+ = albinism

Autosomal genes

mo = mottled (with Ancona and others)
Mo^+ = non-mottled
nj = the particular colour factor with Norwegian Jaerhons
e^+ = wild-type colour (with Brown L. and others; Smyth 1965)
E = extension of black
eWh = dominant wheaten (with NH and others)
ER = birchen (Moore and Smyth 1972)
ig = inhibitor of gold
R = rose comb
I = dominant white
c = recessive white
Db = dark brown (restriction of columbian type; Moore and Smyth 1972b)
Co = columbian restriction

2. Data concerning the above-mentioned genes

The gene designations are in many cases not identical with those used in "Genetics of the Fowl" (Hutt 1949). In its place the more up-to-date and accurate gene symbology, used by Smyth, Somes, Moore (cf. Literature cited) and others has been adopted. B may be called "the autosexing gene", because it is imperative in all autosexing breeds. However, it is only in a combination with, for instance, striped or mottled down, that autosexing can be achieved to 100%. Barred Plymouth Rock has B, but, as carrying extended black (E), the breed is not 100% sexable. White Leghorn always has B.

S, like B, is one of the most valuable genes, being highly important for sexing automation and SMCSS. Excepting the black element in them, breeds such as NH and RIR become white, if bred with S. Light Sussex is one of the best known silver breeds.

K is not a popular gene, as late feathering tends to increase the frequency of feather picking and cannibalism. It may be possible, merely by the use of K, to grade WL-chicks with a 100% accuracy (k^+ k^+ cocks x K-hens). WL-hens may also produce double sex-linked combinations (Silverudd 1968). Trebly sexable combinations may be produced by crossing rapid feathering...
autosexing gold strains \((k^+k^+BBs^+s^+)\) with late feathering autosexing silver strains \((K - B - S -)\). However, K does not apply to combinations of this kind. In Swedish WL an autosomal gene may be found, causing very late feathering. \(mo\) is a very important gene in FF, since, being recessive, it will enhance the possibilities with SMCSS. \(mo\) in FF originated from a Swedish WL and is, as far as we know, identical to \(mo\) in Ancona. Mottling in Orloff, is not due to \(mo\) (Serbrovsky 1926). \(B\) and \(mo\) in combination with \(e^+\) provides in FF, an unparalleled sex differentiation in the feather (Fig. 1). Cocks are \(BBmomo\) and hens \(B-momo\).

3. Explanations and discussion of some terms

**Continuous heterozygosity.** Produced by crossing strains of “continuous homozygosity” type, as far as they are pure to different alleles in homologous loci.

**Continuous homozygosity.** Arises when all fowls within one strain, through planned selection, have become homozygous to one or more specific genes, thus causing this homozygosity to stay permanent from generation to generation.

**Continuous breeding.** Arises when the breeding process is planned so as to never lose any pedigree of interest when shifting cocks. SMCSS makes continuous breeding possible to a great extent.

**Multiple pedigree.** Achievement of complete pedigree, or, at least, pedigree on the paternal side, when keeping more than one cock in each pedigree pen.

**Pedigree accuracy.** With SMCSS a 100% pedigree should be expected and be evident at an early stage, preferably already by the down colouring. When cocks are shifted, or when several cocks are kept in a pedigree pen, there will be many possibility of pedigree accuracy, so that no pedigree of interest is lost.

**Pedigree hatching.** Presupposes trap-nesting, so that the eggs from a particular hen can be marked with the number of this hen and be hatched...
separately. The chicks will be wing-marked as day-olds, and the numbers registered, so as to keep track of pedigree without any break.

*Reciprocal recurrent selection (RRS).* The purpose of RRS is to develop strains which, when crossed, yield progeny superior to either parental strain. "Selection is based not on the performance of the individuals within the strain but upon their ability to combine well or nick to produce the maximum of hybrid vigour. In order that the strains or breeds remain more or less flexible for selection purposes, inbreeding is avoided. Avoiding inbreeding also avoids, of course, the fixing of undesirable characters and the decrease in viability usually associated with inbreeding." (JULL 1960.) It may be mentioned that modifications of RRS exists (FALCONER 1964).

*Strain pedigree.* A simpler form of pedigree, when registration is restricted to the paternal side. Individual control through trap-nesting, will then not be required within the stock. In many cases, the procedure of marking the wings may then be replaced by puncturing the skin between the toes according to a particular system. If hens in a group should have the same parents, strain pedigree may often be required.

*Cock group.* Consists of cocks that have been coordinated in a group in such a way that, with the help of SMCSS, the group may be interchanged with another particular cock group, without losing any pedigree of interest on the paternal side.

*Z-inbreeding.* Implies planned achievement of homozygosity for several sex-linked genes, resulting in a type of inbreeding that will effect the cocks, but not the hens, the latter being hemizygous for Z-genes and hence immune to defects from Z-inbreeding.

*Autosexing.* Implies that a breed is sexable in itself. Legbar, Cambar, Rhodebar, Fiftyfive Flowery, Norwegian Jaerhons, among others, are autosexing breeds. The first autosexing breed, Cambar, was produced in 1930 by PUNNETT and PEASE. Also crosses between autosexing breeds are to be regarded as autosexing.

*Sex-linked sexing.* Sex-linked sexing involves a sexability by crossing two (or more) breeds or varieties, that are not sexable in themselves (or by crossing non-autosexing × autosexing). RIR × LS, NH × LS, BrL × LS, BrL × BR and BIL × BR are typical examples. There are also triple crossbreeds belonging to this category, e.g. BrL × (LS × NH), RIR × (LS × NH), BIL × (BR × RIR), RIR × (BR × AuO) and BIL × (SFF × NJ). Also combinations between cocks of rapid-feathering strains and hens of late-feathering strains are included in this category (feather sexing).

The concept autosexing is often used of combinations that are sex-linked only. This practice creates confusion and should, therefore, be abolished.

4- *Numerical codes for sexing methods*

In order to bring about consistency regarding various concepts in the field of sexing automation, I have adopted the following numerical code (SILVERUDD 1970):

- 0 – Not sexable, or only partly so
- 0+ Sexable, but not 100 % (at least 80 %)
- 1 Sex-linked sexing through mating k+k+ (cock) × K – (hen)
- 2 Sex-linked sexing through combination of gold × silver or non-barred × barred. Thus s+s+ × S – and b+b+ × B –, respectively
- 3 Double sex-linking through 2 + 1
- 4 Autosexing
- 5 Autosexing and sex-linked sexing through 4 + 1
- 6 Autosexing and sex-linked sexing through combination of 4 + 2. The ideal form of sexing automation
- 7 Triple sex-linking through 4 + 2 + 1

One of the advantages of this system is that of admitting tabular statements of hundreds of different crossings in a clear and concentrated form (SILVERUDD 1970). It is to be noted that, in many cases, 4 + 2 may produce combinations with such complete sexability that even one million dayold chicks may be sexed for sale without the risk of a single cock slipping through. When crossing two strains of WL (gold cock strain × silver hen strain) that have been applied for 4 + 2, sexability will be achieved to 100 % much earlier than is the case with the pure strains.

5. *Strains*

A. *Hen strains*

Table 1 presupposes use of the silver variety of Fiftyfive Flowery (SFF) (SILVERUDD 1967) as hen strain(s). In the four breeding-pens, SFF strains
may be used. Having a genotype that suits SMCSS better than does almost any other breed, SFF has been selected as hen strain for the demonstration of SMCSS. SFF, as hen strain, will meet all reasonable demands on a perfect breed with regard to colour genotype.

FF is the first Swedish poultry breed. It appeared in 1958 (in gold, a little later in silver). Fiftynine has gone into the name of the breed, because, in 1955, the first crossbred chicks were hatched, later to be used for experiments started in 1956. Flowery refers to the white mottled markings of the hens, caused by mo (Silverudd 1967).

For the production of FF, old Swedish strains were utilized, primarily some WL-strains from Överlida Poultry Farm, but also a WL-strain from Härsbäcks Poultry Farm, and one of Brown Leghorn. The genes B, mo, and e+ function in a threefold concurrence and harmony that is striking, giving to the breed its unmistakable and characteristic traits. FF has B and mo from WL, and e+ from Brown L. The combination of B, mo and e+ is extremely successful. When Ancobar was produced (Lamoreux 1941), B was combined with mo and E of Ancona. But e+ has proved to be far superior to E in the combination of mo and B. Both with respect to autosexing accuracy, possibilities of a 100% sexable crossings, and the application of SMCSS, FF is far superior to Ancobar. B and mo alike reduce the pigmentation of the feather. FF-hens are hemizygous to B (B-momo), while cocks are homozygous (BBmomo). This will explain the unique difference in the feather colouring between cocks and hens. B and mo, as it were, come out in full blossom with cocks, turning them almost pure white. However, they always have small gray spots on the neck hackles. GFF cocks have a feature of yellowish red, especially on the shoulders. At the time of moulting, the flowery colouring of FF-hens will be intensified, making the fowls appear still more beautiful in their new plumage.

In actual breeding, SFF has turned out to be hardy and, above all, more resistant to Marek's disease. This is due to the fact that SFF has been inbred for more than ten generations and, also, that the breed has not been reared in any real isolation. Strict selection for good phenotype may also have played its part.

B. Cock strains

Tables 2 and 3 include cock strains of a number of various breeds. However, it is not primarily the different breeds that I want to point out in this respect, but, above all, the many genotypes they represent. White Leghorn, for instance, may easily be varied with regard to genotype by synchronizing different strains, so as to adapt their breeding to SMCSS.

SFF has been included in the tables both as cock and hen strain. The cock strain is then taken to be a line that is not included as hen strain, unless a combination of strain breeding and RRS is to be presented in the tabular statements.

Norwegian Jaerhons is an old country breed which, as early as 1916, became the object of a beginning systematic breeding. At that time, a breeding centre was started for rearing this breed. It is somewhat smaller than leghorn, and is autosexing from about 1940. For several decades, the breed has been subject to extensive inbreeding. As early as 1915, or thereabouts, there existed highly inbred strains with an annual production of 200 eggs per hen (Olsson 1930). Jaerhons are still being bred under control in Norway. They are also to be found in Sweden. The breed is characterized by good quality of the eggshell, the colour of the egg often being of a slightly brown shade. A few hens lay rather brown eggs. Crosses between cocks of Jaerhons and hens of Barred Rock are, in Norway, regarded to be just as good layers as White Leghorn (Eskilt et al. 1958).

New Hampshire has existed in Sweden for about 25 years. The best strain in Sweden differs in three respects and in a rather marked way: it is of a smaller and much slender type, it is pure-bred for early feathering, and produces eggs of a darker brown. Some cross-breeds, such as NH × WL and NH × SFF, are still being sold in Sweden.

Fiftyfive Flowery in gold (GFF) is a very beautiful breed. GFF cock × SFF hen produces GFF hens of a pure colour. The silver variety, however, attracts considerably more interest. Black Leghorn has never been widely spread in Sweden, but earlier cross-breeds, as Black L. × SFF, used to be very popular. Today Black L. is very rare, and so no crosses of a black type are offered for sale in Sweden.

Rhodebar is a barred, autosexing variety of RIR. The breed has been described in Autosexing Hereditas 77, 1974
Annual (Lloyd, Hill and Knight 1949). Black Australorps are found in Sweden in small numbers and have never gained a foothold here. The breed can be used for several crossings of a sex-linked type.

Hampbar is a barred variety of NH. A breed of such a light down colour as NH is hard to make definitely sexable only by introducing B into it. However, the breed may well be used for a great number of sexable crossings.

Swedish Reddish Brown (SRB) is principally a flowery (mottled, mo) variety of Swedish New Hampshire. The crossbred SRB × SFF is very popular for small stocks, much on account of its white mottled markings. SRB has been produced, in the first place, with increased possibilities with SMCSS in view.

Results

With a few pedigree strains at disposal it will be possible to make quite a number of RRS-tests, in a short time, by the application of SMCSS. Table 1 comprises 144 combinations for RRS to be performed in less than one year, starting with only four strains (it will, of course, then take some time until the grown-up offspring has been tested and appraised). Tables 1–3 indicate the possibilities of comprehensive and quick RRS-tests. Each table presupposes the silver variety of Fiftyfive Flowery as hen strain(s). In the four strains, four different cock groups, with three cocks in each, are used. The cock groups, designated A, B, C, and D in Tables 1 and 3, are changed every fourth week. Thanks to the different colour genotypes of the cocks, complete pedigree will be obtained for all female chicks, in spite of the fact that continual shiftings of cocks (cock groups) are taking place in the pens. The cock groups, with SFF as hen strain(s), are synchronized to SMCSS with regard to genotypes prevailing both within each cock group and the groups in relation to one another.

The four cock groups are presented in Table 2. A, B, C, D indicate not only the different cock groups but also the order of changing cocks in accordance with Table 1. The cock groups A and C must not follow after each other, since both have SFF and Jaerhons cocks. For a similar reason, B and D must not follow after each other.

Table 1. See text.

| Test number | Week | Pen 1 | Pen 2 | Pen 3 | Pen 4 |
|-------------|------|------|------|------|------|
| 1 — 12      | 1 — 4 | A    | B    | C    | D    |
| 13 — 24     | 5 — 8 | B    | C    | D    | A    |
| 25 — 36     | 9 — 12| C    | D    | A    | B    |
| 37 — 48     | 13 — 16| D  | A    | B    | C    |
| 49 — 20     | 17 — 20| A  | B    | C    | D    |
| 61 — 72     | 21 — 24| B  | C    | D    | A    |
| 73 — 84     | 25 — 28| C  | D    | A    | B    |
| 85 — 96     | 29 — 32| D  | A    | B    | C    |
| 97 — 108    | 33 — 36| A  | B    | C    | D    |
| 109 — 120   | 37 — 40| B  | C    | D    | A    |
| 121 — 132   | 41 — 44| C  | D    | A    | B    |
| 133 — 144   | 45 — 48| D  | A    | B    | C    |

Table 2. See text.

| Breed/variety | Z-genotype concerned | Autosomal genotype concerned | Breed/variety | Z-genotype concerned | Autosomal genotype concerned | Breed/variety | Z-genotype concerned | Autosomal genotype concerned |
|---------------|----------------------|------------------------------|---------------|----------------------|------------------------------|---------------|----------------------|------------------------------|
| SFF           | BBSSk+k             | e+e+momo                    | Jaerhons      | BBs's+k'k'          | b+b's's+k'k'                | New Hampsh.   | b+b's's+k'k'          | eWheWh                      |
| GFF           | BBs's+k'k'          | e+e+momo                    | Black Legh.   | BBs's+k'k'          | b+b's's+k'k'                | EE            |                     |                             |
| SFF           | BBSSk+k'            | e+e+momo                    | Jaerhons      | BBs's+k'k'          | b+b's's+k'k'                | Ew                |                     |                             |
| GFF           | BBs's+k'k'          | e+e+momo                    | Black Australorps | BBs's+k'k'          | b+b's's+k'k'                | EE            |                     |                             |

*Hereditas* 77, 1974
Remarks about Tables 1 and 2

(1) All genes concerned have not been included in Table 2. New Hampshire, for instance, is homozygous both for columbian restriction (Co) and dominant wheaten (e^Wh; SMYTH 1972).

(2) The particular colour factor characterizing Norwegian Jaerhons has been designated nj. The designation is preliminary. With Jaerhons there also exists a colour type, which, in a typical way, differs from the most common colour type, even in the down colour.

(3) In two cock groups cocks are used of the same variety as the hen strain SFF. It is presupposed that the cocks be of a different strain. With cocks of the same strain as the hens, a combination of strain breeding and RRS is obtained.

(4) When GFF-cocks are used, all female chicks will turn out purebred GFF-hens, although of a strain crossing type.

(5) All chicks from the 144 combinations, indicated in Table 1, are sexable (autosexing and/or sex-linked).

(6) As indicated by Table 1 a cock group reappears in the same pen at regular intervals (cock group A, for instance, appears in the same pen in weeks 1, 17, and 33). One of two actions now has to be resorted to, either repeating earlier combinations or exchanging the cocks in respective cock groups for others. As the hens in the different pens are getting too old or, for some reasons, can no longer be used for repeated combinations, replacing the hens at certain intervals will have to be considered.

(7) SMCSS may naturally be made use of with so-called strain pedigree, when the eggs are not pedigreed, but tracks are kept of the origin of the eggs only with regard to the strain on the maternal side. On the paternal side, full pedigree is obtained even with several cocks in each pen (cf. Multiple pedigree, p. 191). In some cases, breeding of this kind, which, needless to say, are far less laborious, may be used, for instance, to quickly investigate which cock strains may be preferred to adapting both cock and hen strains to each other.

(8) SMCSS is capable of great flexibility. The tables should only be regarded as typical examples of the method, which may be varied as required (cf. Discussion, p. 191).

(9) Cocks of White Leghorn may be used with SMCSS, but they will produce a sexable offspring, only with the use of late feathering hen strains (feather sexing).

Table 3 indicates the genotype and phenotype of the offspring of the different cocks of the cocks groups concerned. Also, the type of the sexing method is indicated by a number, explained under "Numerical code for sexing methods". The table presupposes SFF as hen strain, and so do Tables 1 and 3.

Remarks about Table 3

From among autosomal genes only those within E-locus, besides mo an nj, have been included.

Under "Autosomal genes", nj has been placed as allele to e^+, as we have good reasons to assume that nj is an allele to e^+. The designation e^l would, then, be appropriate to the "Jaerhons gene".

Concerning "Phenotype of the dayolds", only a very short description has been given. Coloured illustrations will, better than anything, help us to get a clear conception of this type. "Bulletin 38, Sex Linkage in Poultry Breeding" (COLES 1966) includes coloured pictures, which, in many cases, remind you of the colour differences of combinations in Table 3.

Under "Sexing method", the number 6, (autosexing and sex-linked) has been assigned to Hampbar × SFF. Hampbar, not being fully autosexing, it is an open question, whether or not it may produce autosexing to 100%. But the gold-silver difference is so marked, that it will be immaterial whether 100% autosexing is obtained or not, in a case like this.

The male chicks of RRS-combinations are of no consequence, of course, but from a purely genetic point of view it may, nevertheless, be of some interest to have them specified under "Genes that may be accurately identified in the feather". Regarding B and b^+ we are actually concerned with BB and Bb^+, respectively. The experienced observer will always distinguish between those types in dealing with cross breeds, included in the table.

Discussion

The tables should be taken to indicate my intention to accentuate different genotypes, rather than
Table 3. See text.

| Cocks | Genotype of the progeny | Males | Males and females | Females | Genes that may be accurately identified in the feather | Phenotype of the dayolds | Phenotype of the dayolds | Genes that may be accurately identified in the feather | Sexing method |
|-------|------------------------|-------|-------------------|---------|------------------------------------------------------|--------------------------|--------------------------|------------------------------------------------------|--------------|
| Breed | Z-genotype Autosomal genotype | Cock group | Symbols of individ. cocks | Z-genes | Autosomal genes | BS
k+ | B, S, mo | unstriped, blurred, silver | striped, gold | B, s+ | 4 |
| SFF | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | A 1 | BBSSk+k | BS
k+ | B, S, mo | unstriped, blurred, silver | striped, gold | B, s+ | 6 |
| NJ | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | A 2 | BBSSk+k | BS
k+ | B, S | unstriped, blurred, silver | striped, gold | b', s+ | 2 |
| NH | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | A 3 | BBSSk+k | BS
k+ | B, b', S | unstriped, blurred, silver | striped, gold | b', s+ | 6 |
| GFF | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | B 1 | BBSSk+k | BS
k+ | B, S, mo | unstriped, blurred, silver | striped, gold | B, s', e+, mo | 4 |
| BIL | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | B 2 | BBSSk+k | BS
k+ | B, S | unstriped, blurred, silver | striped, gold | B, s+ | 6 |
| EE | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | B 3 | BBSSk+k | BS
k+ | B, S | unstriped, blurred, silver | striped, gold | B, s+ | 2 |
| SRB | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | C 1 | BBSSk+k | BS
k+ | B, S, mo | unstriped, blurred, silver | striped, gold | B, s+ | 6 |
| GFF | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | C 2 | BBSSk+k | BS
k+ | B, S | unstriped, blurred, silver | striped, gold | B, s+ | 6 |
| AuO | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | C 3 | BBSSk+k | BS
k+ | B, b', S, mo | unstriped, blurred, silver | striped, gold | B, s+ | 2 |
| HBAR | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | D 1 | BBSSk+k | BS
k+ | B, S, mo | unstriped, blurred, silver | striped, gold | B, s', e+, mo | 4 |
| AuO | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | D 2 | BBSSk+k | BS
k+ | B, S | unstriped, blurred, silver | striped, gold | B, s+ | 6 |
| HBAR | BBSSk+k | e+e+momo | Bb+b's+s*'k+k+ eWheWh | D 3 | BBSSk+k | BS
k+ | B, S | unstriped, blurred, silver | striped, gold | B, s+ | 6 |
the different breeds. White Leghorn, for instance, may easily be varied with regard to genotypes and phenotypes. A breeding institution making use of various WL-strains will thus be able to bring them up-to-date so as to represent several of the prevailing genotypes. Since dominant white (I) covers different genotypes of WL, the latter has increasingly come to be a genotypically mixed breed, as far as inherited traits of colour are concerned, in spite of the fact that most WL are EE. But E, in turn, covers many factors through its dominance, which may easily be noted, when I and E are eliminated from a WL-strain, through breeding.

The tables should, further, be regarded only as exemplifications of SMCSS. The arrangement of cock groups with three cocks in each does not imply that, in my opinion, this should always be the ideal thing. The philosophy of breeding is today intimately linked to the “one-cock-system”, and the one who introduces SMCSS will probably apply SMCSS without arranging the cocks in cock groups. However, this will not exclude that, by degrees, a fuller and more intricate grasp of the matter will be developed. The length of intervals suggested between shifting cocks (4 weeks) is also preliminary. In one respect or other, intervals of different length may be relevant under varying conditions. Further, the number of strains is, naturally, still more flexible. As a basic rule the flexibility admitted by SMCSS should be utilized in a way that will best suit each particular case. When it comes to breeds, strains and genotypes, numbers will differ in connection with a more comprehensive establishment than with a smaller one.

SMCSS should primarily be taken as a system to be used on the basis of an autosexing hen strain with combinations of (1) autosexing and sex-linked type, (2) autosexing type, and (3) sex-linked type. It is very typical for SMCSS, that cocks may be divided into cock groups, that may be shifted continuously without loss of any pedigree of interest, at the same time as there is sexing automation.

The concept Multiple pedigree (MPG) is connected with SMCSS, especially if cocks are placed in cock groups as exemplified by the tables. MPG implies that eggs from a pen with two or more cocks may produce a complete pedigree, especially with all female chicks. If, for a pen containing 100 SFF-hens, one cock be supplied of each of the breeds GFF, Jaerhons, BIL, NH, Swedish Reddish Brown, and Rhodebar, each female produced will, through its phenotype, indicate which of the cocks is their father, thus providing for sorting out all male chicks as day-olds. This example goes to show that pens with hundreds of hens may achieve complete pedigree (as far as female chicks are concerned), provided trap-nests are made use of, and the eggs are pedigree hatched. If there are no trap-nests, and consequently the eggs cannot be pedigree hatched, there will still be pedigree on the paternal side, evident in the colouring and the pattern of the female offspring, if not already by the down colour.

A variety of MPG may be practised in large pens, namely the use of, say, five full brothers of each breed or variety concerned. Five full brothers of each of six breeds/varieties makes 30 cocks to a pen, which then may have about 400 fowls.

When it comes to quickly testing cocks of many different types, MPG is more ideal. In a pen with as many as six cocks (or six groups of full brothers), it will hardly be possible to shift to six others of different genotype and phenotype and, at the same time, retain pedigree accuracy on the paternal side. The example of six cocks is, therefore, not of a SMCSS type. With SMCSS we have, at present, to be confined to using a maximum of 3–4 cocks in each pen. This goes a far way.

The examples of the tables with three cocks in each cock group should, as far as the number of the cocks is concerned, prove to be up-to-date for a comparatively long period of time. With more than one cock in each pen, there will also be MPG, with the practice of SMCSS. Hence, MPG is a concept that will always be connected with SMCSS, even if MPG may be used without also applying SMCSS. A breeding institute may very well utilize the possibility of using SMCSS along with MPG, at the same time as MPG is applied to breeding activities apart from SMCSS. Table 3 is a typical example of SMCSS together with MPG.

The concept autosexing has not received the popularity it deserves. One reason is that the so-called Cambridge-breeds (including Legbar, Cambar, and Dorbar) have often shown a comparatively low production (Hagedoorn 1953). But this was due more to White Leghorn having

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been almost entirely excluded from the autosexing philosophy, and, further, to lack of knowledge and to great deal of misunderstanding about the breeding of autosexing breeds and the production of sexable crosses. **Hagedoorn** produced Legbar, autosexing Barnevelder, and Rhodebar through breeding B into Brown Leghorn, Barnevelder and RIR, respectively. Describing the process of production, however, he makes no reference to hen strains having to be in silver, and cock strains in gold, which is one of the most important facts to remember when changing over to autosexing.

**Hagedoorn** criticizes the method often used in England for the production of new breeds, namely that of taking, for instance, 75% of the genes from one breed and 25% from another. He argues that instead of doing so, B gene should be “loaned” to existing breeds so as to create new varieties. But, as a matter of fact, one principle need not exclude the other, because a new breed, with genes from two or more breeds, may, in many respects, be superior to the breed, from which it chiefly stems. It is true, that such goals will not be achieved immediately, but it need not take more than three to four generations of intensified breeding to prove that the direction chosen is right.

**Hagedoorn** bred B into Barnevelder, and presents a process chart of the production, which is extended over a period of 14 (!) years, resulting in autosexing Barnevelder with 123/124 of the genes from the Barnevelder strain that was the basis for the production (**Hagedoorn** 1953). Charts of this kind are not conduction to creating an interest for autosexing. For a wide application of autosexing, White Leghorn will have to be introduced. There is nothing to indicate that an autosexing form of WL should be inferior in any respect. It would carry us too far to discuss, in this connection, the proper methods for the production of an autosexing WL. This matter will, therefore, be treated separately.

It is of interest to note that, due to the fact that cocks, but not hens, may be homozymous for Z-genes (hens are always hemizygous, and so also pure-bred with regard to Z-genes), cocks may be “loaded” more than hens by creating homozygosity for a number of Z-genes in the cocks. This Z-inbreeding may achieve some importance (this may be so, even now), especially if several Z-genes without any negative effect were discovered and found to be useful to commercial breeding. Z-inbreeding may be resorted to without application to autosomes, to any great extent. One single outstanding cock, having obtained top results in connection with appraisal of offspring, may be mated with its daughters and produce a strain inheriting its Z-genes from this single cock to 100%. Then the inbreeding may be continued until practically 100% homozygosity is obtained for the Z-genes within one strain. For a strain to have Z-genes from one cock only does not suffice, since the Z-chromosomes of that cock may, naturally, differ in the setup of genes. There is often homozygosity for genes such as B, S, and Id. With regard to autosexing and SMCSS, homozygosity is necessarily required for certain Z-genes.

As more colour genes are discovered, and more data can be laid down about them, the possibilities of utilizing them commercially will be enhanced. The possibilities of variation increase with the application of SMCSS. The number of known loci for eight Z-genes are mentioned in “Genetics of the Fowl” (**Hutt** 1949). In “New Loci in the Sex Chromosomes of the Fowl”, 13 such loci are stated (**Hutt** 1960), and in “Bulletin No. 38, Sex Linkage in Poultry breeding”, loci are noted for 15 genes in “A Map of the Sex Chromosomes of the Fowl” (**Coles** 1966).

In connection with breeding, certain genes are, however, inconceivable on account of their negative effects, in one respect or the other. A few Z-genes are known, the loci of which we do not know as yet. Since genes with loci close to each other are linked to a degree proportional to the distance between the loci, this relationship may be used for practical purposes, as for the production of new breeds/varieties. For the production of Automatic Leghorn, use was made of the close linkage between S and K (**Silverudd** 1968).

For obvious reasons, colour genes will, no doubt, be of great importance for all future breeding programmes, including the following aspects:

1. Sexing automation
2. The application of SMCSS and/or MPG
3. As indicators of existing linkages (for instance with blood group genes)
4. As phenotypical characteristics of different strains. In practice this may involve advantages such as facilitating the co-breeding of different
strains, without the slightest risk of mixing them. If different strains should be practically identical with regard to phenotype, extreme care must be taken in collecting and storing the eggs as well as hatching and breeding, so as to avoid mixing.

(5) As homozygous setups of genes in pure strains, as opposed to such setups of another colour type in corresponding loci in other strains, thus permanently providing for heterozygosity, when such strains are crossed. Through linkage, homozygosity tends to increase in closely adjacent loci. If a particular gene should lack importance regarding overdominance, an effect of overdominance may be produced through genes that are linked with the gene in question. It is true, that different theories exist of overdominance (see Müntzing 1971), but in spite of this, there can be no doubt about the importance of heterozygosity in the production of livestock for practical purposes.

Quite a number of colour genes would be conceivable for producing new strains that differ in many respects. But there are also many other kinds of genes as, for instance, blood group genes (which may induce overdominance; Falconer 1960), genes for colour and shape of eggs, quality of shell, size of eggs, type and size of comb, length of down, position of tail, and so on. Colour genes, affecting the colour of ears or eyes, may also be mentioned. Although the value of a planned differentiation of strains can be discussed from various points of view, the basic principles can hardly be rejected. What previously has been said of sexing automation, as well as SMCSS and MPG, represents good examples of the value of differentiation between strains with regard to certain colour genes. Naturally, distinction has to be made between different kinds of differentiation, such as being of advantage for sexing automation, SMCSS and MPG, and promoting higher production, increased hardiness and resistance, higher hatchability, and so on. If two strains are selected on account of highest possible differentiation, and crossed (while retaining the two original strains for comparisons), a better conception may be gained of the advantage of selections of this kind. It is evident that a particular gene may have a quite specific effect. The blood group gene B\(^l\) gives a definitely lower mortality than B\(^{14}\) (Hansen and Law 1970). SMCSS presupposes that either strain or breed crossing is of current interest. Heterosis in general is so well known that, only in passing, it should be emphasized that hatchability, age when starting laying, egg production, and size of eggs will be favourably affected by cross breeding (Hutt 1964). It is also interesting to note, that “the Austra-white hybrids from Australorps × WL are more resistant to respiratory diseases than the parent breeds. This valuable effect of hybrid vigour is also found in crosses between different strains of the same breed” (Hutt 1964). As early as in 1939 Gert Bonnier, Sweden, started experiments that may be considered a beginning to RRS (Lijedahl 1973). To-day “Nick-Chick” is nothing less than a trade mark for a hybrid product.

Through SMCSS a gene like mo will get a practical significance that it has never had before. And there are several genes that may get a similar significance. Genes like B, S, and \(s^+\) have, for very long, proved to be of economic value, although they have not been exploited nearly as much as they deserve.

With SMCSS also other genes, besides the colour genes, may come to the fore. A case in point is the gene for rose comb (R), whose presence or absence is evident in dayold chicks, even if it cannot be observed as instantly as many distinct colour differentiations. But genes to be selected should not have any negative effects. Subfertility of cocks homozygous for the autosomal R gene (rose comb) was observed a long time ago. This subfertility of RR cocks is due to an anomaly in the sperms (Petitjean 1970). This reduces the interest in R, which, however, is worthy of attention also for other positive reasons.

Table 4 presents some examples, indicating how cocks may be shifted when autosexing hen strains are not made use of. The cocks of a particular group may be used simultaneously (without shiftings) or else shifting them one by one (or two by two, in some cases) with full pedigree.

In group E there is an Automatic Leghorn (AL) hen strain. AL is to approximately 97 % produced from a couple of old Swedish WL strains. AL cocks are, from a phenotypical point of view, identical with WL cocks, while AL hens have a slight but characteristic tinge on the body, but wholly white neck. AL has neither E nor \(e^+\).

The colour genes of E-locus cannot be specified and there may be several different genes of yellow/brown/red type. It is typical for AL that, although

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Table 4. See text.

| Group | Sexing method | Males | Z-genotype       | Females | Z-genotype       |
|-------|---------------|-------|------------------|---------|------------------|
| A     | 1             | WL    | BBS's+k'k'k'     | Black Australorps | b's+kK       |
|       | 1             | RIR   | b'b+s's's+k'k'   | RIR     | b's+kK       |
|       | 1             | SFF   | BBSSSk'k'        |         |                 |
| B     | 1             | RIR   | b'b+s's's+k'k'   | L. Sussex | b'SK       |
|       | 1             | Black L. | BBS's's'k'k' | Barred Rock | BSK       |
|       | 1             | GFF   | BBS's's'k'k'     |         |                 |
|       | 1             | WL    | b'b+s's's+k'k'   |         |                 |
| C     | 3             | RIR   | b'b+s's's+k'k'   |         |                 |
|       | 3             | Hampbar | BBS's's'k'k' | Automatic Lehorn | BSK       |
|       | 3             | GFF   | BBS's's'k'k'     | Barred Rock | BS       |
|       | 3             | Brown L. | b'b+s's's+k'k' |         |                 |
| D     | 1             | Jaerhons | BBS's's'k'k' |         |                 |
|       | 1             | WL    | BBS's's'k'k'     |         |                 |
| E     | 1             | RIR   | b'b+s's's+k'k'   |         |                 |
|       | 1             | Black L. | BBS's's's'k'k' |         |                 |
|       | 1             | WL    | BBS's's'k'k'     |         |                 |
| F     | 2             | RIR   | b'b+s's's+k'k'   | Silver Barred NH | BS_k       |
|       | 2             | Hampbar | BBS's's'k'k' |         |                 |
|       | 2             | Black L. | b'b+s's's+k'k' |         |                 |
|       | 2             | GFF   | BBS's's'k'k'     |         |                 |

the breed is a silver breed and pure to dominant white (I), yet occasional colour genes will penetrate in the phenotype of the females. As indicated by Table 4, AL will produce doubly sex-linked cross-breeds, when AL hens are mated with cocks of red (or similar) colour (Silverudd 1968).

Silver Barred NH was produced in Sweden about 1960. It has B and S from Barred Rock. The breed now existing in Sweden has been supplied with 25% English RIR. Through the combination of RIR and NH genes, a darker brown colour of the shell has been obtained compared to what is the case with NH and RIR.

White Leghorn has been considered to be s+s+, because all WL strains that I have examined for S and s+ have been s+s+ (s+-). But often there has appeared ig (inhibitor of gold), which tones down gold to cream. In many cases fowls that are pure to s+ and ig cannot be phenotypically distinguished from silver fowls.

SMCSS may also be applied to the breeding of meat breeds for the production of broilers. However, some fundamental differences should be observed in this connection. In the case of broilers, the proper colour type is far more important, light colours always being aimed at. RRS is much closer connected with layers than with meat-type breeds. But RRS (or modifications of RRS) may gain increased importance, in dealing with meat-type breeds. Crossing and heterosis are, no doubt, of the same significance for both categories. Shifting of cocks without loss of pedigree accuracy may be practised also with breeds for meat production, in rare cases when RRS is resorted to. When rearing meat-type breeds, extremely short generation intervals are already used that cannot be shortened appreciably. Through SMCSS it should be possible, to some degree, to accelerate breeding by performing more tests and by the use of more cock strains. A quicker adaptation of the new strains to another may also be achieved. Z-genes as B, S, s+, Id, and s+I, and autosomal, as Db, Co, eWh, c, and I, may be used to colour the strains for production of broilers. Today we know that the genotype EERCoCoDbDb gives a similar effect as eWhCoCo (Moore and Smyth 1972). The increased clarification about, for instance, the columbia type (NH and L Sussex are typical representatives) has made it easier to specify genotypes for meat-producing breeds (and, naturally, also for laying breeds and for fancy breeds), which will be of more concern, if there is an eye for autosexing, sex-linked crosses, SMCSS.
and MPG. "Columbian" genes and genes appearing together with them in some sort of harmony, make out a context, of which we now have more knowledge than previously (cf. SMYTH 1970; SOMES and SMYTH 1963, 1965b, 1966, 1967; SOMES, Fox, and SMYTH 1966; MOORE and SMYTH 1972, 1972b). Since the broiler of today often is of a sex-linked type, the usefulness of SMCSS may very well be considered, even if an ideal colour type may hardly be said to have been presented as yet in any colour combination suitable for broiler production. Autosexing hen strains in silver, and cock strains of, for instance, genotype \(BB(b^+b^+);s^+CoCoe^{Whe}\), are conceivable. When interest is concentrated on 10 to 12 genes, there will be a great variety of more or less conceivable genotypes. I is a problematic gene, if 100% accurate and rapid sexing is desired. If I is to be included, this should be in cock strains, which often consist of considerably smaller numbers of fowls.

With turkeys, ducks and geese there are also Z-linked colour genes (COLES 1966). It will probably be possible to utilize these in a somewhat similar shifting system.

**Practical advantages**

Since practical advantages have already been emphasized in this paper, only a summary will now be given, besides a few comments.

1. Continuous cock shiftings without loss of pedigree accuracy may be performed in many different ways. The number of RRS-tests may, in this way, be increased, avoiding having breeding fowls that produce only table eggs, for some time after shifting cocks.

2. More than one cock may be kept in each pen without loss of pedigree. Then "multiple pedigree" (MPG) is applied.

3. Several strains, especially cock strains, may be utilized within the same pen.

4. New strains may, more rapidly, be adapted to each other through an advanced breeding of SMCSS type. Also, the possibilities of starting from a more complicated genotype will be enhanced.

5. For several loci a constant heterozygosity may be achieved by crossing the strains that are homozygous for different alleles in homologous loci.

6. SMCSS will reduce the cost per test of RRS-type or similar tests, also when applied in part. Since SMCSS is closely connected with sexing automation, emphasis should also be laid on the advantages of high class sexing.

7. Lower sexing costs (or, at best, none) both regarding pure autosexing strains and crosses with them.

8. Special sorting personnel will not be required, nor sorting contracts etc.

9. Diverse paraphernalia may be dispensed with, such as tables, lamps, apparatuses etc.

10. Risk of infections through sexing operators is completely eliminated (higher mortality through coli bacteria, for instance, has been observed in some cases).

11. The collection and sexing of dayold chicks will be reduced to one action.

12. With pedigree hatching the registration of males and females separately, in connection with marking, will be facilitated. It will be easier to escape marking those males that are not to be used for breeding, or only for the production of fowls for sale.

13. When dayold female chicks are sold for breeding purpose, there will be no risk of a male slipping through, to be used by the buyer for further breeding.

14. Without being hampered by the need of sexing operators, chicks may be picked out from an incubator at a somewhat earlier stage, for instance, when a consignment is to be dispatched over a long distance and, therefore, has to be sent as early as possible.

The flexibility of SMCSS should be pointed out. Thousands of varieties are conceivable. For one thing, this will be important, with regard to the results that future research may arrive at. The usefulness of SMCSS is linked up with that of RRS. In a special way, it provides for "continuous breeding", so as to facilitate continuous shiftings without loss of pedigree accuracy in connection with any planned development.

The importance of "continuous heterozygosity" deserves special attention. Research on this subject may lead to discovery of some facts of special interest and importance for poultry breeding. The great interest existing for blood group genes should also include colour genes far more than hitherto. In the past, colour genes have received attention as indicators of linkage. If, for instance, a linkage is found between a colour gene and a desirable blood group gene, this will

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involve, for instance, that, in producing a new strain to be a carrier of the blood-group gene concerned, a number of fowls of the desired genotype may be obtained quicker, or, at least, with a smaller number of tests. When such a blood-group gene appears in a low frequency, in producing a new strain, the linkage with a colour gene may be of great importance.

The importance of sexing automation for the hatcheries has not received due attention. In the combination of autosexing and sex-linked sexing, a group of, say, 1000 chicks may be picked out from an incubator, sexed, counted and packed into boxes in about 15 minutes. The male chicks will, of course, not be counted. The fact that we are living in the computer age will make it possible for us to utilize the theoretical possibilities with SMCSS in a way that would not otherwise be possible. The computer adds to the importance of SMCSS, and SMCSS adds to the importance of the computer.

Acknowledgment. — The author would like to express his sincere gratitude and appreciation to Dr. Bo Hammar for valuable advice and great interest in the research work carried out by the author.

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