A Comparative Study of the Chromosomes in 5 Species of Birds from the Genus *Aratinga* (Psittaciformes: Aves)¹

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While many species representing most of the major groups of birds have been karyotyped in recent years, the Psittaciformes belong to the least studied groups of birds. So far, the karyotypes of no more than nine species are known: van Brink (1959), Rothfels *et al.* (1963) and Ohno *et al.* (1964) studied the karyotype of *Melopsittacus undulatus*; Ray-Chaudhuri *et al.* (1966, 1969) described the karyotypes of three species of the genus *Psittacula* and one of the genus *Loriculus*; Lucca (1974) showed that *Brotogeris sanctithomae* had $2n=72$ chromosomes, while de Boer and Belterman (1980) described the karyotypes of three parrots (*Nestor notabilis*, *Amazona ochrocephala* and *Psittacus erithacus*).

The aim of the present paper is to bring on record the data of 5 *Aratinga* species, most of which are new to cytology. Possible mechanisms involved in karyotypic evolution in this group are discussed.

Materials and methods

The following species have been investigated: *Aratinga aurea* (2 males and 2 females); *A. auricapilla* (2 males); *A. cactorum* (1 male and 1 female); *A. leucophthalmus* (2 males and 2 females) and *A. solstitialis* (2 males).

Chromosome preparations were obtained from colchicized bone marrow cells by the conventional flame-drying technique (Ford and Hamerton 1956). For G-bands a modification of the technique of Seabright (1971) was used. The technique of Jorge and Benirschke (1977) was used for C-bands.

Relative length and arm ratio were calculated according to Rothfels and Simionovitch (1958). In the chromosome measurements the microchromosomes were always included. Morphometric analysis of the karyotypes was based on five well spread metaphase plates. The system of Levan *et al.* (1964) was followed for the nomenclature of chromosomes.

Results

Table 1 shows the values of relative length and arm ratio of the first eight pairs

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of autosomes and sex-chromosomes of the species investigated.

The somatic macrochromosomes obtained for each species are presented in Figures 1 to 5. The G-band karyotypes of *A. aurea*, *A. cactorum* and *A. leucophthalmus* are presented in Figures 6, 7 and 8 respectively. The C-band (constitutive

Figs. 9–11. 9, metaphase plates of *Aratinga aurea*. A, heterochromatin stain (C-bands) of a male (arrow: Z chromosomes); B, metaphase cell of a female *Aratinga aurea* showing the heterochromatic W chromosome (small arrow). Large arrow shows the Z chromosome. 10, heterochromatin stain (C-bands) of a female *Aratinga cactorum* (small arrow: W chromosome; large arrow: Z chromosome). 11, C-bands of a female *Aratinga leucophthalmus* showing the heterochromatic W chromosome (small arrow). Large arrow shows the Z chromosome.

Figs. 1–8. 1, the somatic macrochromosomes of a female *Aratinga aurea* ($2n=70$). 2, the somatic macrochromosomes of a male *Aratinga auricapilla* ($2n=70$). 3, the somatic macrochromosomes of a female *Aratinga cactorum* ($2n=70$). 4, the somatic macrochromosomes of a female *Aratinga leucophthalmus* ($2n=70$). 5, the somatic macrochromosomes of a male *Aratinga solstitialis* ($2n=70$). 6, partial G-banded karyotype of a female *Aratinga aurea*. 7, partial G-banded karyotype of a male *Aratinga cactorum*. 8, partial G-banded karyotype of a female *Aratinga leucophthalmus*.

heterochromatin) karyotypes of *A. aurea*, *A. cactorum* and *A. leucophthalmus* are shown in Figures 9, 10 and 11 respectively. The schematic representation of the G- and C-banding patterns of the macrochromosomes of the five species examined are shown in Figure 12. It is concluded that the diploid chromosome number in *Aratinga* is 70 for all the analysed species. There is a very sharp boundary between the macro- and microchromosomes. There are 8 pairs of macrochromosomes.

In the female karyotype the Z and W chromosomes were identified: the Z chromosome is a metacentric chromosome slightly smaller than the autosomes of pair 4 and the W chromosome is somewhat larger than the autosomes of pair 8 but it shows a variation in its morphology: metacentric in *A. aurea* and *A. cactorum* and subtelocentric in *A. leucophthalmus*.

According to the size and centromeric position the first four pairs of autosomes and the Z chromosome have direct counterparts in the karyotype of *Aratinga*. Contrary to this situation, the remaining chromosomes show a variation in the cen-

Table 1. Average relative length and arm ratio of the chromosomes of the analysed species

Species	Chromosome pairs										
		1	2	3	4	5	6	7	8	Z	W
<i>Aratinga</i>	RL	12.4	11.5	9.8	8.9	7.1	6.6	4.9	2.6	8.1	3.2
<i>aurea</i>	AR	1.1	4.6	3.8	3.4	2.4	3.0	2.0	2.0	1.0	1.0
<i>Aratinga</i>	RL	10.7	10.4	8.7	8.0	6.1	5.4	4.3	2.6	6.6	Uniden-
<i>auricapilla</i>	AR	1.1	4.2	4.2	3.0	2.6	7.0	1.7	1.7	1.0	
<i>Aratinga</i>	RL	9.6	8.6	7.5	7.2	5.3	5.3	4.9	2.6	6.1	3.0
<i>cactorum</i>	AR	1.2	4.3	3.0	3.5	2.3	4.0	1.5	2.3	1.3	1.4
<i>Aratinga</i>	RL	10.2	9.9	9.1	8.6	6.2	6.2	5.2	2.8	6.8	2.8
<i>leucophthalmus</i>	AR	1.1	4.8	3.6	4.0	2.7	10.0	1.3	1.0	1.0	5.0
<i>Aratinga</i>	RL	12.6	11.7	10.9	9.6	7.6	6.7	5.0	1.7	8.3	Uniden-
<i>solstitialis</i>	AR	1.1	4.6	3.3	6.7	3.5	3.0	1.0	7.0	1.5	

RL=Relative length; AR=Arm ratio

tronic position (Table 1 and Figs. 1 to 5) probably due to pericentric inversions.

Comparison of the G-banding patterns of the chromosomes of these bird species (Figs. 6 to 8 and Fig. 12) demonstrates that the largest pairs of macrochromosomes have similar patterns whereas the Z chromosome of *A. aurea* is unique.

The C-band positive regions are similar in all species, except that *A. solstitialis* appears to possess less constitutive heterochromatin, whereas *A. cactorum* appears to possess more constitutive heterochromatin. The macrochromosomes possess only a small amount of constitutive heterochromatin near the centromere, whereas the W chromosome is darkly stained in all the three species showing a distinctively darker region near the centromere. The microchromosomes possess varying amounts of heterochromatin, and some of them possess more C-band materials than the macrochromosomes except the W (Figs. 9 to 11 and Fig. 12).

In our *A. cactorum* material one chromosome in the 4th pair showed a distinctive C-band in the short arm (Fig. 13).

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Figs. 12-13. 12, schematic representation of the G- and C- banding patterns of the macrochromosomes of *Aratinga*. Aca: *A. cactorum*; Aau: *A. aurea*; Ale: *A. leucophthalmus*; Aap: *A. auricapilla*; Aso: *A. solstitialis*. 13, C-bands of a male *Aratinga auricapilla*. The arrow shows the heterochromatization of the small arm of a homologous of chromosome 4.

Discussion

The order Psittaciformes is known cytologically from the study of nine species belonging to a single family Psittacidae. Three out of these nine worked out species are congeneric and the remaining six belong to different genera.

As indicated above, the karyotypes of *Aratinga* are very much alike. The only differences concern the morphology of the chromosomes of the 5th pair in *A. solstitialis*, 6th pair in *A. auricapilla* and 7th pair which is made up of submetacentrics in *A. aurea* and *A. auricapilla*; in the remaining species the 7th pair is composed of metacentrics. The 8th pair of macrochromosomes is represented by submetacentrics in *A. aurea*, *A. auricapilla* and *A. cactorum*, metacentrics in *A. leucophthalmus* and telocentrics in *A. solstitialis*. The diploid chromosome number of these species is 70 and there is a clear boundary between macro- and microchromosomes. Five of the psittacine karyotypes described so far lack the sharp macro-microchromosome boundary. *Loriculus vernalis* (Ray-Chaudhuri *et al.* 1969) has a quite distinct karyotype in that it shows only one pair of metacentric chromosomes, all the other elements being telocentric. *Brotogeris sanctithomae* (Lucca 1974) has a karyotype closely related to that of *Loriculus vernalis* with $2n=72$ and the morphology of the chromosomes of this species like in *Loriculus*, is strikingly different from that of any other species so far described; only the Z and W are metacentric chromosomes, all the remaining elements being telocentric. *Melopsittacus undulatus* (van Brink 1959, Rothfels *et al.* 1963, Ohno *et al.* 1964) is shown to have a very distinct karyotype including several pairs of smaller bivalent chromosomes probably evolved from fusions of microchromosomes, which may account for the relatively low diploid number ($2n=58$). *Nestor notabilis* and *Amazona ochrocephala* (de Boer and Belterman 1980) show many similarities in spite of the fact that *Nestor* presents a diploid number of 62 and *Amazona*, 70. The major differences lie in the structure of the chromosomes of pair 1, the W chromosome and the slightly higher number of microchromosomes in *Amazona*.

Psittacula krameri (Misra 1974, Ray-Chaudhuri *et al.* 1969), *P. alexandri* (Ray-Chaudhuri *et al.* 1969) and *P. erithacus* (de Boer and Belterman 1980) are assumed to be very closely related because they have almost identical karyotypes. They have the same number of macrochromosomes with a sharp macro-microchromosome boundary. The only difference with *P. erithacus* seems to be that the elements of pair 6 are acrocentric in both *Psittacula* species. *Psittacula cyanocephala* (Ray-Chaudhuri *et al.* 1969) has a slightly different karyotype. In this species large telocentric chromosomes (nos. 6 and 7) are absent, which are replaced by a metacentric one corresponding to the combined relative lengths of nos. 6 and 7 chromosomes in other forms of *Psittacula*. A similar change has been ascribed to the Robertsonian fusion in three of the four species studied by Ray-Chaudhuri *et al.* (1969) where two telocentrics are found instead of one metacentric.

The karyotypes of *Aratinga* show great similarity to those of *Psittacula krameri* (Ray-Chaudhuri *et al.* 1969, Misra 1974), *P. alexandri* (Ray-Chaudhuri *et al.* 1969), *P. erithacus* and *Nestor notabilis* (de Boer and Belterman 1980). Characteristic features of these species are the large size of chromosomes in pairs 1, 2, 3 and 4.

The karyotypes of *Psittacula krameri*, *P. alexandri*, *Amazona ocreocephala*, *Psittacus erithacus* and species of the genus *Aratinga* are characterized by the subtelocentric autosomes in pairs 2, 3 and 4. Ray-Chaudhuri (1973) however, states that the longest telocentrics of *Loriculus vernalis* are similar in length to the three pairs of subtelocentrics in *Psittacula*. The karyotypes of *Loriculus vernalis* and *Brotogeris sanctithomae* show great similarity with a predominance of telocentric chromosomes. A series of pericentric inversions are the only explanation for the derivation of the karyotype of these species. The Z chromosome is also telocentric in *Loriculus* while it is metacentric in all the remaining species of Psittaciformes.

The banding patterns of bird chromosomes have revealed a surprising similarity for the three or four largest chromosomes (Takagi and Sasaki 1974, Stock *et al.* 1974, Stock and Mengden 1975, Rytman *et al.* 1979, Rytman and Tegelström 1981). This fact is obvious for the largest chromosomes in *Aratinga*. Therefore, it is not surprising that the karyotypes including the G- and C-bands of the closely related species studied here are found to be nearly identical.

The C-band positive heterochromatin has hitherto been studied in only a limited number of avian species (Stefos and Arrighi 1971, Comings and Mattoccia 1972, Stock *et al.* 1974, Au *et al.* 1975, Raman *et al.* 1978, Rytman *et al.* 1979, Carlenius *et al.* 1981). It has been observed that 1) although the W is the only heterochromatic chromosome in the parakeet, pheasant, duck and quail, in the dove, pigeon, Japanese quail, bald eagle, chicken, myna, jungle babbler and duck, the centromeres of several microchromosomes are also C-band positive, 2) the centromeres of the macrochromosomes are either devoid of the C-band or possess it in only a trace.

The C-band positive regions are similar in all the five species, but *Aratinga solstitialis* appears to possess less constitutive heterochromatin whereas *A. cactorum* appears to possess more.

As mentioned elsewhere, the 4th pair of chromosomes in *A. cactorum* are heteromorphic in terms of the C-band pattern of the short arm (Fig. 13). Stock *et al.* (1974) and Carlenius *et al.* (1981) described that the telomeric C-bands of the Z chromosome in *Gallus domesticus* are polymorphic in size.

In some orders (Charadriiformes and Ciconiiformes) there is an obvious tendency to reduction in the number of chromosomes. This tendency is clearly expressed in the species so far analysed in the order Psittaciformes. In *Melopsittacus undulatus* the smallest macrochromosomes have been created by Robertsonian translocation between large microchromosomes as judged by their metacentric morphology.

Ansari and Kaul (1979) suggested a possible occurrence of microchromosomal addition to the telocentric chromosome 3 in *Oriolus xanthornus*. Stock *et al.* (1974) investigated the G-banded karyotype of the pigeon and the dove and suggested that the interspecific differences in karyotypes result from the fusion of four pairs of microchromosomes of the pigeon to form two pairs of metacentric macrochromosomes in the dove. In the order Psittaciformes, Ray-Chaudhuri *et al.* (1969) state that in *Psittacula cyanocephala* a single translocation of the Robertsonian type is the most simple explanation of the derivation of a large metacentric chromosome. Lucca (unpublished) found a translocation involving chromosomes 1 and 6 in *Forpus*

xanthopterygius.

A greater amount of constitutive heterochromatin was found in Psittaciformes compared to Columbiformes (Lucca 1980). He suggested that a part of the heterochromatin which was added to the macrochromosomes from microchromosomes was insertionally translocated into the pericentromeric region.

Summary

Karyotypes were compared in 5 species of *Aratinga* (Psittaciformes). The macrochromosomes of each species were analysed by the conventional Giemsa staining, with cytobiometry, and G- and C-banding. All the species showed $2n=70$ chromosomes. These karyotypic data are compared to those in the literature on nine other parrot species. The reduced chromosome number in *Aratinga* was attributed to the fusion of microchromosomes into macrochromosomes.

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