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Exceptional response by female Red Crossbills to dietary carotenoid supplementation.—Carotenoid-based pigmentation accounts for much of the yellow, orange, and red coloration of feathers (Brush 1978, Goodwin 1984). It has long been known that animals cannot synthesize carotenoid pigments *de novo* and must obtain such pigments from their diet (Giersberg and Stadie 1933, Brockmann and Völker 1935, Brush 1978, Goodwin 1984). However, the extent to which dietary access to carotenoid pigments can affect individual expression of plumage coloration and can generate variation in color expression within a populations has only recently been emphasized (Brush and Power 1976, Hill 1992, 1993a,b). While the brightness or hue of carotenoid-based plumage can be altered by diet, the distribution of pigmentation across the surface of a bird (i.e., the pattern of coloration) is not generally affected by diet (Hill 1993a). Similarly, in the few species that have been studied, differences between the sexes in expression of carotenoid-based integumentary coloration are not affected by dietary access to carotenoid pigments (Miskimen 1980, Burley et al. 1992, Hill 1993b). Here we report a dramatic change in the plumage coloration of female Red Crossbills (*Loxia curvirostra*) that were fed a diet rich in canthaxanthin during molt.

The Red Crossbill is a sexually dichromatic cardueline finch. Adult males have carotenoid-based ornamental coloration (Völker 1957) over their entire body plumage that varies in appearance from drab yellow to bright red (Tordoff 1952, Jollie 1953, Kemper 1959, Phillips 1977). Most males in definitive plumage are reddish-orange in coloration (Kemper 1959). Females are dull olive-gray to yellow-gray with faint streaking on their flanks and breast that is lacking in adult males (Jollie 1953, Phillips 1977). A few females show a wash of red coloration (Jollie 1953, Phillips 1977). In the wild, however, there is no overlap in the coloration of males and females: the most drably plumaged male is brighter and redder than the most brightly plumaged female (Tordoff 1952, Jollie 1953, Kemper 1959, Phillips 1977).

We used diet supplementation to test the effect on plumage coloration in male and female Red Crossbills. Diets were enhanced with red carotenoid pigments during pre-basic molt. Six male and three female Red Crossbills of call type 5 (Groth 1993) were captured 18-19 September 1993 near Aspen, Colorado, and four male and three female Red Crossbills of call type 2 (Groth 1993) were captured near Los Alamos, New Mexico 5-6 October 1993. Female crossbills of call type 5 were sexed by presence of a brood patch at the time of capture. Females of call type 2 were sexed by plumage. The birds were divided by call type and housed on the campus of New Mexico State University, Las Cruces, in an indoor room that was divided with 1.2 cm mesh screen into two 1.55 × 2.74 × 2.24 m aviaries. Birds were provided with grit and with water containing vitamins and calcium supplement. Fresh cones, usually ponderosa pine (*Pinus ponderosa* var. *scopulorum*), were provided daily, supplemented with sunflower seeds. Fresh pine branches were provided weekly. The red carotenoid pigment canthaxanthin was added to the drinking water of birds in the form of

starch-gel beadlets (Roxathin Red 10 WS, Hoffmann-LaRoche Inc., Nutley, NJ; approximately 0.004 g/ml water). This form of canthaxanthin is stabilized and water soluble.

At the time of capture most males of both call types were drab red-orange over their entire body plumage, and females were olive-gray. A few males were drab orange with patches of yellow plumage. All individuals underwent complete pre-basic molt in captivity from November 1993 to January 1994. At the completion of molt, the body plumage of both males and females was bright red-orange, and the sexes were indistinguishable. All males showed brighter plumage after captive molt than at the time of capture, and all females showed much brighter plumage after captive molt, having changed from drab olive-gray to bright orangish-red. There was no difference between birds from the two call types.

To our knowledge, this is the first example of sex-specific plumage coloration being completely obscured by response to dietary pigment supplementation. The effects of carotenoid supplementation on the expression of plumage coloration in female House Finches (*Carpodacus mexicanus*) were quite different. The House Finch is a sexually dichromatic cardueline finch with carotenoid-based plumage coloration that is similar to that of Red Crossbills (Brush and Power 1976, Hill 1992, 1993a). Feeding female House Finches large quantities of canthaxanthin during molt caused them to grow redder and more extensively pigmented plumage than they had displayed at the time of capture (Hill 1993b), but sex-specific differences in plumage pigmentation were not obscured. The brightest female House Finch from the feeding experiment was still less intensely pigmented than the drabbest male (either captive or wild), and females from the feeding experiment retained their sex-specific plumage pattern with heavy melanin streaking on the throat and upper breast, fore crown, and rump (Hill 1993b). Moreover, carotenoid supplementation in the House Finch did not cause females to express plumage pigmentation beyond that seen in wild populations; the most brightly plumaged female from the feeding experiment showed plumage pigmentation very similar to that of the most brightly pigmented females in wild populations (Hill 1993b).

Compared to House Finches, Red Crossbills differ much less between the sexes in melanin pigmentation (females show faint ventral streaking that is lacking in males). Sex-specific plumage differences are primarily differences in plumage hue and brightness, not in the distribution of feathers with carotenoid pigmentation. Therefore, to change from a female-typical to a male-typical appearance in the Red Crossbill, all that is required is to brighten and redden the plumage. We found that such change was effected by carotenoid supplementation.

A small proportion of wild female Red Crossbills from all geographic races show some red coloration in their plumage (Jollie 1953, Phillips 1977). We know of no reports, however, of wild female Red Crossbills displaying male-like plumage. If all female Red Crossbills have the potential to grow bright red plumage, and yet such coloration is not seen in wild females, this suggests that wild females do not obtain sufficient dietary carotenoids for full expression of plumage coloration. Because most male Red Crossbills have bright red plumage, one might surmise that they consume substantially more carotenoid pigments than females during molt. This assumes, however, that male and female Red Crossbills have the same physiological mechanisms for carotenoid uptake, transport, and deposition (Brush 1990). More likely, there are substantial sex-specific differences in such physiological mechanisms that may or may not be compounded by sex-specific differences in dietary intake of carotenoid pigments. Only in situations where birds consume huge quantities of carotenoid pigments, such as feeding experiments, are differences in physiology between the sexes overwhelmed. Nevertheless, revealing the capacity for male-like color expression in females of a highly dichromatic bird is interesting and further indicates that much remains to be learned about the proximate control of plumage coloration.

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