Transgenic pollen harms monarch larvae

Although plants transformed with genetic material from the bacterium *Bacillus thuringiensis* (*Bt*) are generally thought to have negligible impact on non-target organisms[1], *Bt* corn plants might represent a risk because most hybrids express the *Bt* toxin in pollen[2], and corn pollen is dispersed over at least 60 metres by wind[3]. Corn pollen is deposited on other plants near corn fields and can be ingested by the non-target organisms that consume these plants. In a laboratory assay we found that larvae of the monarch butterfly, *Danaus plexippus*, reared on milkweed leaves dusted with pollen from *Bt* corn, ate less, grew more slowly and suffered higher mortality than larvae reared on leaves dusted with untransformed corn pollen or on leaves without pollen.

Pollen for our assay was collected from N4640-*Bt* corn and an unrelated, untransformed hybrid, and was applied by gently tapping a spatula of pollen over milkweed (*Asclepias curassavica*) leaves that had been lightly misted with water. Pollen density was set to visually match densities on milkweed leaves collected from corn fields. Petioles of individual leaves were placed in water-filled tubes that were taped into plastic boxes. Five three-day-old monarch larvae from our captive colony were placed on each leaf, and each treatment was replicated five times. Milkweed leaf consumption, monarch larval survival and final larval weight were recorded over four days.

Larval survival (56%) after four days of feeding on leaves dusted with *Bt* pollen was significantly lower than survival either on leaves dusted with untransformed pollen or on control leaves with no pollen (both 100%, $P = 0.008$) (Fig. 1a). Because there was no mortality on leaves dusted with untransformed pollen, all of the mortality on leaves dusted with *Bt* pollen seems to be due to the effects of the *Bt* toxin.

There was a significant effect of corn pollen on monarch feeding behaviour ($P = 0.0001$) (Fig. 1b). The mean cumulative proportion of leaves consumed per larva was significantly lower on leaves dusted with *Bt* pollen (0.57 ± 0.14, $P = 0.001$) and on leaves dusted with untransformed pollen (1.12 ± 0.09, $P = 0.007$) compared with consumption on control leaves without pollen (1.61 ± 0.09). The reduced rates of larval feeding on pollen-dusted leaves might represent a gustatory response of this highly specific herbivore to the presence of a 'non-host' stimulus. However, such a putative feeding deterrence alone could not explain the nearly twofold decrease in consumption rate on leaves with *Bt* pollen compared with leaves with untransformed pollen ($P = 0.004$).

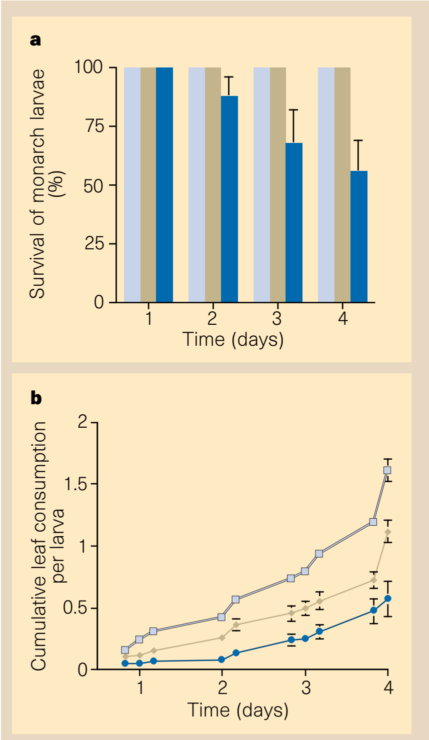

Figure 1 Survival and leaf consumption of second- to third-instar monarch larvae on each of three milkweed leaf treatments: leaves with no pollen (light blue), leaves treated with untransformed corn pollen (green) and leaves dusted with pollen from *Bt* corn (dark blue). **a,** Mean (±s.e.m.) survival based on the proportion of larvae surviving in five replicates of each treatment. **b,** Mean (±s.e.m.) cumulative leaf consumption based on the total amount of leaf area consumed per larva in five replicates of each treatment. The amount of leaf area consumed per larva in each experimental unit was calculated for each time interval by dividing the amount of leaf area consumed in that interval by the number of larvae alive during the time interval. Cumulative consumption was calculated by summing the leaf area consumed per larva at each interval. Colours of lines correspond to those of the bars in **a**.

The low consumption rates of larvae fed on leaves with *Bt* pollen led to slower growth rates: the average weight of larvae that survived to the end of the experiment on *Bt*-pollen leaves (0.16 ± 0.03 g) was less than half the average final weight of larvae that fed on leaves with no pollen (0.38 ± 0.02 g, $P = 0.0001$).

These results have potentially profound implications for the conservation of monarch butterflies. Monarch larvae feed exclusively on milkweed leaves[4]; the common milkweed, *A. syriaca*, is the primary host plant of monarch butterflies in the northern United States and southern Canada[5]. Milkweed frequently occurs in and around the edges of corn fields, where it is fed on by monarch larvae[6]. Corn fields shed pollen for 8–10 days between late June and mid-August, which is during the time when monarch larvae are feeding[7]. Although the northern range of monarchs is vast, 50% of the summer monarch population is concentrated within the mid-western United States, a region referred to as the 'corn belt' because of the intensity of field corn production[8]. The large land area covered by corn in this region suggests that a substantial portion of available milkweeds may be within range of corn pollen deposition.

With the amount of *Bt* corn planted in the United States projected to increase markedly over the next few years[9], it is imperative that we gather the data necessary to evaluate the risks associated with this new agrotechnology and to compare these risks with those posed by pesticides and other pest-control tactics.

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The mystery of female beauty

Yu and Shepard[1] have reported a preference for heavy women with high waist-to-hip ratios (WHR) in a culturally isolated population in southeast Peru. Their findings are interesting because a preference for low WHR is widespread in westernized populations[2–5]. However, we disagree with their argument that cultural invariance is necessary for an adaptionist interpretation of WHR preference.

WHR and waist circumference are positively correlated with testosterone and negatively associated with oestrogen[6]. Women with low WHR have better health and fertility than women with high WHR[5]. However, women in England and Texas with high

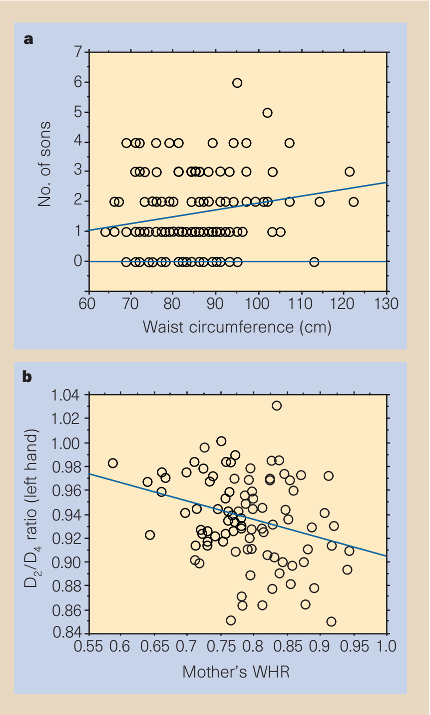

Figure 1 Relations between female body shape and the number of sons and testosterone levels in their children. **a,** Number of sons and waist circumference in 141 Jamaican women; **b,** D_2/D_4 ratio for the left hands of 95 Jamaican children and the WHR of their mothers. The lines are least-squares lines of best fit: **a,** $y=0.023x-0.34$; **b,** $y=-0.155x+1.059$.

WHR and thick waists tend to have more sons[7,8], and a preference for women with high WHR might result in selection for increased testosterone levels in children. Men in societies that prize sons over daughters and in which strength is an advantage might therefore be expected to show a preference for high WHR.

We present data from a rural Jamaican population showing that: (1) in agreement with the data from England and Texas[7,8], there is a positive association between a woman's waist circumference and her number of sons; and (2) a high WHR in women is associated with a marker for high testosterone (a low ratio of the lengths of the second and fourth digits, or D_2/D_4; ref. 9) in their children.

Our Jamaican sample was drawn from Southfield in the parish of St Elizabeth and was part of a large long-term study of developmental stability (the Jamaican Symmetry Project). We measured 141 women whose mean age was 34.63 ± 7.23 s.d. years. The waist was measured at the narrowest portion between the ribs and the iliac crest, and hips were measured at the level of the greatest protrusion of the buttocks. All subjects were standing and wore light outdoor clothing.

Photocopies of children's hands were used to measure digit length (95 subjects, mean age 8.00 ± 1.43 s.d. years, were asked to place hands palm-down on the glass platen). Digits were measured from the crease proximal to the palm to the tip of the digit[9]. Repeated measurements on the photocopies and comparisons with X-rays of the hands indicated that there was a high concordance with the photocopied measurements. The mean D_2/D_4 ratio for the right hand was 0.93 ± 0.03, and 0.94 ± 0.04 for the left.

The waist circumference of mothers was significantly and positively related to the number of sons (Fig. 1a) but not to the number of daughters. The relation between a woman's waist circumference and the number of her sons remained significant after the effect of the age of the mother was partialled out (partial correlation, number of sons and waist circumference: $r=0.18$, $P=0.03$; and age of mother: $r=0.30$, $P=0.0005$).

Similar, but weaker, relationships were present between hip circumference and WHR and the number of sons. Waist and hip circumference and WHR were positively but not significantly related to the proportion of sons (Table 1). The D_2/D_4 ratio was significantly and negatively related to WHR in the right and left hands; that is, women with high WHR tended to have children with low D_2/D_4 ratios (Table 1 and Fig. 1b). As a low D_2/D_4 ratio is indicative of a high testosterone level in adults, this probably means that women with high waist-to-hip ratios have children with high testosterone.

Of course, our Jamaican sample is westernized and we have no data on WHR preferences in adults. However, the positive relation between waist circumference and/or WHR and a tendency to produce sons has now been demonstrated in three populations and may well be universal. The high testosterone found in the children of high-WHR women might relate to muscular strength (it is already known that high-WHR women have heavier and taller babies than low-WHR women[10]). This might explain why traditional societies in which sons are valued over daughters may prefer tubular women, which is consistent with an adaptionist interpretation of these preferences.

Table 1 **Effects on offspring of WHC and WHR of Jamaican women**

Trait	No. of sons		No. of daughters		Proportion of sons		D_2/D_4 right hand		D_2/D_4 left hand	
	r	*P*	*r*	*P*	*r*	*P*	*r*	*P*	*r*	*P*
Waist circumference	0.21	0.01	0.02	0.79	0.17	0.052	−0.15	0.15	−0.18	0.08
Hip circumference	0.14	0.09	0.07	0.41	0.16	0.06	−0.02	0.87	−0.01	0.92
WHR	0.15	0.08	0.05	0.56	0.10	0.27	−0.20	0.048	−0.29	0.004

The relations are shown between measurements of waist and hip circumference (WHC) and waist-to-hip ratio (WHR) for Jamaican women, and the proportion of sons (arcsine transformed, $n=141$ women) and the number of sons and daughters ($n=141$ women) they have, and the D_2/D_4 ratio in the left and right hands of their children ($n=95$ women). *r*, Coefficient of correlation; *P*, probability of wrongly rejecting the null hypothesis.

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Evolutionary psychology suggests that a woman's sexual attractiveness might be based on cues of reproductive potential. It has been proposed that a major determinant of physical attractiveness is the ratio between her waist and hip measurements (the waist-to-hip ratio, or WHR): for example, a woman with a curvaceous body and a WHR of 0.7 is considered to be optimally attractive[1–3], presumably because this WHR is the result of a fat distribution that maximizes reproductive potential[4]. It follows that the preference for a curvaceous body shape in women should be universal among men and not be culturally based, because natural selection presumably favours cues indicative of the most fertile body shape.

Yu and Shepard have challenged this hypothesis[5]. They tested the preferences of a culturally isolated tribe of Peruvian Indians (the Matsigenka) by using a set of line-drawn figures of women who varied in apparent body-mass index (BMI) and WHR[1]. They claim that their results indicate a preference by this tribe for a tubular body shape, rather than the curvaceous shape favoured in the United States[5]. However, we believe that the conclusions of Yu and Shepard are undermined by a flawed assumption.

The drawings used by Yu and Shepard are arranged in three series[5]: underweight, normal and overweight. Within each series, the BMI of each of the four figures is supposed to be held constant, while the WHR is varied by narrowing the waist. However, we believe that this assumption is false