cation that macro-engineering believes it has overcome all basic technical challenges for such exposed installations, including tsunami displacement!

Sri Lanka and India suffer under restrictive opportunity conditions owing to their endemic national energy shortages; there is untapped hydro and wind potential in Palk Strait. What if Palk Strait were spanned by ~16 km of VAHTs lodged in a structure permitting a free-flow of its sea water in either direction? What if that realized fixed link were studded with many units of 'Windformer', from Asea Brown Boveri Ltd, a WT specifically designed to survive the high mean winds offshore that translate into high electrical production? Ultimately, macro-engineers can expect WT units with capacities of >10 MW[14]. WT foundations must be designed to forestall any chance of their becoming destructive pry-bars during tsunami impacts.

Additionally, there are other tasks for a PSPS installation: (a) supporting a freshwater supplies pipeline from India to Sri Lanka; (b) carrying a slurry pipeline for Indian coal exports to Sri Lanka; (c) conveying several telecommunications conduits connecting two populations; (d) being a roadbed for a railway such as a maglev or, more speculatively, an evacuated tube transport[15]. I do not recommend the PSPS structure carry a motor highway like the Overseas Highway US 1 in USA, a 170 km-long motor roadway linking Florida Keys islands with 35 bridges, approximately 15% of the total distance. I urge others on scene give this sketched macroproject suggestion some elaborating technical and geopolitical thought[16].

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SCIENTIFIC CORRESPONDENCE

Pollen fertility of interspecific F_1 hybrids in genus *Citrullus* (Cucurbitaceae)

Significant contribution has been made for the improvement of many crops through interspecific crosses. In *Citrullus*, however, such achievements have been meagre. Besides cross-incompatibility between wild and cultivated species, the low pollen fertility of F_1 hybrids is one of the major difficulties found in developing lines with introgression of economically useful characters. Though, two species of the genus *Citrullus*, viz. *C. colocynthis* (wild) and *C. vulgaris* are morphologically closely related, Khosoo[1] reported 30–40% pollen fertility in interspecific F_1 hybrids and Singh[2] reported 48% pollen fertility in natural hybrid, locally known as 'ta-tumba', of these two species. *C. colocynthis* locally known as tumba, is one of the predominant species abundantly growing wild in the hot Indian arid zone. It has the potential to yield one million tonnes of oil-rich seeds from the four major districts of Rajasthan, i.e. Jaisalmer, Barmer, Bikaner and Jodhpur. Looking at the tremendous economic importance of this plant, crosses were attempted between these two species involving two accessions of *C. colocynthis* (GP 177 and GP 3), three cultivars of *C. vulgaris* (RW 177-3, AHW 19 and Kalinga) and four interspecific derivatives (TD 7, TD 11, TD 18 and TD 22). This correspondence discusses pollen fertility and the possible causes affecting it in 20 F_1 combinations, which could lead to appropriate breeding methodology to improve fertility level of the hybrids.

All the nine parental genotypes and 20 F_1 hybrids were examined for pollen fertility in both the seasons, viz. zaid 1998 and kharif 1998. In zaid (April) the range of minimum relative humidity, maximum relative humidity, minimum temperature and maximum temperature was 16–19%, 35–48%, 22.5–27.6°C and 35.0–40.1°C, respectively. In kharif (September) these were found to be 41–69%, 80–90%, 24.3–25.7°C and 31.9–35.8°C, respectively. Five plants of each parent/F_1 hybrid from each replication (total four replications) were examined for pollen fertility. Anthers from freshly-opened flowers were dusted on micro-slides and released in acetocarmine (1%) mixed with a little glycerol and mounted using a cover slip. Pollen fertility was estimated by stainability technique[3].

The pollen fertility in different hybrid combinations has been presented in Table 1.

Table 1. Pollen fertility of parents and F_1 hybrids of different cross-combinations in genus *Citrullus*

	Pollen fertility (%)			
Parent/cross-combination	Kharif		Zaid	
GP 177	97.5		97.7	
GP 3	96.0		97.8	
RW 177-3	89.1		93.3	
AHW 19	93.3		92.1	
Kalinga	93.4		90.3	
TD 7	95.6		95.5	
TD 11	90.0		97.3	
TD 18	96.6		96.3	
TD 22	96.5		98.3	
C. colocynthis × *C. vulgaris* var. watermelon	Cross	Reciprocal	Cross	Reciprocal
GP 177 × RW 177-3	24.5	86.2	26.6	84.1
GP 3 × RW 177-3	18.5	76.0	24.5	69.2
Mean	21.5	79.1	25.6	76.6
C. colocynthis × *C. vulgaris* var. matira				
GP 177 × AHW 19	27.3	84.7	20.3	83.6
GP 3 × AHW 19	41.3	84.0	29.3	83.5
Mean	34.3	84.4	24.8	83.4
C. colocynthis × *C. vulgaris* var. kalinga				
GP 177 × kalinga	34.2	84.3	29.0	83.4
GP 3 × kalinga	46.0	65.2	43.0	77.7
Mean	40.1	74.7	36.0	80.6
General mean	31.9	79.4	28.8	80.3
C. colocynthis × tumba derivative				
GP 177 × TD 7	30.1	80.2.	24.2	80.0
GP 177 × TD 11	32.0	86.2	21.3	80.3
GP 177 × TD 18	29.1	86.2	24.2	80.2
GP 177 × TD 22	38.4	47.8	30.5	39.6
Mean	32.4	75.1	25.0	70.2
CD at 5%	4.1		4.8	

The parental genotypes had high pollen fertility and uniform pollen grains (Table 1; Figure 1 *c*). Compared to parental genotypes having more than 90% fertility (RW 177-3 = 89.1% in kharif) and uniform-sized pollen grains, F_1 hybrids depicted lower pollen fertility (unstained pollen grains, Figure 1 *f*, *i* and *l*). Pollen fertility in *C. colocynthis* and *C. vulgaris* was reported as high as 93–95% (refs 1, 2, 4, 5), confirming our results. Low pollen fertility of interspecific F_1 hybrids was due to meiotic abnormalities (Figure 1 *d*, *e*, *g* and *h*), which is in agreement with the study of Roy and Jha[6].

Results further revealed that the pollen fertility in the hybrids of *C. colocynthis* × *C. vulgaris* varied with different cultivar combinations. Among three cross-combinations, the F_1 hybrid of combination *C. colocynthis* × *C. vulgaris* var. kalinga showed maximum (average) pollen fertility (40.1%) followed by *C. colocynthis* × *C. vulgaris* var. matira (34.3%) and *C. colocynthis* × *C. vulgaris* var. watermelon (21.5%). Variation in pollen fertility exhibited by different genotypes/cultivars indicated that genotypes of *C. colocynthis* may differ from cultivars of *C. vulgaris* by an inversion, as a bridge with fragment was observed at anaphase I in a few pollen mother cells (PMCs) of these hybrids (Figure 1 *e*). Singh and Yadava[7], in species crosses in *Cucumis*, also observed genotypic differences in pollen fertility.

In all the hybrids involving *C. colocynthis* as female parent pollen fertility was observed to be lower than their respective reciprocals during both seasons. Simultaneously, in these hybrids meiotic abnormalities, viz. unequal distribution of chromosomes ranged from 15.0% (GP 177 × TD 11 and GP 177 × TD 18) to 28.3% (GP 177 × TD 22), cells with laggards at anaphase (I and II) varied from 15.2% (GP 177 × TD 22) to 37.5% (GP 3 × matira) and the frequency of cells with bridges, with or without fragments, was less than 10% (Table 2).

With *C. colocynthis* as female parent, F_1 hybrids with low percentage of cells having regular distribution of chromosomes and high percentage of cells hav-

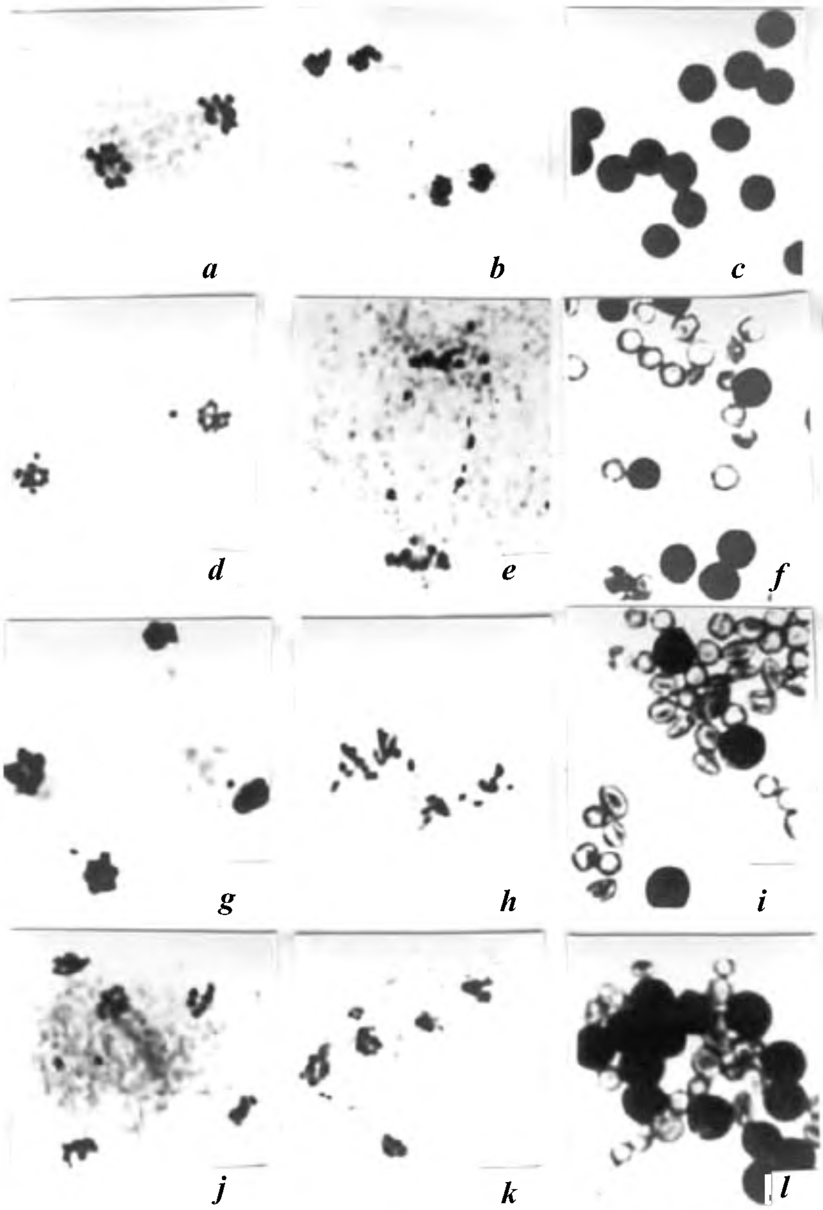

Figure 1. ***a***, AI normal disjunction of chromosomes; ***b***, AII normal disjunction of chromosomes; ***c***, Stained pollen grains; ***d***, AI showing laggards; ***e***, AI showing laggards with bridge fragments; ***f***, Stained and unstained pollen grains; ***g***, AII showing laggards; ***h***, AII showing laggards; ***i***, Stained and unstained pollen grains; ***j***, Late AII showing laggards and pentad; ***k***, Late AII showing laggards and hexad; ***l***, Stained and unstained pollen grains. A, Anaphase.

ing unequal distribution of chromosomes at the poles compared to their respective reciprocals, resulted in low pollen fertility. Similarly, incidence of laggards at anaphase I and II was higher in the straight crosses than in the reciprocals (Table 2). Consequently, pollen and achene fertility in the F_1 hybrids of crosses involving *C. colocynthis* as female parent was reduced. The pollen fertility of F_1 hybrids of different crosses has shown a clear pattern, where it was significantly low in case of hybrids between *C. colocynthis* and *C. vulgaris* than in the corresponding reciprocals (Table 1). This clearly indicates the influence of wild-species cytoplasm contributing to the observed pollen sterility in case of *C. colocynthis* × *C. vulgaris*. Reciprocal differences in pollen fertility of F_1 hybrids of interspecific crosses in family Cucurbitaceae were also reported earlier[7–9]. High pollen fertility in reciprocal hybrids observed in the present study in terms of stainability, does not mean high germinability of pollen grains. Berg[10] and Bhatnagar *et al.*[11] also reported this type of relationship. Low pollen fertility of F_1 hybrids involving *C. colocynthis* as female parent was also reflected in the morphology of anther development. Anthers in these hybrid plants were chaffy and deformed. Patel *et al.*[12] observed this type of morphological anther deformity in species crosses of arid legumes. In some of the F_1 hybrids, pollen grains of various shapes and sizes forming pentad (Figure 1 *j*) and hexad (Figure 1 *k*) were observed, which affected the pollen fer-

Table 2. Chromosome distribution at anaphase (I and II), pollen fertility in F_1 hybrids and reciprocals (in parentheses) of *Citrullus* species

Cross	Percentage cells with regular distribution	Percentage cells with unequal distribution	Percentage cells with laggards at anaphase I	Percentage cells with laggards at anaphase II	Percentage cells with bridge(s)	Percentage pollen fertility (kharif)
C. colocynthis × *C. vulgaris*						
GP 177 × RW 177-3	33.3	24.2	21.2	15.2	6.1	24.5
	(92.5)	(2.5)	(2.5)	(2.5)	(0.0)	(86.2)
GP 3 × RW 177-3	32.5	27.5	25.0	7.5	7.5	18.5
	(80.0)	(6.7)	(6.7)	(4.4)	(2.2)	(76.0)
GP 177 × AHW 19	34.3	25.7	22.9	11.4	5.7	27.3
	(87.5)	(5.0)	(2.5)	(2.5)	(2.5)	(84.7)
GP 3 × AHW 19	37.5	17.5	25.0	12.5	7.5	41.3
	(90.0)	(4.0)	(4.0)	(0.0)	(2.0)	(84.0)
GP 177 × Kalinga	37.8	22.2	17.8	13.3	8.9	34.2
	(95.0)	(0.0)	(3.3)	(0.0)	(1.7)	(84.3)
GP 3 × Kalinga	40.0	16.7	23.3	15.0	5.0	46.0
	(81.5)	(5.6)	(7.4)	(3.7)	(1.8)	(65.2)
C. colocynthis × interspecific derivative						
GP 177 × TD 7	41.2	17.6	23.5	11.8	5.9	30.1
	(90.9)	(0.0)	(4.5)	(2.3)	(2.3)	(80.2)
GP 177 × TD 11	47.5	15.0	27.5	7.5	2.5	32.0
	(88.0)	(4.0)	(4.0)	(2.0)	(2.0)	(86.2)
GP 177 × TD 18	47.5	15.0	19.0	12.5	5.0	29.1
	(87.3)	(3.6)	(5.5)	(1.8)	(1.8)	(86.2)
GP 177 × TD 22	52.2	28.3	8.7	6.5	4.3	38.4
	(58.7)	(13.1)	(12.2)	(4.3)	(8.7)	(47.8)

tility to some extent. These observations are in agreement with the studies made in wheat[3] and in *Felecia begiriana*[13].

Pollen fertility in F_1 hybrids of the combination *C. colocynthis* × *C. vulgaris* (31.9%) and the combination *C. colocynthis* × interspecific derivatives (32.4%) did not differ significantly during both seasons. This behaviour in the crosses between *C. colocynthis* and interspecific derivatives ruled out the expectation of increased pollen fertility in early generations through interspecific derivatives.

It may be noted that in most of these crosses pollen fertility was low even after high bivalent association. Higher value of per cent cells with regular distribution of chromosomes further suggested closer relationship between *C. colocynthis* and interspecific derivatives (established) compared to cultivars of *C. vulgaris*, viz. var. watermelon and var. matira. Singh and Yadava[7] reported close relationship between the species of *Cucumis*, F_1 hybrids of which exhibited higher bivalent association and low pollen fertility. These results are of significance from the breeding point of view.

Information regarding status of pollen fertility of F_1 hybrids and causes affecting it (chromosome association, etc.), enables a breeder to have right choice of selection of parents for hybridization. This would further help to isolate and stabilize economically desirable lines having seeds with thin testa and high oil content. Then tumba would not only save valuable foreign currency for the Government by adding to its oil production, but it would also make the desert bloom, bringing more land under cultivation which is at present lying fallow and waste.

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