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"Taro"-the Ancient Food Crop: Designing for Adaptive Food- Nutrition and Livelihood

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ABSTRACT: *Taro [Colocasia esculenta (L.) Schott] belonging to the family Araceae (Aroideae).Worldwide it is the 5th most consumed root crops. Irrespective of taro farming in different nations and islands around the world, to ascent with this ethnic crop, its inherent challenges and opportunities need to be reviewed. The greatest challenge is genetic erosion owing to continuous vegetative propagation resulting in sexual degeneracy in most of taro growing areas. Outside of Southeast Asia, narrow genetic base has made the crop vulnerable to a range of damaging biotic stresses and the most serious one is taro leaf blight (TLB) caused by Phytophthora colocasiae Racib.Lack of flowering, erratic flowering,protogynous nature and cytogenetical anomalies impedes conventional hybridization thereby gene flow. Taro is an environment friendly unique crop able to grow in harsh ecological conditions wherein other crops fail to grow. It is highly productive (15-20 t/h), short duration and shade loving thereby fits as a profitable inter-crop. Considering the opportunities across the globe, an International network project on taro was launched in 2011 involving 22 different countries with the 'breeding thrust' of widening the genetic base and to breed through farmers-researchers participatory approach to adapt taro in climatic and commercial changes. As the programme is through National Agricultural Research System (NARS), farmers across the globe have easy access to wide genetic resources of different regions. The steps for in land programme involved in vitro multiplication, hardening, field multiplication and onfarm evaluation for tolerance to biotic and abiotic stresses and commercial traits. Such efforts resulted in developing desirable combinations of exotic and Indigenous taro. DNA analysis revealed two gene pools. Gene pool 1 contained accessions from Southern States as well as from North, East and North-Eastern States. Gene pool 2 contained accessions only from North and North-Eastern parts, India. Yield and other valued traits including starch, minerals especially Fe, Zn, Ca contents are encouraging across the globe for adaptive food, nutrition and livelihood with ancient ethnic crop like taro.*

Key words: *Taro, participatory breeding, INEA, adaptive, food-nutrition.*

INTRODUCTION

Taro [*Colocasia esculenta* (L.) Schott] belonging to the family Araceae (Aroideae). It ranks fourteenth among staple/vegetable crops worldwide. It is most popular food cum vegetable crop in many parts of the humid tropics and sub tropics. This crop responsive to organic farming is the staple of people live in islands and fragile environment around the world. It has wide adaptability and can fit well into agro forestry systems as well as in challenged soil conditions like swamps. Further the origin, domestication, botany as well as the challenges and opportunities of taro farming reflect the immense potentiality of conserving its valued genetic resources for food nutrition and livelihood.

DISPERSAL, ORIGIN, DOMESTICATION AND BOTANY

A commonly accepted speculation is that the centre of origin and domestication of taro in Southeast Asia. Matthews (2004) explained that domestication occurred in many places across the natural distribution through wild progenitor. Two gene pools appeared with domestication occurring in Southeast Asia and with separation of the land masses of Sunda and Sahul overlapping in Indonesia (Lebot *et al.* 2004). Based on these gene pools, two botanical varieties of

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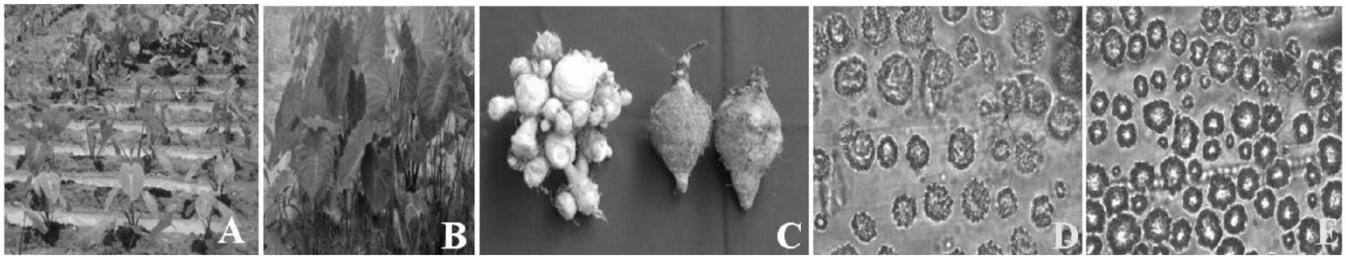

Figure 1 (A-E): Diversity in taro, Eddoe & dasheen type (A-C), diploids (D) and triploids (E)

taro have been designated *C. esculenta* var. *esculenta*, commonly known as dasheen and *C. esculenta* var. *antiquorum*, commonly known as eddoe with different cytotypes. There are diploid (2n=2x=28) and triploid (2n=3x=42) cytotypes (Mukherjee *et al.* 1998).

In general, cytotypes (triploids, diploids) varied at high altitude and latitude environments suggesting that such conditions promote the occurrence of unreduced gametes. The genetic diversity of cultivated forms of taro (*C. esculenta*) was initially assessed based on morphological and cytological characters (Yen and Wheeler 1968; Kuruvilla and Singh 1981). Isozymes studies were also conducted on major collections of five Southeast Asian countries and two Pacific countries (Indonesia, Malaysia, Papua New Guinea, Philippines, Thailand, Vanuatu and Vietnam) under TANSAO, "the Taro Network for Southeast Asia and Oceania". The results from those studies reflected two distinct gene pools one in Southeast Asia and the other from southwest Pacific. Further the allelic diversity of the wild taros was similar to that of cultivated forms indicating its domestication over a span of time. This crop has its inherent characteristics to adapt widely across the globe. This flexibility has enhanced its visibility as life support crop in many Islands and fragile ecosystems since ancient time. Taro is grown as an important vegetable in most of the states in India. In Odisha state, India, its importance revalidated during post super cyclone period as life support crop when all other staples and vegetables failed to grow. Such climatic adversities are now becoming frequent all over the world. Thereby importance of "taro" the wide adaptive ethnic crop is reassessed in all taro growing countries including India (Mukherjee et al 2011a, Mukherjee et al 2011b).

In India the progress and prospects of this ethnic crop through National, International research and developmental programme are enumerated as follows.

INTEGRATED PARTICIPATORY BREEDING APPROACH IN INDIA TO ADAPT HARSH CONDITIONS

India is said to be the secondary centre of origin of taro endowed with diverse genetic resources. That has been further conformed with wide variations in isozyme profiles of Asian taro from India, Indonesia and Japan (Lebot and Aradhya, 1992). It is grown in most of the states of India in a wide range of agro ecological conditions. Both tubers and leaves of these crops are an alternative source of dietary energy. Taro starch is easily digested and used in baby food. Some of the land races of this ancient crop found to have desirable stress tolerant traits. To make taro more adaptive to climate changes and commercial demands, an extensive study was taken up to evaluate the genetic resources. Integrated conventional and non conventional methods were adopted to tap the vast potential of its diversity in isolating biotic (blight) and abiotic (drought, salinity and water logging) stress tolerant taro coupled with high yield, dry matter, high starch with non acrid, good cooking quality and palatability.

Under NATP-CGP grant of ICAR, a stock of diverse genetic resources (eddoe, dasheen and different cytotypes [Fig.1 (A-E)] were screened *in vitro*, *in vivo* and *in situ* for targeted valued traits to evolve varieties viable to commercial and climate changes (Mukherjee *et al.* 2011a & b Mukherjee *et al.* 2013).

Such studies resulted in identifying biotic (blight) and abiotic (salt, drought, submergence) stress tolerant taro [Fig. 2 (A-E)] with good yield (12-15 t/ha) [Mukherjee *et al.*, 2011a & b, Mukherjee et al 2013]. Higher antioxidant and pronounced isozymes activities were also recorded in tolerant genotypes under stress (Mukherjee *et al.*, 2004a, Sahoo *et al.*, 2007, 2009 & 2010). Cluster analysis of tolerant and sensitive lines [Fig. 2(D & E)] revealed that tolerant lines share the same node [Mukherjee, 2004; Mukherjee *et al.*, 2011a, Mukherjee *et al.* 2011b].

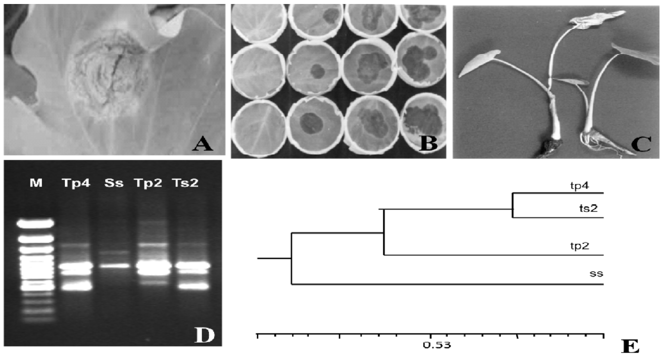

Figure 2: (A-E). Biotic (A&B), abiotic (C), stress tolerance in taro, DNA and cluster analysis of tolerant and sensitive types

Progressive evaluation and AICRP recommended studies resulted in developing five stress tolerant taro varities coupled with good yield (12-15 t/ha). The varieties viz. Muktakeshi, Jhankri and Sonajuli are tolerant to taro leaf blight, drought, salinity whereas the varieties like Panisaru-1 and Panisaru-2 are tolerant to submergence stresses (Mukherjee et al 2011a & b).

CHALLENGES AND OPPORTUNITIES OF TARO FARMING

Irrespective of taro farming in different nations and islands around the world, to ascent with this ethnic crop, its inherent challenges and opportunities need to be reviewed for its global prospects.

CHALLENGES -GENETIC EROSION, GENETIC VULNERABILITY, BOTTLENECK IN TARO BREEDING

Genetic erosion owing to continuous vegetative propagation resulting in sexual degeneracy in most of taro growing areas. The genetic base of taro, outside of Southeast Asia is narrow and vulnerable to biotic and abiotic stresses. In the Pacific, and in relatively new taro cultivation regions, narrow genetic base has made the crop vulnerable to a range of very damaging biotic stresses such as taro beetles (Papuana spp.), taro viruses such as Alomae-Bobone virus complex (ABVC), and the most serious one is taro leaf blight (TLB) caused by *Phytophthora colocasiae* Racib. Lack of flowering, erratic flowering, protogynous nature and cytogenetical anomalies like triploidy impedes conventional hybridization thereby gene flow.

OPPORTUNITIES: LAUNCHING OF INTERNATIONAL PARTICIPATORY BREEDING PROGRAMME THROUGH *INEA*

Taro is an environment friendly unique crop. It is able to grow in harsh ecological conditions wherein other crops fail to grow. It is highly productive (15-20 t/h), short duration and shade loving crop. Shade tolerance fits the crop as a profitable inter-crop. It is also associated with ethnic culture and revenue generation in fragile ecosystems across the globe. It fits well as an alternative crop in the rice-based cropping systems as land that has been prepared for flooded rice is equally suitable for flooded taro. Considering the opportunities across the globe, an International network project on taro was launched in 2011 involving 22 different countries **(Fig. 3)** with the **'breeding thrust' of widening the genetic base and to breed through farmers-researchers participatory approach to adapt taro in climatic and commercial changes.** As the programme is through National Agricultural Research System (NARS), farmers across the globe can have easy access to wide genetic resources rather gene sources of different regions. The source for international transfer of genetic resources was in vitro plants (Fig. 4) through NARS. The steps involved for inland programme is presented in Fig. 5.

BIOCHEMICAL AND DNA ANALYSIS OF INDIAN TARO

Starch and mineral contents of Indian taro (Table 1) revealed very high micro nutrients especially contents of Ca, Fe, Zn. Such high valued crops can address the issues on 'hidden hunger' apart from its calorie value. Recently under *INEA* programme a sample core germplasm of India was evaluated (UMR-AGP, France), DNA analysis of which revealed wide diversity of taro genetic resources in India

Figure 3: International Network for Edible Aroids (*INEA*)

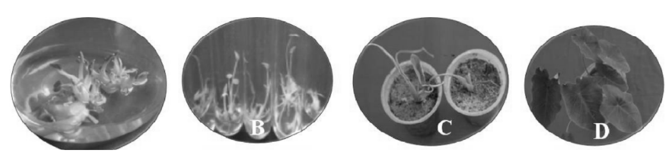

Figure 4: Stages of adaptation (A-D) of in vitro exotic taro plants

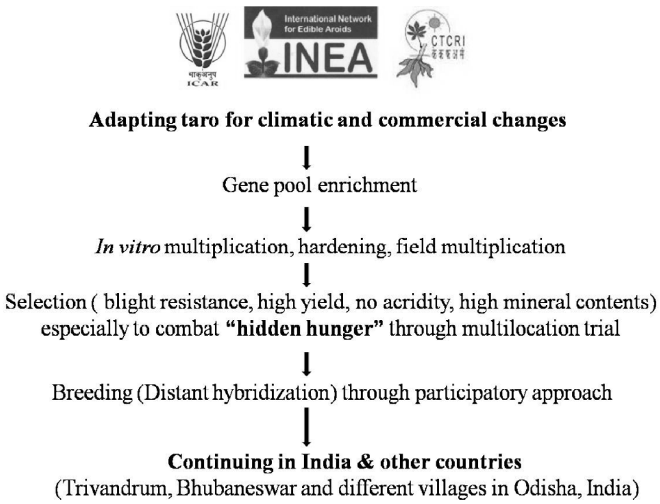

Figure 5: Participatory taro breeding under INEA-taro, India

(Unnikrishnan *et al.,* 2013). It revealed following two distinct gene pools with wide genetic diversity (Fig.6).

- Gene pool 1 contained accessions from Southern States as well as those from North, East and North-Eastern States.

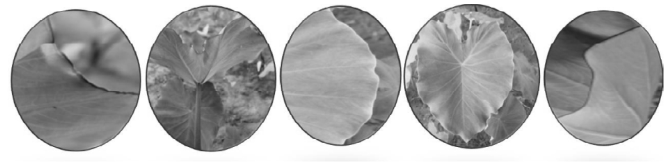

Figure 6: Genetic diversity in taro

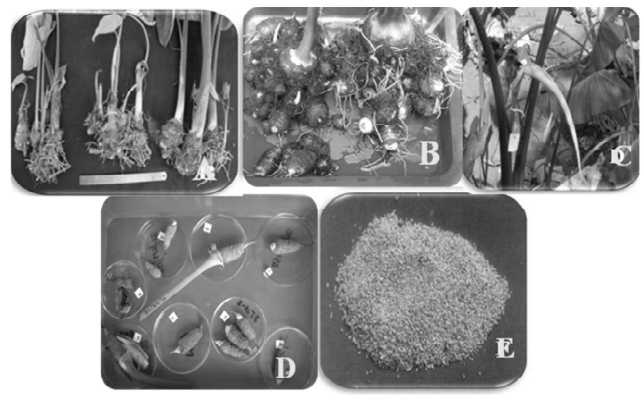

Figure 7: Participatory distant hybridization in taro for adaptive food-nutrition, taro plants dasheen type(A), eddoe type tubers (B), hybridized flower (C), fruiting (D) & seeds (E)

Table 1
Starch and mineral contents in taro, India

Sample	Starch (%)	Elemental Concentration							
		(mg/kg)						(%)	
CEIC-Acc. No.		Ca	Cu	Zn	Mn	Fe	Mg	K	P
264484	53	3775	3.53	50	43	64	2227	3.24	0.472
419621	62	1327	9.66	94	30	67	1947	1.61	0.465
089560	55	3134	13.1	101	90	38	1532	1.79	0.277
211584	64	2357	11.3	73	24.0	46	1102	1.62	0.279
204239	52	2230	11.5	131	49	74	2036	2.59	0.451
089624	62	1366	9.14	63	20.5	41	1426	1.44	0.425
204336	55	2976	12.5	118	82	41	1899	2.33	0.261
12459	64	1727	13.7	82	20.0	61	1100	2.04	0.362

Source: INEA

- Gene pool 2 contained accessions from only North and North-Eastern parts of India-pooled results indicate wide diversity in North-Eastern parts.

BIOCHEMICAL AND MOLECULAR MARKERS FOR PHYLOGENY OF WIDE CROSSES

RFLP analysis of chloroplast DNA was also used to study phylogenetic affinities between taro and other species in genus *Alocasia* (Yoshino 1994; Yoshino *et al.* 1998). These studies indicated the presence of *Alocasia* chloroplast DNA in *Colocasia* samples, suggesting possible hybridization between the two genera. Lebot & Aradhya (1991) studied isozyme variation in 1417 cultivars and wild type taros from Asia and Oceania. Asian cultivars showed greater variation than the Oceanic cultivars. Hence wide hybridization between indigenous and exotic taro through participatory breeding under *INEA* project can strengthen the adaptive food-nutrition and livelihood programme in all taro growing nations.

In this context, a thorough breeding integrating molecular dissection of the field tolerant and susceptible lines, their progenies and their character association studies through bulk segregate analysis would help to identify ESTs for stress resistance to recover the desirable one (Mukherjee *et al* 2011 a & b) towards climatic and commercial demands.

After adapting *in vitro*, exotic taros under *INEA* project India were then multiplied and evaluated in field for morphological traits (Table 2). Based on these, 35 different exotic taro were selected (Table 3) for onfarm evaluation and breeding. The exotic taro lines which gave yield more than 12t/ha are presented in Table -4. Based on different morphological parameters including flowering the exotic and indigenous taros were selected for onfarm hybridization (Table -5). The fruiting observed in certain combinations (Table-6) were used to extract F1 seeds [Fig.7 (A-E)].

Seeds were germinated *in vitro* following the methodology of Mukherjee *et al.* (2004 b) to isolate superior types. The generation of F1 progenies using

Table 2
Morphological traits of exotic taro

SL no	*Type of petiole*	*Accession*	*Pollen fertility (%)*	*Type of tuber*	*Edible*	*Yield*
1	**Purple petiole**	BL/HW/08	90%	Tall Dasheen	All parts	High
2		BL/IND/14	18%	Tall Dasheen	All parts	High
3		BL/SM/80	80%	Tall Dasheen	All parts	High
4	**Dark/Light green petiole with purple sheath**	BL/SM/116	82%	Tall Dasheen	Tuber	High
5	**Dark/Light green petiole with purple tip**	BL/IND/32 Tolerant to TLB	90%	Medium intermediate	Non edible	Low
6		CE/IND/06	80%	Medium intermediate	All parts	Medium
7		CE/IND/07	80%	Tall intermediate	leaf	Low
8		CE/IND/12 Tolerant to TLB	80%	Tall intermediate	Non edible	Medium
9		BL/PNG/11 Resistant to TLB	100%	Tall Dasheen	All parts	Medium
10		BL/SM/111	90%	Tall Dasheen	Tuber	Medium
11		BL/SM/151	90%	Tall Dasheen Stoloniferous	Tuber	High
12		BL/SM/152	80%	Tall Dasheen	All parts	High
13		BL/SM/120	88%	Medium Dasheen	All parts	High
14	**Dark/Light Purplish green petiole**	CE/MAL/06	98%	Medium intermediate	All parts	Medium
15		CE/IND/10	100%	Tall Dasheen	All parts	Low
16		BL/PNG/12	100%	Tall Dasheen	All parts	High
17		BL/SM/158	88%	Tall Dasheen	All parts	High
18		BL/SM/143	80%	Tall Dasheen	Tuber	Medium
19	**Cream colour petiole**	CE/MAL/12	80%	Tall Dasheen	All parts	High
20	**Dark/ light green petiole**	CE/MAL/14	90%	Tall Dasheen	All parts	High
21		BL/PNG/10 Tolerant to TLB	100%	Tall Dasheen	Non edible	High
22		BL/SM/134	80%	Tall Dasheen	All parts	High

Table 3
Performance and selection of exotic INEA lines for onfarm evaluation and breeding

Group	*Country*	*No. of lines received*	*Yield*	*Performance Edibility*	*Reaction to TLB*	*Selection*
1.	Hawaii	3	500gm & > 500gm / plant	Corms and leaves	2 tolerant 1 less tolerant (BL/HW/08)	3 lines BL/HW/08,26 & 37
2.	Indonesia	9	200gm & < 200gm/ plants	7(Corms and leaves)	All tolerant	7 lines CE/IND/06,07,10, 20,24 ,31 & BL/IND/14
3.	Malaysia	3	200-400 gm/ plants	Corms and leaves	tolerant and resistant	3lines CE/MAL/06,12 & 14 CE/MAL/06 (TLB symptoms in 2013)
4.	Papua New Guinea	5	100-400 gm/ plants	Corms and leaves	4 lines tolerant	4 lines BL/PNG/9,11,12 & 13
5.	Samoa	18	7 lines Good yield 400-1kg/plants	All edible except BL/SM/149	All 18 lines tolerant	17 lines BL/SM/43,80,111,114,115,116,120,128, 132,134,135,143,147,151,152,157,158
6.	Thailand	7	Moderate	All lines edible, 3 with edible tubers	4 tolerant	6 lines CE/THA/05,07,09,10,12 & 24.
7.	Japan	5	Low to moderate	Tubers and leaves (4)	Tolerant (4)	4 lines CA/JP/01,02,06 & 08

Ranking of the lines from the different groups

The following 35 lines were subjected to participatory trials considering their overall performance and potential in the multiplication trials conducted in India.

***INEA* lines for participatory trials**
(1). BL/HW/08, 26, 37 (**3 lines**), (2). CE/IND/ 06, 07, 10, 20, 24 & BL/IND/14 (**6 lines**)
(3). CE/MAL/ 06, 12, 14 (**3 lines**), (4). BL/PNG/ 09, 11,12 (**3 lines**)
(5). BL/SM/43, 80, 111, 115, 116, 120, 128, 134, 151, 152, 158 (**11 lines**)
(6). CE/THA/ 05, 07, 09, 10, 12, 24 (**6 lines**), (7). CA/ JP/ 02, 04, 06 (**3 lines**)
Total: 35 lines

exotic and indigenous taro is reported here for the first time.

The developed stress tolerant, nutrient rich taro are now being popularized in tribal, backward areas through National (Tribal Sub Plan) and International (*INEA*) programme. In this context, LANSA (Leveraging Agriculture for Nutrition in South Asia) and FSN (Farming System for Nutrition) programme led by Prof. M. S. Swaminathan needs special mention for its popularization in remote areas.

CROSS SECTION : PROGRESS AND PROSPECTS WITH TARO FARMING

To address the issues of 'environmental protection', 'food security', 'climate change', 'genetic erosion' and 'gene sources'- The "primitive ethnic crop like taro" is the best alternative. To overcome its breeding challenges, 'International Network Programme for Edible Aroids' is an unique step towards global food-nutritional security. 'Participatory distant hybridization' under INEA, integrating all techniques with region specific agro techniques through NARS is the demand. Success through the integration of modern and traditional tools depends on proper planning, political will, support and public awareness with the real spirit of belongingness. World today needs an evergreen, sustainable growth. Certain issues like "Farmer's right", "intellectual property right" and "socio-economic ethical chaos" advocated with 'gene source' & 'modern tools' need to be resolved sensibly.

Participatory distant hybridization, whether traditional or advanced, ultimately what matters is "Goals"- to design the crop for its 'product' with 'qualitative' and 'quantitative' precision. Most of the cases, the hypothecated programme is found to be reality. Hence the concept of I*NEA* programme Coordinated through SPC, Fiji and led by the Global leader- Dr. Vincent Lebot, CIRAD, France involving twenty two different Nations and their NARS systems is the unique step towards redesigning the ethnic crop 'taro' to adapt in harsh conditions and to satisfy consumer needs of 'global community'.

Table 4
The accessions yielded more than 12 t/ha

Sl No.	*Accession*	*Yield (t/ha)*
1	CE/IND/06	17.25
2	CE/THA/10	19.96
3	CE/THA/07	12.5
4	BL/SM/116	23.6
5	BL/SM/151	25.65
6	BL/SM/157	17.98
7	CA/JP/02	16.03

Table 5
List of hybridization carried out among the flowering accessions in farmers' field in Odisha, India under *INEA* Taro programme

Sl.no	*Female parent*	*Male parents*
1.	CE/IND/06	Jhankri, Muktakeshi, Sonajuli, CE/IND/12
2.	CE/IND/12	Jhankri, Muktakeshi, Sonajuli, CE/IND/06, BL/SM/120
3.	BL/SM/120	Muktakeshi, BL/HW/08
4.	BL/SM/151	Muktakeshi
5.	CE/THA/10	Jhankri, Muktakeshi, CE/IND/12
6.	BL/SM/157	Jhankri, Sonajuli, CE/IND/12
7.	CE/IND/10	Muktakeshi, Sonajuli, CE/THA/07
8.	CE/THA/07	Muktakeshi, CE/IND/06, CE/IND/12
9.	BL/HW/08	BL/SM/157, Muktakeshi
10.	Muktakeshi	CE/IND/06
11.	Sonajuli	CE/THA/10
12.	Jhankri	CE/IND/12

Table 6
Seed setting observed in combinations in farmers field

Sl. no	*Female parents*	*Male parents*
1.	BL/SM/157	Muktakeshi
2.	BL/SM/157	Sonajuli
3.	BL/SM/157	CE/IND/12

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