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Research Bulletin 37

Growth Environment and Production Physiology of Water Chestnut under Shallow Waterlogged Condition and Swamp Taro in Marshy Land

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BHUBANESWAR
WTCER

WATER TECHNOLOGY CENTRE FOR EASTERN REGION
(Indian Council of Agricultural Research)
Bhubaneswar - 751023, Orissa, India
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Cover Photo
Front cover : A farmer with his water chestnut crop
Back cover : A view of full grown swamp taro crop

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Preface

Enhancing agricultural productivity in waterlogged areas is becoming more relevant for food security due to increasing pressure on arable land. About 11.6 million ha of land in India is affected directly or otherwise due to problem of waterlogging impeding agricultural productivity. Problems like excess water, lowlying topography, crop susceptibility to submergence, wetland soils make these areas difficult for usual cultivation. There are several useful but neglected crops, having potential to grow under such condition. Water chestnut or *"Singhara Phal"* or *"Pani Singhara"* as it is known locally has immense potential to grow in areas where water remain stagnant at least for six months in a year to a depth upto 0.5-m. Mainly grown in railway track side or highway track-side depressions, this crop is liveihood option for many marginal farmers in our country. Similarly swamp taro is also a potential vegetable crop having market acceptance and is grown in lowlying **marshy** areas. But these neglected crops are generally cultivated without improved package of practices and lack better germplasm, hence their productivity remain low. These is also little information on physiological basis for yield variation in these crops. For improvement of yield of any crop, it is imperative to understand critical morphological and physiological characters contributing towards yield. Keeping these points in view this technical bulletin has been prepared by compilation of information generated through a research project. Objective of this research project was to identify physiological features that limit growth and productivity of these neglected crops in order to increase productivity of non-arable waterlogged areas.

Authors are grateful to honorable DDG (NRM) and ADG (IWM) of ICAR for their constant support, encouragement and valuable guidance. Our sincere thanks are also due to all the colleagues and staff members of WTCER, Bhubaneswar for their support and help to bring out this publication.

We hope that the information compiled in this technical bulletin will be of immense use to the researchers in the field of crop improvement programme, agricultural water management and above all to the farmers for whose cause we all are committed.

Authors

CONTENTS

Summary

Crop diversification is one of the important strategies for reclamation of waterlogged areas. In India, productivity in about 11.6 million ha area in affected by problems of waterlogging and other associated causes. There are several neglected but important crops which have built-in adaptability to grow under such non-arable condition. 'Singhra' or waterchestnut and 'lati' or swamp taro are two much important plant species which have ability to grow under waterlogged condition or marshy soil. But very little in known about growth physiology and physiological basis of yield variation of these crops and environmental details of waterlogged or marshy condition, in which they grow. (With good acceptability in market as fruit or vegetable, these crops are grown by marginal farmers and form a important part of their agricultural income.)

In waterchestnut, out of the total six months of crop growth period, the vegetative growth period extends for about three months from mid-June to mid-September whereas flowers and fruiting continues upto minimum three months from mid-September to December. Between two types of waterchestnut cultivars, viz. green peel fruit cultivars and red peel fruit cultivars, fruits appear earlier in the former. The elongation response to submergence has also been found faster in former type, making them more suitable under lowlying/flood prone areas. The mature water chestnut fruits are consumed either raw or kernels are sun-dried before making flour. We have found out that for raw consumption fruits of upto 14 day old are optimum whereas older fruits beyond this stage (21 days old fruit) are suitable for making flour, due to higher dry matter and starch content.

Swamp taro have been found to be a potential crop under marshy waterlogged condition. The runner emerging from the base of petiole at field surface in mainly consumed as vegetable. The crop is of approximately 8-10 months duration. The physiological characters like greater leaf area for longer duration and better crop growth rate positively influenced runner yield among five swamp

taro cultivars tested. (The runner yield also increased exponentially with increase in harvest index among different cultivars.) The photosynthetic rate has also been found to be influenced by light intensity and temperature. Lower photon flux density and shade have been found to favour better photosynthesis in swamp taro. A cultivar BCST15 has been found to retain higher leaf chlorophyll and root nitrate reductase activity during post submergence recovery period. The cultivar also showed higher yield potential during post submergence period.

Thus, better plant height (to avoid complete submergence), higher leaf area, leaf area duration, better dry matter production and higher partitioning efficiency were found useful physiological characteristics for better productivity of swamp taro. Higher maintenance of root nitrate reductase activity with better leaf chlorophyll retention during post submergence period, lead to higher runner yield in cultivar BCST15 making it suitable for cultivation in lowlying submergence prone marshy land.

1. INTRODUCTION

In India, about 11.6 million ha area is either waterlogged or prone to water logging (Velayutham and Bhattacharyya 2000) . A significant portion of this vast area remain non arable due to unfavuorable soil and water regime . In inland areas, this situation is caused mainly due to introduction of irrigation in arid and semi arid areas whereas in coastal areas waterlogging is mainly due to intense rainfall coupled with inadequate drainage or in sites with topographical depressions leading to submergence or swampy condition. There are few crops like water chestnut (*Trapa bispinosa*), swamp taro (*Colocasia esculenta*), etc. which have natural adaptability to grow under such environment. Water chestnut (*Trapa bispinosa* Roxb.) or 'singhara phal or 'pani phal' or 'pani singhara' is one of the few neglected but economically important aquatic crops grown in different parts of India and even in several other southeast Asian countries like Bangladesh, Thailand and Myanmar, etc. The origin of water chestnut is India as there is mention about the crop in ancient literature (Jha 1999). Similarly, swamp taro is also originated from Assam or north–eastern part of India as the region has a natural rich diversity of Colocasia germplasm (Saud and Barua 2000). In India, water chestnut is cultivated in north from Jammu and Kashmir , Uttar Pradesh, to upto Madhya Pradesh. In east, from Bihar, West Bengal, Orissa to upto Gujrat and Maharastra in western part of the country. The crop is

Field view of a water chestnut crop with full canopy

Close view of a swamp taro crop

mainly grown in roadside depressions or railway trackside depressions in addition to localized topographical depressions where water remains stagnant at least upto the month of January (Hazra *et al.* 1996, Ahmed and Singh 1999). Otherwise, the lowlying areas of 8 million ha shallow low land

A large patch of water chestnut field along the railway trackside depression

ecosystem in the country, of which 5.8 million ha in eastern India itself, provides ideal condition for cultivation of this crop, mainly duing *kharif* season. Fruits are generally consumed as raw or after boiling as a vegetable. After sun drying, nut-flour is also used as source of non-cereal carbohydrate diet. A significant portion of the nut

Water chestnut grown in roadside depression

is processed for use as flour (Alam *et al.* 2001) for food or for textile sizing (Srivastava and Vatsya 1986).

In eastern part of India, swamp taro or *Colocasia esculenta*, locally known as 'pani kachu', 'lati' or 'kachu lati' grow naturally in swampy environment, hence is known as swamp taro. Depending on varieties, entire plant parts from

Boiled water chestnut fruit being sold in market

Close view of runner developed at the base of swamp taro plant. Emerging buds of new runners are also seen

leaves, petioles, stolon or runners are consumed as green vegetable especially in States like, Assam, Bihar, eastern Uttar Pradesh and West Bengal (Goswami and Sen 2000, Saud and Barua 2000). There is potential for cultivation of this crop in about 1.2 million ha waterlogged / marshy land in these States. A medium harvested swamp taro crop can give up to Rs 43,000/ha and net profit from water chestnut can reach upto Rs. 20,000-25,000/-. But these crops are mainly grown following traditional practices without proper package of practices or better germplasm (Saud and Barua 2000). A clear understanding of the physiological parameters that limit growth and production provides the basis of yield improvement of any crop. But very little attention has been paid to understand physiological basis of yield variation of these wetland crops. Therefore, research studies were conducted with following objectives :

1. Identification of key physiological and biochemical parameters controlling productivity of water chestnut and swamp taro under waterlogged condition.

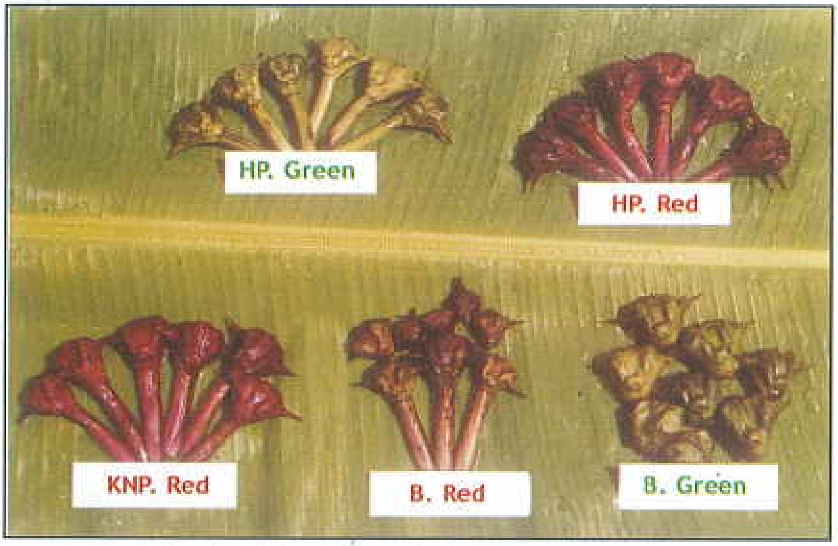
2. Identification of suitable genotypes of these crops for increased productivity under waterlogged condition.

2. WATER CHESTNUT

2.1 Materials and methods

Plant material

The experiments were conducted at Research Farm of Water Technology Centre for Eastern Region at Mendhasal ($20^{0}30'$ N and $87^{0}48'10''$ E) from June to December during 2001-04. Five local water chestnut cultivars were grown in randomized block design with four replications. Two green fruit varieties, viz., 'Balasore green' and 'Haldipada green'. and three red fruit varieties, viz., 'KNP red', 'Haldipada red' and 'Balasore red' were used in this study. Experimental plots each of 2m x3 m size were demarcated by 45 cm wide nylon net on the surface of the water body. Compost @ 8 t/ha was applied before planting. N: P: K fertilizers @ 40:60:40 kg/ha were applied in three splits. One third of N as urea, one third of K as muriate of Potash and full dose of P as single super phosphate were applied as basal fertilizers. The rest 2/3rd N and K were applied in two equal splits at two and four months after planting.



HP green : *Haldipada green*
HP red : *Haldipada red*
B. red : *Balasore red*
B. green : *Balasore green*

A view of fruits of five water chestnut cultivars used in experiment

Measurements with instruments

Dissolved oxygen content and temperature of water were recorded with a YSI 550 hand-held dissolved oxygen and temperature system (YSI Inc., Yellow Spring, Ohio, USA). Data on plant height were recorded by uprooting plant from bottom of the water body and represented the length of main shoot. Water pH was measured with a hand-held portable pH meter (Hanna Instruments, Portugal).

Dr. J.S. Samra, DDG (NRM), ICAR visiting one water chestnut growing site

Dr. Ashwani Kumar, Director, WTCER interacting with water chestnut growing farmers

Leaf area was measured by detaching leaves and using a LICOR 3000 leaf area meter (LICOR Inc., USA). Flowering and fruiting of water chestnut crop started from about 95-100 days after planting. The fruits were harvested periodically from 14th week after planting till the crop decomposed and started disappearing from the surface of the water body.

Measurement of fruit size

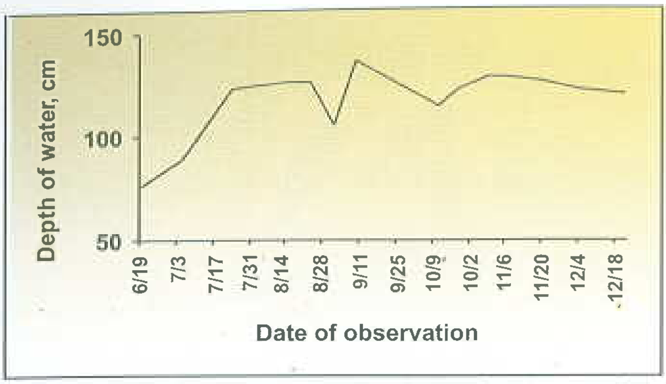
For study of changes in fruit volume and in carbohydrate composition at 100 days after planting, individual fruits from three randomly selected plants per replicate were marked with waterproof adhesive level at the base of the fruit stalk for age and identity of particular fruit. The tagged fruits were then periodically harvested at 7, 14 and 21 days after appearance of small visible fruit. Volume of five fruits from three randomly selected plants and was recorded through displacement of water by submerging them in measuring cylinder.

Measurement of carbohydrate and starch

The percentage dry matter content of the fruit was determined by separating the peel carefully without damaging the fruit. The fresh fruit was weighed and then dried in an oven at 70°C to determine the dry weight. The soluble as well as insoluble carbohydrate contents of 7, 14 and 21 day old fruits were measured with anthrone reagent (CTCRI 1983) and absorbance was measured at 630 nm using a UV-VIS spectro-photometer (Chemito, India). The insoluble carbohydrate content was analyzed for estimation of starch from this extract (Yoshida *et al.* 1976). Fruits normally appeared from 14th week and the harvest continued periodically till decomposition of the crop at 23rd week after planting. The analysis of variance and standard error of observations, the least significant difference of treatment means, correlations and regressions were calculated following Gomez and Gomez (1984).

2.2 Salient Findings

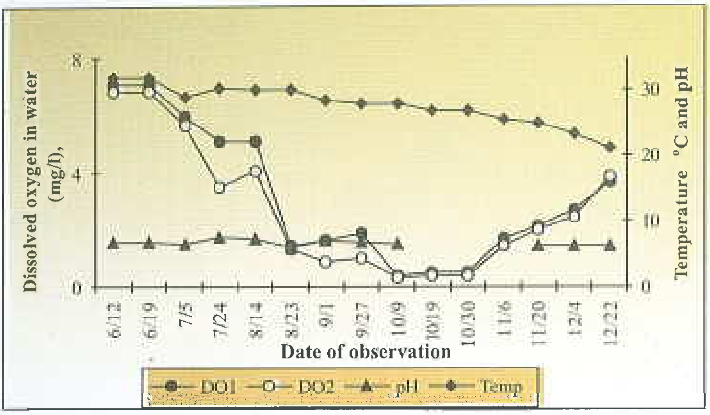
Water and soil environment



After Roy Chowdhury et.al 2003

Fig.1: The depth of pond water during growth period of water chestnut varieties.

Water depth at the experimental site varied from 76 cm in June to 136 cm in October. Throughout the growth period during monsoon season (July-September), it ranged from 105 cm to 136 cm (Fig. 1). Temperature of the water steadily decreased over the period of growth (Fig 2). The dissolved oxygen level showed a sharp decrease from 2nd month after planting onwards reaching its lowest at 3rd month and continued till crop started decomposing at 5th month. Thereafter, the dissolved oxygen content started rising again. The pH of water however did not change appreciably over the period of crop growth (Fig 2). The soil was slightly acidic and non-saline. The nitrogen [2 MKCl extractable], organic carbon and potassium [1 N NH_4OAc extractable] availability were much higher in soil at bottom of the pond than at its bank and side. This was obviously due to erosion of the nutrient rich clay particles from bank and sides and their accumulation at the bottom of the pond. Relatively higher P (Bray & Kurtz 1) availability in soil at the bank of pond could be due to application of P feriliser to crops grown there. Mobility of P through soil is very low (Table 1).



After Roy Chowdhury et.al 2004b

Fig.2: The changes in dissolved oxygen concentration at 30 cm (DO1) and 60 cm (DO2) water depth, temperature and pH at 30 cm depth during the growth period of water chestnut varieties

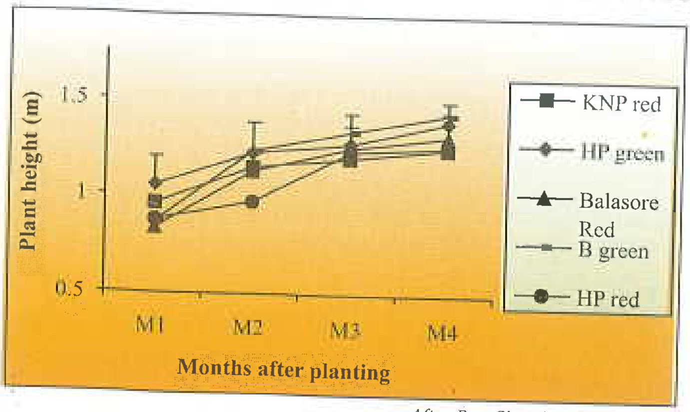
Changes in plant height with increased water level

For any crop prone to submergence, ability to maintain plant height has an important role for survival and establishment of the crop. Height of water chestnut plants

Table 1. Analyses of bottom sediment and soils from submerged side and bank of experimental site at Deras farm

Soil sample from	Sample no.	pH (1:1)	EC (1:1) dS/m	Organic C (%)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)
Pond bottom	1	6.5	0.12	1.35	83	1.66	194
	2	6.4	0.10	1.11	91	0.40	156
	3	6.4	0.10	1.18	95	1.26	170
	4	6.2	0.09	1.17	94	0.58	164
Pond bank	1	5.8	0.04	0.50	10.8	6.20	32
	2	5.9	0.03	0.47	13.0	6.30	26
	3	5.8	0.02	0.46	11.7	6.10	40
	4	5.9	0.03	0.29	10.8	5.72	24
Pond side	1	5.5	0.02	0.32	9.3	0.38	104
	2	6.1	0.04	0.78	9.3	0.68	104
	3	5.5	0.02	0.37	9.3	0.30	96
	4	5.3	0.02	0.38	9.3	0.38	98

increased steadily upto 3rd month after planting in almost all the cultivars (Fig.3). The increase was found maximum in both the green cultivars, 'Haldipada green' (H.P. green) and 'Balasore green' (B. green) and it was minimum in 'KNP red' and 'HP red' at three-month stage. Compared to two green types, plant height was significantly less in these two red types. The rate of increase also varied from cultivar to cultivar. Most of the cultivars showed highest rate of increase in the second month after planting (MAP; Table 2). The cultivar 'Balasore green' showed increase as high as 42.52% at 2 MAP whereas in 'H.P.red' the peak rate of increase (26.56%) was attained at third month stage. However at 4 MAP, the rate of increase declined in all the cultivars (Table 2). In general, the plant height was positively correlated with depth of water in different cultivars (r=0.83 to r=0.98* ; Table 3). This indicated that water chestnut plants adapt well under increasing level of water and can be grown in flood-prone low lying areas where there is chance of slow and steady increase in depth of water (Roy Chowdhury et al. 2003).



After Roy Chowdhury et.al 2003

Fig.3: The plant height of water chestnut varieties at various plant growth stages. Each value is mean of four replications. Vertical bars are LSD at p=0.05 level of significance

Table 2: The rate of increase in height of water chestnut plants (primary stem) compared to previous month at different growth stage of the crop growth.

Cultivars	% increase		
	2nd MAP	3rd MAP	4th MAP
KNP red	19.79	4.34	5.0
HP green	15.09	4.68	8.59
Balasore red	34.52	11.50	4.76
Balasore green	42.52	8.06	7.46
HP red	11.38	26.56	2.41

MAP= months after planting

In anticipation of quick rise in water level in flood-prone areas, effect of short term submergence on elongation ability of one green (Haldipada green) and one red (Haldipada red) cultivars was studied under controlled submergence. About 30 cm long seedling was immersed to a depth of 0.5 meter in water. The stem elongation and increase in internodal length was monitored upto 7th day until the plant surfaced out. The stem elongation in green type was more both at 3 and 7 day after submergence (Fig. 4). At 3rd day, red cultivar showed 37.42% while the green type showed 44.02% elongation. After 7 days the green type

Table 3: The relationship between water level increase (m) and plant height (m) in different cultivars of water chestnut.

Cutivars	Correlation co-eff. (r)	Linear regression equation of plant ht. (Y)
KNP red	0.83	Y=1.2745x-0.5367
Haldipada green	0.84	Y=1.3645x-0.5602
Balasore red	0.88	Y=2.2134x-1.7786
Balasore green	0.83	Y=2.4520x-2.0067
Haldipada red	0.98*	Y=2.2295x-1.8449

After Roy Chowdhury *et al*.. 2003

* Significant at P=0.05

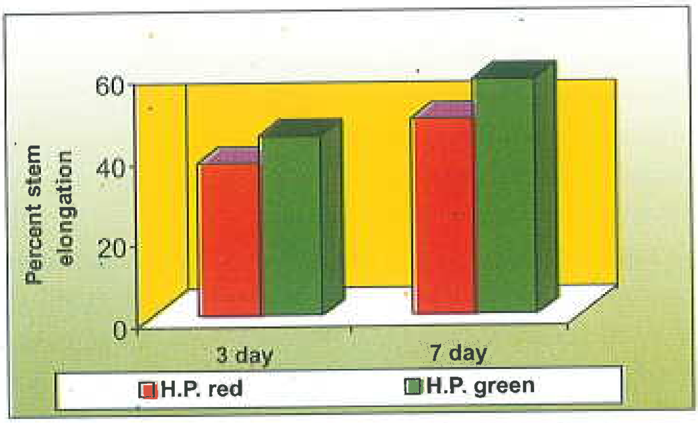


Fig.4: The percent increase in stem elongation at 3 and 7 days after submergence in two cultivars of water chestnut plant, haldipada red and haldipada green. Symbols are as in Figure

showed 57.62% elongation while in red type it was only 48.35%. After 7 days, the increase in internodal length in top 10 cm and bottom 10 cm was about 42 and 44% in red type and 66 and 33% in green type. Maximum increase in internodal length after 7 days was observed in mid region of the stem in both red (55%) and green (88%) type (Fig. 5). The trans-

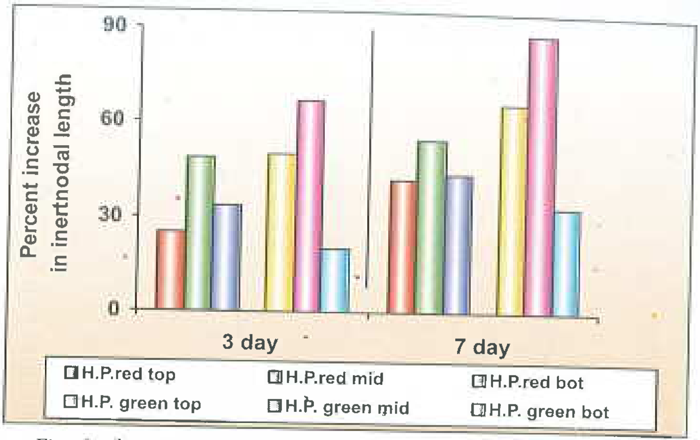


Fig. 5: The percent increase in internodal elongation at 3 and 7 days after submergence in two cultivars of water chestnut plant, haldipada red and haldipada green. Symbols are as in Figure

verse section of submerged stem in green type showed more compactness of cells than red type. Well developed vessels were observed in green type (both in submerged and control). More epidermal hairs were observed in submerged portion of red type than green type. Thus greater elongation ability in green type with rise in water level appeared

Early canopy development in waterchestnut field

a reliable parameter for better crop survival especially in low lying areas, where depth of water is likely to rise during monsoon months.

Canopy development

Typically, leaf area in all the cultivars increased steadily upto third month after planting followed by a decline at [illegible] 5th month stage (Fig. 6). Both the extent of initial increase and rate of subsequent decrease in leaf area were high in two green cultivars.

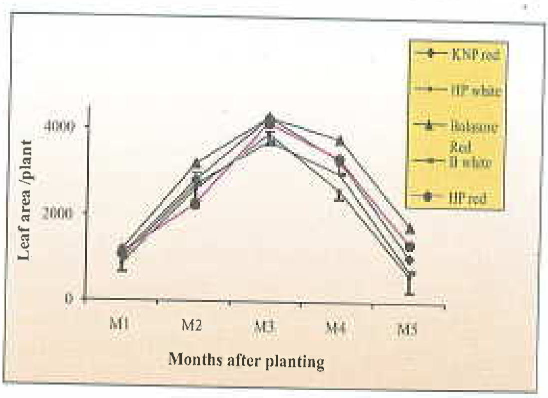
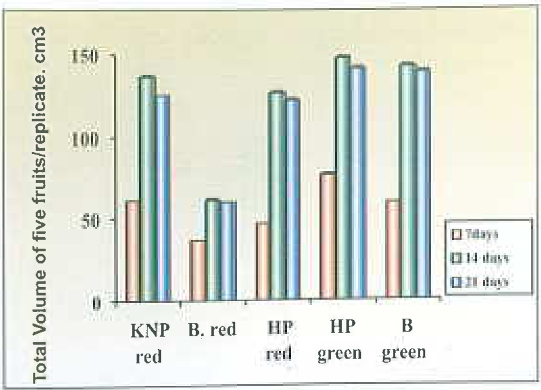


Fig. 6: The changes in leaf area in five different water chestnut varieties at various plant growth stages. Each value is mean of four replications. Vertical bars are LSD at p=0.05 level of significance



After Roy Chowdhury et.al 2004a

Fig.7: The changes in fruit volume (volume of total five fruits,cm3) at 7,14 and 21 days after fruit initiation. Each value is mean of four replications±SE.Symbols are as in Figure

Among three red cultivars, Balasore red maintained significantly higher leaf area for longer duration over entire period more so at later stage of crop growth (Fig. 6).

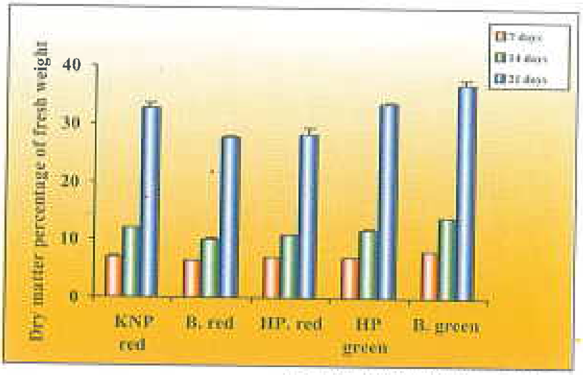
Fruit development and changes in fruit dry matter and carbohydrate content

The size of water chestnut fruits increased steadily upto 14 days after fruiting initiation (Fig.7). The kernel dry matter of fruits increased slowly from 7^{th} day to 14^{th} day but in next seven days, i.e. between 14^{th} - 21^{st} days it almost doubled in all the five varieties (Fig. 8). In 14 -day old fruits, soluble carbohydrate:starch ratio was 49: 51. But in older fruits (21-day old), starch content in all the five cultivars increased to 88-94% and soluble carbohydrate decreased to 6-12%. This is the reason for sweet taste of tender fruits while mature fruits (hard to peel) are less sweeter. So for raw consumption, 14-day stage was

Close view of flower in water chestnut plant

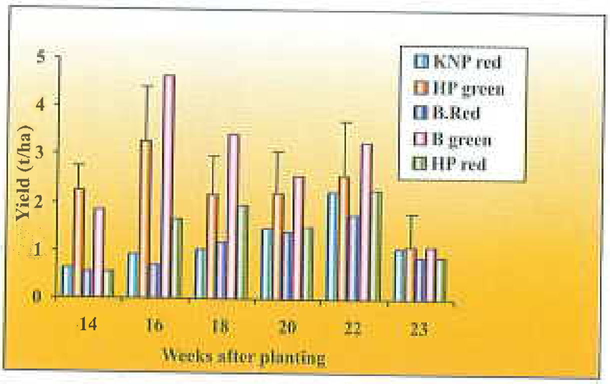
—>>>>> *About 5-6 fruits developed below crown of leaf as shown in photograph*

optimal for sweetness, dry matter and starch content as well as for desirable nut size. Delayed harvest to 21 days subjected fruit to over-maturity and reduction in sweetness. But as dry matter and starch content after this stage increased considerably, fruits were more suitable for making flour out of it (Roy Chowdhury *et al.* 2004a).



After Roy Chowdhury et.al 2004a

Fig. 8: The changes in kernel dry matter (percentage of freshweight) at different stage 7, 14 and 21 days after fruit initiation. Each value is mean of four replications±SE.Symbols are as in Figure



After Roy Chowdhury et.al 2003

Fig. 9: Fruit yield of any water chestnut varieties at different grpowth stagers. Each value is mean of four replications. Vertical bars are LSD at p=0.05 level of significance

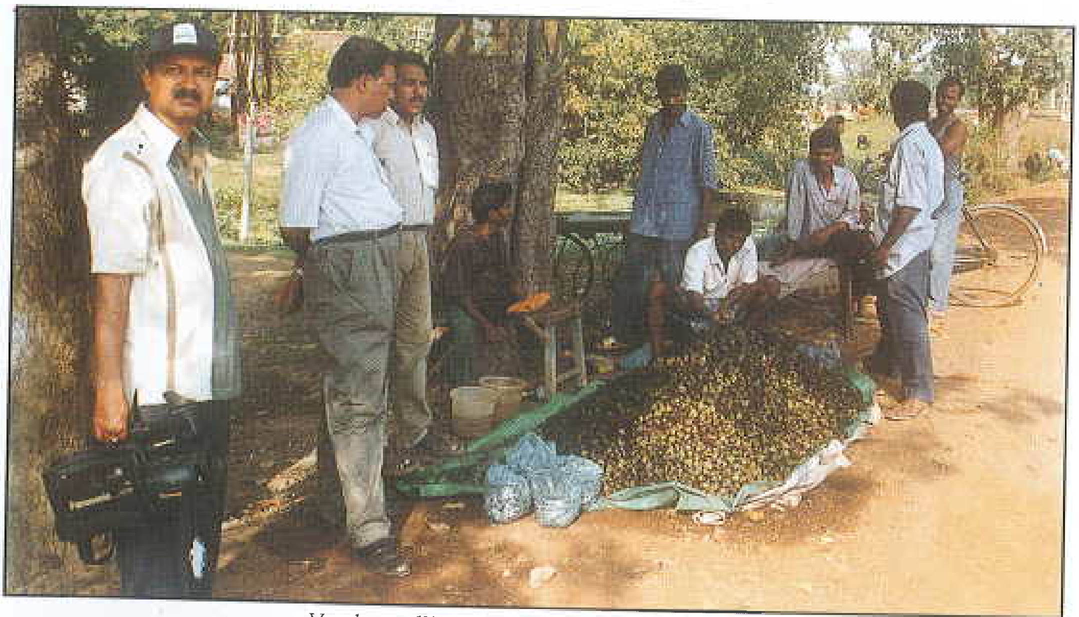
Yield and economics

Fruits generally appear from September onwards, from three months after planting. Usually green fruits appeared earlier than red fruits. Earlier flowering and fruiting in green cultivars provide longer pick span and is one of the reason for higher yield than red ones. There were six harvests in the harvesting period of 75 days spread from 14th to 23rd weeks after

Table 4 : The cost of cultivation of water chestnut in one ha area

Item	Amount (Rs)
Labour cost	
Nursery preparation	2500
Pond preparation & planting, 60 man days @ Rs 50/-	3000
Weeding & intercultural operation, 50 man days	2500
Supervision charge,10 man days	500
Harvesting and post harvest handling,57mandays	2850
Input cost	
Seedling cost	5000
FYM @ 8t	3000
Fertiliser (N:P:K) 40:40:60	
Urea 86 kg @ 4.00/kg	350
SSP 250 kg @ 3.00/Kg	750
MOP 60 Kg @ 5.00/Kg	300
Insecticide (Rs)	1000
Growth regulator	500
Fixed cost - land rent	4500
Total Cost of cultivation (INR)	26750
Gross income (INR) 10 t /ha @ Rs 4.50/kg*	45000
Net Profit	18250
B : C ratio	**1.68**

*This is the lowest farm gate price. At times in isolated smaller scale, farmers fetch price as high as Rs 15-20 per kg especially at early festive season of September - October at local market.



Vendors selling waterchestnut fruit in market planting (Fig. 9). Between two green cultivars, except first harvest, Balasore green always maintained higher yield at all the remaining five picking compared to Haldipada green cultivar. Among three red cultivars, the HP red significantly outyielded other two red cultivars up to 18th week. However, "KNP red' and 'Balasore red' showed higher yield from 4th harvest i.e.20th weeks after planting. In general, yield in all the cultivars decreased at 6th harvest significantly (Fig. 9). Total yield was found to be the highest in the green cultivar "Balasore green" (16.84 t/ha) followed by "Haldipada green" (14.09 t/ha) and it was found lowest in "Balasore red" type (6.67 t/ha). Among the red cultivars, Haldipada red was the highest yielder (8.83 t/ha). The cost of cultivation of water chestnut in one ha area is given in table 4.

2.3 Conclusion

Adaptability of water chestnut to rising water level was better in green- than in red fruited cultivars due to faster stem elongation in green cultivars. This trait makes them more suitable in low lying areas where there is chance of slow rise in water level during monsoon months. Even under submergence, stem of green-fruited cultivars elongated faster than red cultivars and mid region of the stem contributed significantly for the elongation. Despite longer canopy duration in red cultivars, flower and fruit set was earlier in green cultivars. Longer fruit and flower span might have contributed to higher yield in green cultivars. Fruit size and carbohydrate composition of fruit kernel changed significantly with age of the fruit among different cultivars. For optimum size, better sweetness and firmness, 14 -day old fruits were found suitable whereas allowing the fruits to over mature beyond 14 days increased dry matter and starch content significantly higher and is more suitable for making flour. In general, green cultivars were higher yielder than red ones. With average fruit yield of about 10 t/ha, the B:C ratio is 1.68 whereas the productivity of water is about Rs 5.00 per cubic meter of water.

3. SWAMP TARO

3.1 Materials And Methods

Plant material

The experiment was conducted at the Research Farm of Water Technology Center for Eastern Region at Mendhasal (20°30′ N and 87°48′10" E) during January to October . The crop was planted at a spacing of 60cm x75 cm during January in marshy waterlogged condition using five cultivars, viz., BCST21, BCST23, BCST15, BCST4 and BCST2. Farmyard manure @ 8 t/ha was added to soil at the time of field preparation and N: P: K fertilizers @ 52:60:63 kg/ha were applied in three split doses at 2nd, 5th and 8th month stage of the crop. Hand weeding was done each time before application of fertilizer.

Measurement of photosynthesis by gas exchange and chlorophyll fluorescence

The photosynthetic rate, stomatal conductance and environmental parameters like photosynthetically active radiation, leaf temperature and substomatal CO_2 concentration were measured on intact plants using a LI-6200 portable photosynthetic system (LiCor Inc., Lincoln, NE, USA). The system was under maintenance with personnel authorized by LiCor Inc. There was no drift for calibration curve for water vapor and CO_2 calibration curve. A 250 ml leaf cuvette was used and stomatal conductance ratio was kept at 1.00 during the measurement. Average area of the selected leaf for measurement ranged between 550 and 600 cm^2. A side portion of leaf from mid-region was enclosed in the cuvette for measurement. The observations were taken from 3rd mature leaf of three randomly selected plants from 0700 hrs throughout the day till 1600 hrs at regular intervals. Different chlorophyll fluorescence parameters like electron transport rate (ETR), minimum (F_0) and maximum (Fm) fluorescence were determined by dark adaptation of leaf with dark adaptation clip (Hansatech Instrument Ltd. UK) for one hour. From fluorescence yield under saturated light (Fs), the maximum fluorescence at light adapted state (Fm') was measured with saturating light of 2000 $\mu mole.m^{-2}.s^{-1}$ photon flux density for 0.5s using a chlorophyll fluorescence system (FMS2, Hansatech Instrument Ltd, UK).

Other measurements

Leaf area was measured with a LICOR 3100 leaf area meter. Leaf chlorophyll content was analyzed by extracting leaf chlorophyll with 80% acetone and measuring the absorbance at 652 nm with a Chemito UV-VIS spectrophotometer (Yoshida *et al.* 1976). The nitrate reductase activity was measured in root samples following Jaworski (1971).

Dr. J.S. Samra, DDG (NRM), ICAR visiting a swamp taro field

Specific leaf weight (SLW) was calculated from leaf area, after oven drying the leaves at 80ºC following Hunt (1990). The stolons or runners are the most popular portion of the plant used as vegetable. They were harvested periodically from 4 months after planting onwards till 10 months after planting and yield data were recorded. The data were statistically analyzed following Gomez and Gomez (1984).

3.2 Salient Findings

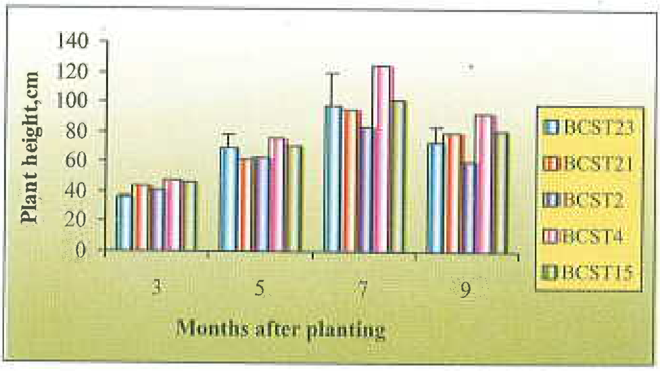
Soil

Fertility analysis of the swamp taro growing soils at the experimental site (Table 5) showed similar values to that of typical wetland soil rich in organic matter. Organic C, available N [2 MKCl extractable], P [Bray & Kurtz 1]as well as K [1

Table 5. Fertility analyses of soils collected from planted and adjacent unplanted swampy land. Deras farm,

Type of swampy land	Soil sample no.	pH (1:1)	EC (1:1) dS/m	Organic C (%)	Available N (mg/kg)	Available P (mg/kg)	Available K (mg/kg)
Unplanted	1	7.1	0.22	0.71	17.1	0.78	88
	2	7.1	0.34	1.03	16.1	0.88	114
	3	7.0	0.26	0.88	17.6	0.78	110
	4	7.2	0.42	0.81	19.5	0.68	122
Planted to swamp taro	1	7.3	0.43	2.20	36.1	7.82	200
	2	7.3	0.34	1.90	46.4	6.00	212
	3	7.3	0.26	1.95	43.0	11.92	272
	4	7.3	0.35	2.10	43.0	9.24	218

NNH_4OAc extractable] contents in swampy land planted to ' swamp taro' were much higher than those in unplanted land. It was probably due to application of manures and fertilizer to taro and also decomposition of decayed roots and shoot of the crop into the soil. Since permeability of swampy land is very low, mineralized nutrients get accumulated into the root zone along with other toxicants like organic acids, etc.



After Roy Chowdhury et.al 2004b

Fig. 10: The changes in plant height of swamp taro at different stages of crop growth. Vertical bars are LSD at p=0.05 level of significance.

Plant height

Under low lying marshy condition, maintenance of better plant height is of importance mainly to avoid submergence. Height of swamp taro plant is represented by the height of petiole. The plant height (height of petiole) steadily increased from 3rd month onwards steadily in all the cultivars reaching its peak at 7th month stage, declining thereafter (Fig.10). Among different cultivars, BCST 4 and BCST 15 showed better plant height than others (Roy Chowdhury *et al.* 2004 b).

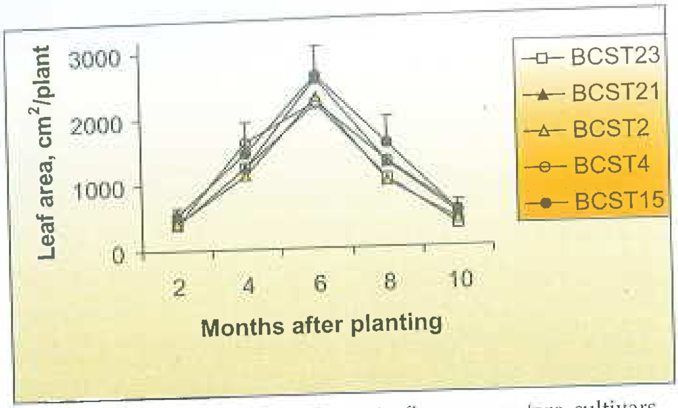
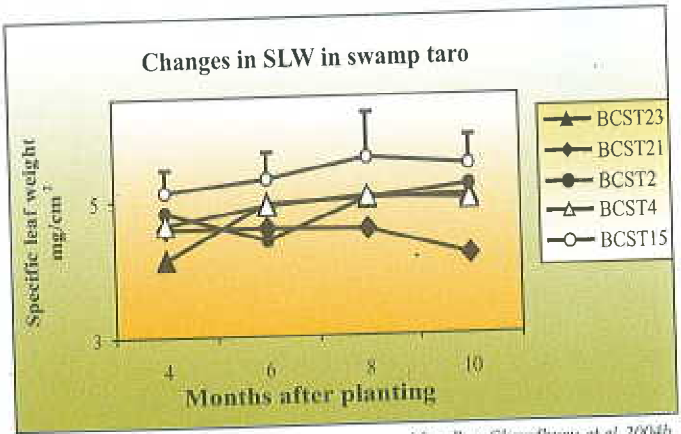


Fig.11: The changes in leaf area in five swamp taro cultivars at various plant growth stages. Each value is mean of four replications. Vertical bars are LSD at p=0.05 level of significance. Symbols are as in Figure

Canopy development and specific leaf weight

Leaf is the main site of photosynthate assimilation. So leaf area development and specific leaf weight play important roles in plant productivity (Monteith and Elston 1983) even in taro (Roy Chowdhury 1995). The leaf area index also increased with age of the crop reaching its peak between 6 and 7 month stage showing a decline thereafter (Table 6). The rate of decline in leaf area however varied among cultivars (Fig. 11). In cultivar BCST 23 and BCST 2, the leaf area declined sharply at 7-8th month stage followed by a slow decline upto 10th month stage. In cultivars like BCST 15 and BCST 4, the decline in leaf area was gradual. Thus these two cultivars maintained greater leaf area for longer duration. Maximum increase in leaf area index was observed in BCST 21 and BCST 15 (Table 6). The specific leaf weight (SLW)



After Roy Chowdhury et.al 2004b

Fig.12: The variation in specific leaf weight of five swamp taro cultivars at different stages of crop growth. Vertical bars are LSD at p=0.05 level of significance

Table 6. Changes in crop growth rate and leaf area index in swamp taro cultivars

Cultivar	Crop growth rate g/m²/day day Months after planting		Leaf area index Months after planting			
	3	6	4	6	8	10
BCST23	0.65	1.85	0.30	0.48	0.23	0.07
BCST21	0.96	3.91	0.27	0.57	0.28	0.11
BCST2	0.60	1.50	0.36	0.49	0.29	0.09
BCST4	0.92	1.29	0.36	0.49	0.29	0.12
BCST15	1.24	1.51	0.32	0.58	0.34	0.12
lsd at p=0.05	0.23	0.80	0.10	0.09	0.09	0.04

After Roy Chowdhury *et al.* (2004 c)

did not vary much at different stages of growth between BCST 23, BCST 4 and BCST 2 (Fig. 12). But in BCST 21, SLW declined with the age of the crop. Among all the cultivars, BCST 15 showed highest SLW (Roy Chowdhury *et al.* 2004 b ; Fig. 12).

Dry matter production and partitioning

The highest crop growth rate was observed in BCST15 followed by BCST4 and BCST21. The two cultivars, BCST23 and BCST2 showed lowest dry matter production rate. The dry matter production rate during later growth stage was comparatively higher than previous period (Roy Chowdhury *et al.* 2004c ;Table 6) The dry matter production rate per unit land area, or crop growth rate upto 6 month stage showed high positive association (r=0.93**) with runner yield. The positive correlation between dry matter production rate and yield was reported in sweet potato (Bourke 1985, Roy Chowdhury and Verma 1997), eddoe type colocasia (Roy Chowdhury and Ravi 1996). In yams, *Dioscorea* spp. it was observed that partitioning efficiency of dry matter (harvest index) was more important for determining tuber yield than rate of dry matter production (Roy Chowdhury 1998). The highest harvest index was recorded in BCST15 (0.56) and it was lowest in BCST23 (0.35). The harvest index showed positive association with runner yield (r=0.77). The runner dry matter increased exponentially with

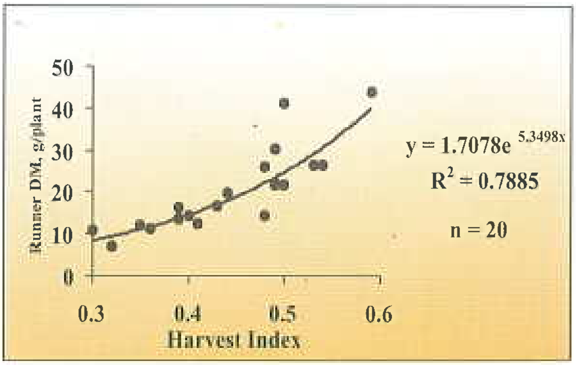


Fig.13: The relationship between runner dry matter content per plant and harvest index in swamp taro cultivars.The equation and number of observations are as in Figure

increasen harvest index (Fig. 13). This further emphasized the critical role of dry matter partitioning for runner production. Thus along with total dry matter production rate (CGR), dry matter partitioning efficiency (HI) and leaf area in swamp taro could be useful physiological indices for yield improvement either through selection or for improvement through breeding program (Roy Chowdhury *et al.* 2004 c).

Photosynthesis

Colocasia leaves exert significant control over plant productivity (Roy Chowdhury 1995). A diurnal variation of photosynthesis behaviour was monitored in best performing cultivar BCST15 during its peak runner production stage at 225 days after planting. The aim was to understand changes in short-term photosynthesis in response to various environmental factors like temperature, light and more importantly humidity as it is a wetland crop. The photosynthetically active radiation, (PPFD; $R^2 = 0.61^*$), air ($R^2= 0.81^{**}$) and leaf temperature ($R^2=0.80^{**}$) showed significant relationship with photosynthesis indicating importance of light intensity and temperature on photosynthesis rate (Table 7)

With increase in PAR, the CO_2 fixation rate changed in a curvilinear manner attaining maximum CO_2 fixation rate of 9.97 µmole $CO_2.m^{-2}.s^{-1}$ at 1190 µmole.$m^{-2}.s^{-1}$ PAR. This suggested that during monsoon, the main production season of swamp taro, crop might maintain its photosynthesis rate without much influence of low light stress due to cloudy weather. Further chlorophyll fluorescence study also corroborated above findings that electron transport rate showed more scattering when grown under light compared to swamp taro plants in shade. (Fig.14). Along the pathway of diffusion of CO_2, stomatal conductance has an important role (Parkhurst 1994). In swampy environment under high humidity, where transpiration is profuse due to abundance of water, stomatal movement has a crucial role in building up of partial CO_2 pressure in substomatal region of

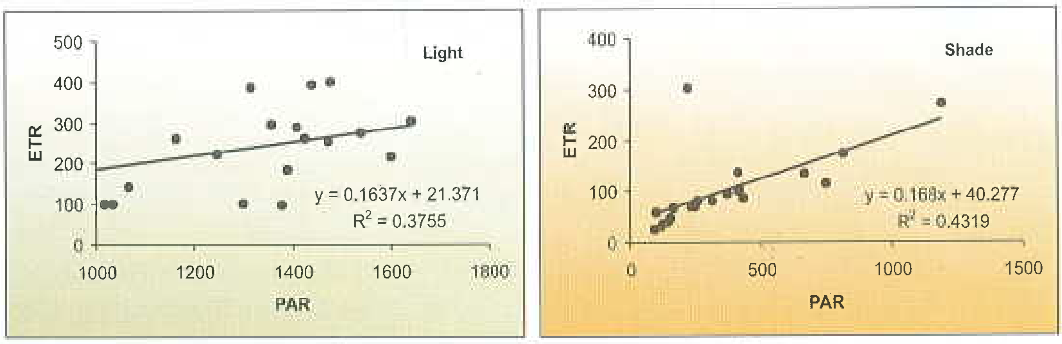
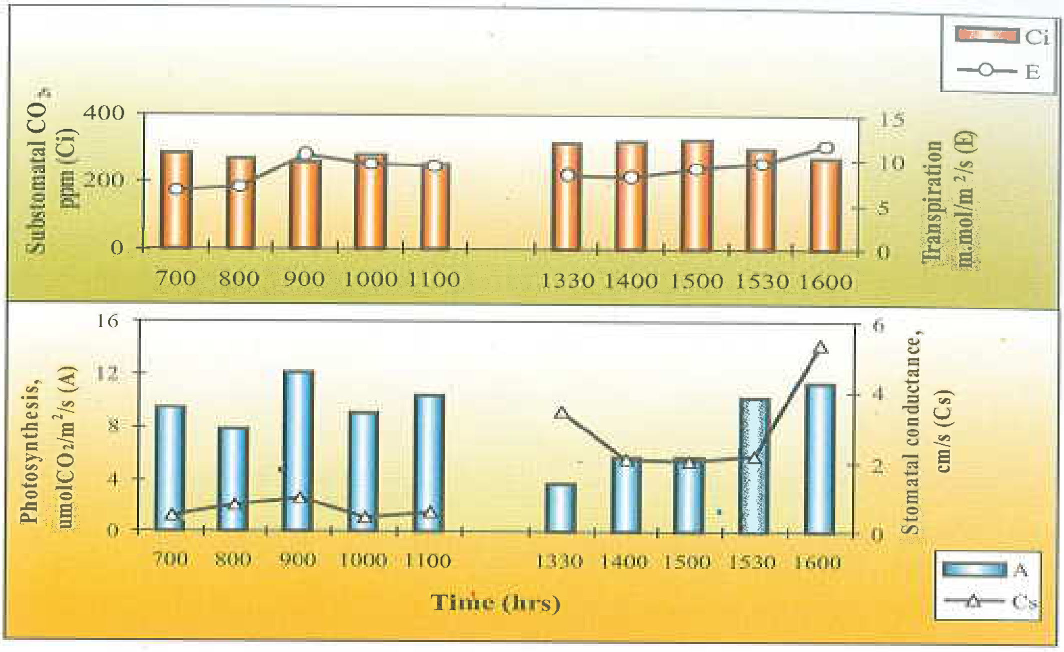


Fig.14: The changes in relationship between electron transport rate (ETR) and various levels of photosynthetically active radiation (µmol/m²/s) in swamp taro cultivar BCST15 grown in light and shade



After Roy Chowdhury et.al 2004d

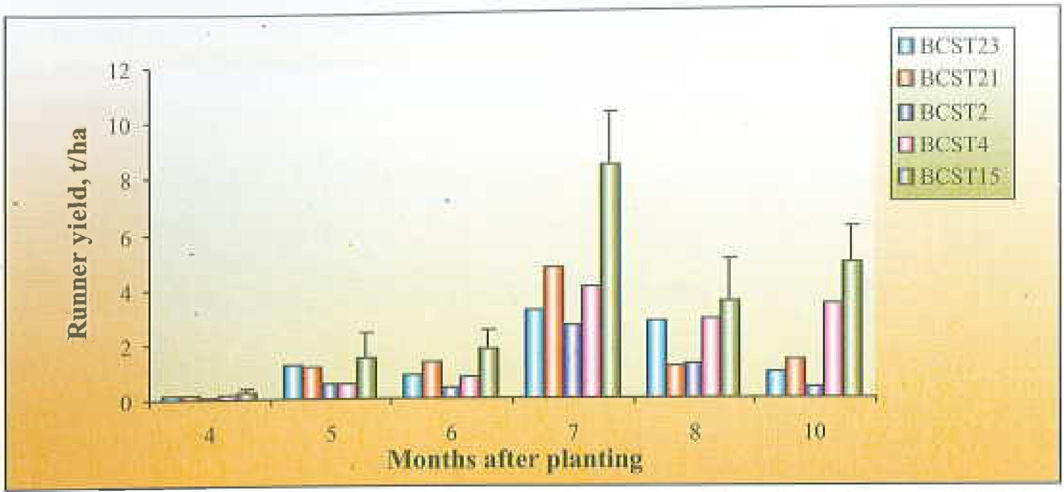
Fig.15: The diurnal variation in substomatal CO_2 concentration,transpiration, stomatal conductance and photosynthesis rate in swamp taro cultivar BCST15. Symbols and units of observations are as in Figure

the leaf. A significant positive correlation between relative humidity and stomatal conductance was noted (Y = 0.2367X – 14.704: R^2 = 0.6969) suggesting that high relative humidity (a prevalent condition in swampy land) favored stomatal opening in swamp taro. However, CO_2 fixation rate was not much influenced by substomatal CO_2 concentration (Fig. 15). Even though CO_2 diffusion in swamp taro leaves was controlled by humidity and stomatal conductance, its fixation was apparently under control of light, temperature and other non-stomatal factors (Roy Chowdhury *et al.* 2004 d).

Post submergence recovery of cultivar BCST 15 in the experimental field

Identification of suitable genotypes

From the comparative performance of the cultivars studied, it was observed that BCST15 maintained higher plant height, better specific leaf weight and also gave higher runner yield than



After Roy Chowdhury et.al 2004c

Fig.16 The runner yield of five swamp taro cultivars at different stages of crop growth. Vertical bars are LSD at p=0.05 level of significance.

other cultivar throughout the growth period of the crop. Whenever the crop suffered from submergence, leaf chlorophyll content declined in all cultivars due to submergence (Table 8). However, decline in leaf chlorophyll due to submergence was least in BCST 15, which also maintained higher root nitrate reductase activity during post-

Assessment of runner formation in swamp taro field

Swamptaro brought to vegetable market for selling

Table 7. Effect of photosynthetically active radiation (PAR, µmole.$m^{-2}.s^{-1}$), **air and leaf temperature on photosynthesis** (Y , µmole $CO_2.m^{-2}.s^{-1}$) **in swamp taro**

Parameters	Equations	R^2
PAR	$Y= -0.00006X^2 + 0.0119X + 2.8973$	0.6141
Air temperature	$Y= -0.2811X^2 + 19.348X-321.74$	0.8182
Leaf temperature	$Y= -0.1325X^2 + 9.1778X -147.71$	0.8095

After Roy Chowdhury et al. 2004d

Table 8. Effect of submergence in changes in nitrate reductase activity (NRA; µ mole nitrite formed/g fresh weight root tissue/hr) **leaf chlorophyll level** (Chl; mg/gFW/hr) **and yield** (t/ha) **in selected swamp taro cultivars**

	Pre-sub mergence		Submergence		Post submergence		Runner
	(4 MAP)	(4 MAP)	(8 MAP)	(8 MAP)	(9 MAP)	(10 MAP)	yield
	NRA	Chl	NRA	Chl	NRA	Chl	
BCST4	6.21	4.64	2.19	3.51	4.76	4.00	3.45
BCST23	8.16	4.61	3.22	2.98	6.14	3.66	1.90
BCAT15	10.42	4.56	6.37	4.22	8.29	4.40	5.96
Lsd at p=0.05	2.33	0.50	1.12	0.61	1.79	0.46	0.55

submergence period compared to other cultivars. Even when yield decreased due to submergence, BCST 15 maintained highest yield compared to other cultivar (Table 7). Due to these physiological features like greater plant height, higher specific leaf weight, biochemical features like better post submergence chlorophyll retention, root nitrate reductase activity and more importantly higher yield, BCST 15 appeared better suited to the low lying marshy areas (Table 8).

Runner yield and economics

In general, swamp taro plants started yielding runners from 4th month after planting onwards (Fig.15). However yield increased significantly from 5th month. It reached peak at 7th month stage during peak monsoon period of July- August, which is a lean period for availability of other vegetables in the market. In each stage of harvest, runner yield was consistently more in BCST 15 compared to other cultivars. The runner yield decreased from 8th month onwards till 10th month.

The details of cost of cultivation of swamp taro are as follows:

Table 9. The cost of cultivation of swamp taro in one ha area

Item	Amount (Rs)
Labour cost	
Nursery preparation	2500
Field preparation & planting, 85 man days @ Rs 50/-	4250
Weeding & intercultural operation, 160 man days	8000
Harvesting and post harvest handling,200 mandays	10000
Input costs	
Seedling cost	12000
FYM @ 8t	3000
Fertiliser (N:P:K) (52:60:63)	
Urea 113 kg @ 4.00/kg	452
SSP 375 kg @ 3.00/kg	1125
MOP 105kg @ 5.00/kg	525
Insecticide (Rs)	1000
Miscellaneous Growth regulator	540
Fixed cost - land rent	5000
Total Cost of cultivation (INR)	**48490**
Gross income (INR) Income from 15 t runner (approx) @ Rs 6.50 per kg	**97500**
Net Profit	**49010**
B : C ratio	**2.01**

3.3 Conclusion

Swamp taro (*Colocasia esculenta* L. Schott) showed active leaf area development upto 6-7th month stage. Among five different cultivars studied, BCST 15 with greater leaf area for longer duration and high crop growth rate showed highest runner yield. The photosynthetically active radiation, (PPFD; $R^2 = 0.61^*$), air ($R^2 = 0.81^{**}$) and leaf temperature ($R^2=0.80^{**}$) showed significant relationship with photosynthesis indicating importance of light intensity and temperature on photosynthesis rate. The optimum PPFD (photosynthetic photon flux density) was 1190 μmole.m^{-2} s^{-1} at maximum photosynthesis rate of 9.9778 μmole CO_2.m^{-2} s^{-1}. Similarly optimum air and leaf temperatures were found 34.4°C and 34.6°C for maximum photosynthesis rate of 11.1887 and 11.2181μmole CO_2 m^{-2} s^{-1} respectively. The PPFD appeared critical for increasing leaf temperature directly (R^2=0.92**) rather than its effect on CO_2 fixation rate (R^2 = 0.61*). The closer positive association of RH (R^2=0.69**) with stomatal conductance (g_s) suggested that CO_2 diffusion in swamp taro leaf was controlled by humidity and stomatal conductance while fixation of CO_2 appeared under control of light, temperature and other non-stomatal factors. The leaf area index (r = 0.90*) and dry matter production rate (r = 0.93**) showed significant positive association with runner yield. The cultivar BCST15 maintained greater plant height and more specific leaf weight and showed higher runner yield. Runner yield also increased exponentially with increase in harvest index (R^2 = 0.78). Thus greater plant height, more leaf area with high dry matter production and partitioning efficiency appeared useful physiological traits for better runner yield in swamp taro cultivars. Better chlorophyll retention and higher root nitrate reductase activity and higher runner yield during post submergence period made the cultivar BCST 15 more suitable for cultivation in low lying marshy areas.

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