Status of Makhana (*Euryale ferox* Salisb.) Cultivation in India

Lokender Kumar
V.K. Gupta
B.K. Jha
I.S. Singh
B.P. Bhatt
A.K. Singh

ICAR Research Complex for Eastern Region, Patna
Research Centre for Makhana - Darbhanga
Bihar-846 005

Correct Citation:

Technical Bulletin No.R-32/PAT-21

Status of Makhana (*Euryale ferox* Salisb.) Cultivation in India

Authors:

Lokender Kumar[1], V.K. Gupta[1], B.K. Jha[2], I.S. Singh[1], B.P. Bhatt[3] and A.K. Singh[4]

[1]ICAR Research Complex for Eastern Region, Research Centre for Makhana-Dharbhanga

[2]ICAR Research Complex for Eastern Region, Research Centre - Ranchi, Jharkhand

[3]ICAR Research Complex for Eastern Region, Patna

[4]ICAR, Krishi Anusandhan Bhawan, New Delhi

Year : 2011

Published by the Director, ICAR Research Complex for Eastern Region, Patna-800 014, Bihar.
Laser typeset and Printed in The Composers Press, A-26, Phase-II, Naraina Industrial Area, New Delhi-110 028. Tel.: 011-25707869; (M) 9810771160

डा. एस. अय्यप्पन
सचिव एवं महानिदेशक

Dr. S. AYYAPPAN
SECRETARY & DIRECTOR GENERAL

भारत सरकार
कृषि अनुसंधान और शिक्षा विभाग एवं
भारतीय कृषि अनुसंधान परिषद
कृषि मंत्रालय, कृषि भवन, नई दिल्ली–110 114

Government of India
Department of Agricultural Research & Education
and
Indian Council of Agricultural Research
Ministry of Agriculture, Krishi Bhawan
New Delhi-110 114
Tel.:23382629; 23386711 Fax:91-11-23384773
E-mail: dg.icar@nic.in

FOREWORD

Euryale ferox Salisb. (Makhana), an important aquatic crop, has tremendous potential to support the livelihood of resource poor farmers, particularly fisherman community in Eastern Region of India, where agriculture is, by a large, Complex, Diverse and Risk prone. It has a fair distribution in North Eastern and Eastern Region, Jammu & Kashmir, however, commercial cultivation of Makhana is confined only in some parts of Bihar. In order to tap the potential of seasonal water bodies of Eastern and North-Eastern Region, Makhana cultivation offers the unique opportunity.

ICAR Research Complex for Eastern Region has developed suitable integrated farming system model, wherein Makhana is the major commodity which needs wider adoption by various line departments. The Institute has also standardized a technology for Makhana cultivation in agricultural fields along with various agricultural crops. This particular technology is very helpful to reduce the drudgery associated with farming of Makhana in pond ecosystem. Its horizontal expansion is essentially required keeping in view the commercial variability of this particular crop.

Post harvest and processing of Makhana is, however, still a challenging task ahead which need to be addressed sincerely. The skill of Makhana cultivation including its harvesting and popping is confined to fisherman community of Bihar. Effort should, therefore, be made for capacity building of other stateholders, so as to popularize its cultivation in other parts of the country.

I compliment to the scientists of the complex for developing suitable technologies for Makhana cultivation and, I am sure, the problems associated with post harvest of Makhana shall be addressed by the Institute in collaboration of other ICAR organizations, so as to commercialize Makhana cultivation.

(S. Ayyappan)

Preface

Research centre, Darbhanga of ICAR Research Complex for Eastern Region is exclusively responsible to conduct research on germplasm collection and evaluation, varietal development, development of farming system models and agro-techniques, post-harvest, processing, diversification and value addition etc. in Makhana (*Euryale ferox* Salisb.), an important aquatic plant. The effective use of stagnant water bodies like ponds, land depressions, oxbow lakes, swamps and ditches is possible through Makhana cultivation. Integration of Makhana with fishes and Water chestnut has been found one of the viable farming system models in Eastern region.

Makhana cultivation in cropping system mode is a classical example, which offers unique opportunity to cultivate it at shallow water depth with optimum yield. Water chest nut, paddy, wheat, Barseem and other crops could be successfully cultivated in Makhana growing fields. This provides the gainful employment besides food security to the farming families. Makhana cultivation in the fields have been found ecologically and economically most viable compared to pond ecosystem. So far Bihar is the only state in India which produces Makhana on commercial scale.

Though production technologies are available by now, processing in Makhana is still carried out manually. Sincere attempts are, therefore, needed for mechanization of seed grading and popping, which is otherwise highly skilled, very tedious and painstaking task, carried out by fisherman community in Bihar. Even for horizontal expansion of Makhana cultivation, mechanization is essentially required. Otherwise this important crop may reach to the stage of extinction. Credit facilities to Makhana growers also need to be strengthened besides ensuring marketing facilities. Further, the partnership with different stake holders in supply chain and value addition of Makhana at regional, national and international level will give paradigm shift to Makhana at global level.

It is a proven fact that the global climate is changing very fast and like other commodities, its impact is severe on water resources. Makhana based integrated farming system has, however, the potential to mitigate the impact of climate change through natural resource management and diversification of agriculture, besides providing nutritional and environmental security.

Through this document, the authors have made a humble attempt to provide the research findings on various aspects of Makhana cultivation. We hope that the information will be useful to policymakers/planners in order to improve the livelihood of the Makhana growers and also to increase the area under Makhana cultivation.

Authors

Contents

Salient Achievements

- A total number of 112 germplasm of Makhana have been collected and evaluated, and 24 pure lines have been isolated, out of which six have been found most promising for higher productivity.
- The seed yield of the promising strains have been found to be 2.8 t/ha compared to 1.6 t/ha in local check.
- One promising line of Makhana is in the pipe line for release as a variety.
- In general, Makhana is a crop of pond eco-system, however, in order to enhance the productivity and facilitate the horizantal expension of Makhana, a field based cultivation technology has been standardized, which is being adopted by the farmers.
- Makhana based cropping systems, i.e., Makhana-Water chestnut, Makhana-Barseem, and Makhana-Rice-Wheat have been developed.
- Makhana with fish and Water-Chestnut integrated farming system model have also been developed which is gaining popularity among the farmers.
- Economics of different Makhana based cropping systems have been worked-out and net monetary returns have been recorded highest through Makhana-Rice-Wheat cropping system (` 1,22,570.00 per ha), followed by Makhana - Barseem (` 98,465.00 per ha), and Makhana-Water chestnut (` 88,790.00 per ha).
- Net monetary returns through Makhana-Fish-Water chestnut was estimated to be ` 88,910.00 per ha.

Introduction

Euryale ferox Salisb is an important aquatic crop, belonging to family Nympheaceae. It is commonly known as Makhana, Gorgon nut or Fox nut, and grown in stagnant perennial water bodies like ponds, land depressions, oxbow lakes, swamps and ditches. Makhana seeds are also called as Black Diamond. It is a plant of tropical and subtropical climate. For its proper growth and development, the conducive range of air temperature is 20^0C-35^0C, relative humidity 50%-90% and annual rainfall 100cm-250cm (Mandal *et al., 2010).* Makhana cultivation provides livelihood to thousands of resource poor farmers, particularly in Bihar and Manipur. It is a cash crop (dry fruits) and marketed in the form of popped makhana commonly known as *Makhana lawa*.

Makhana plant is considered as a native of South-East Asia and China, but distributed to almost every parts of the world. In general, its distribution is extremely limited to tropical and sub tropical regions of South-East and East Asia and known to exist in Japan, Korea, Russia, North America, Nepal, Bangladesh and some parts of India. In India, it is distributed in West Bengal, Bihar, Manipur, Tripura, Assam, Jammu & Kashmir, Eastern Odisha, Madhya Pradesh, Rajasthan and Uttar Pradesh. However, its commercial cultivation is limited to North Bihar, Manipur, parts of West Bengal and Madhya Pradesh.

In the state of Bihar, major Makhana producing districts include Darbhanga, Sitamarhi, Madhubani, Saharsa, Supaul, Araria, Kishanganj, Purnia and Katihar. Approximately, 80% of total production of processed Makhana comes from Darbhanga, Madhubani, Purnia and Katihar districts alone. Area under makhana cultivation is about 13,000 ha.

Keeping in view its commercial importance, a regional centre was set-up to conduct research on various aspects of Makhana in Darbhanga district of Bihar under the administrative control of ICAR Research Complex for Eastern Region. Through this document, the authors have made a humble attempt to present production technologies, integrated farming system models, cost-benefit analysis, chemical analysis and processing of Makhana.

Makhana cultivation in Manipur

Botanical Characteristics

Ecologically, *Euryale ferox* Salisb. has been classified as an annual aquatic herb with gigantic floating leaves, emergent macrophyte of monotypic genus, growing in the littoral parts of the flood plain wetlands of stagnated shallow water (4-6 ft) which are of perennial in nature. Botanical description of *Euryale ferox* is depicted below:

Propagation

Makhana is an absolutely seed propagated plant and its new plants arise upon the germination of its fully matured seeds.

Seed germination

The germination of Makhana seed is of "hypogeal" type. Upon the germination, the cotyledons and hypocotyls of seeds remain in the soil.

Sequence of Makhana Seed Germination

Roots

It has the cluster roots. The roots are thick, long (40-50 cm), fleshy and fibrous in nature and also having a number of air pockets. Each plant has about 3 – 5 clusters of roots and each of these cluster is consisting of about 10-15 rootlets.

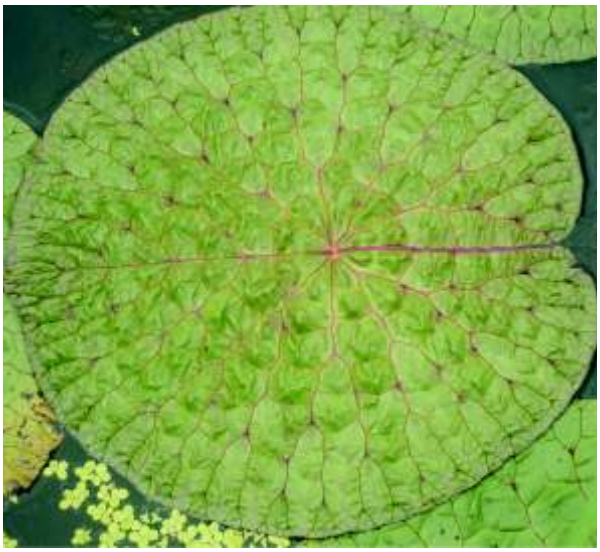
A Close view of makhana roots

Stem

The Makhana plant has rhizomatous stem. The rhizome is short thick and erect, leaf buds are folded up in involucre.

Leaves

Leaves are alternate, round, large (1 -2m) and floating in nature. These are born on a 3-5 feet long petiole. The colour of upper surface appears to be green while the lower one looks deep purple. Both surfaces are covered by numerous thorns.



A close view of young leaves of Makhana

A dorsal view of gingentic leaf of Makhana

Flowers

The flowers are complete, big, solitary, bright purple in colour with long pedicel. The thalamus is fleshy and goblet-shaped.

Calyx

The number of sepals is four. They are persistent, green and thorny which gradually merge into the petals.

Makhana flowers in bloom

Corolla

The petals are of purple colour. They are numerous (> 40). The inner ones are lobate while the outer ones are obovate. They gradually merge into the stamens.

Androecium

The stamens are numerous, free and adnate to the fleshy thalamus that envelops the carpels.

Gynoecium

The stigma is sessile and the ovary is inferior, multicarpellary, syncarpous and multilocular (7-12 loculates).

Fertilization

Makhana is an exclusively self polinated plant. In the flowers of makhana, fertilization (seed setting) takes place at an extremely early stage of their development.

Early stage of fertilized flower

Fruit

It is berry, large (5-8 cm diameter) , spongy, spiny and crowned with persistent sepals. Each fruit has about 20 to 200 seeds.

Close view of Makhana fruit

Internal view of well developed fruit

Seed

The fresh seeds are lumpy, and surrounded by a streaked bright red arils. After some time (3-4 days), the aril of fresh seeds get decomposed and they turned into black colour. Seeds are enough bold and having a hard outer covering. The diameter

Fresh seeds of Makhana (immediatelly after fruit bursting)

Makhana seeds at the time of collection

varies from 0.5 to 1.5 cm. The edible part of seed is its perisperm, which is white and starchy in nature.

Related species

Euryale is a monotypic genus. Hence, there is no other species under this genus.

Chromosome number

Makhana is a diploid plant and the chromosome constitution of this plant is 2n=2x=58

Crop Cultivation

Makhana is cultivated either in perennial water bodies having water depth of 4-6 ft or in the field system.

Pond system

This is the traditional system of Makhana cultivation. Seed sowing is not required in old makhana growing ponds since left over seeds of the previous crop serves as a planting material of subsequent crop. However, Makhana cultivation may be started either through direct seed sowing or transplanting the plantlets in new water bodies.

Tranditional Makhana cultivation in water bodies

In the traditional system, apart from Makhana, air breathing fishes *viz*. Magur (*Clarias batrachus), Singhi (Heteropneustes fossilis),* Kawai *(Anabas testudineus),* Garai *(Channa punctatus*), Trash fishes (*Trichogaster fasciatus, Puntius sp.*), etc. get enter into the ponds as wild fishes alongwith flood water and harvested by the farmers as an additional crop.

Direct sowing

For direct sowing, an amount of 80–90 kg of healthy Makhana seeds are broadcasted on the upper surface of water bodies in the month of December. After 35-40 days of sowing (December-January), seed germination starts at bottom of the pond and by the end of February and beginning of March, the Makhana plantlets come out to the upper surface of the water. At this stage, an optimum distance of 1 X 1 m from row to row and plant to plant is maintained by the thinning of extra plants.

Transplanting method

Healthy and young plants of Makhana are transplanted in the month of March-April at a spacing of 1 X 1 m between row to row and plant to plant. Approximately after two months of transplanting, the bright purple and solitary flowers start to appear in unsynchronized manners.

After 35-40 days of flowering, the fruits get fully developed and matured. The fruits and entire parts of Makhana are thorny. After getting full maturity, the spongy fruits of Makhana get start bursting. Upon bursting, the seeds float on the surface of

water and after 2-3 days, they start to settle down in the bottom of pond. The process of flowers' development and bursting of matured fruits continues up to the month of September. In the month of September/October with the help of a local device (Gaanja), all the accumulated seeds of Makhana are collected from the bottom of water bodies by professional labours. After two-three months of harvesting, the remaining seeds (left out during the collection) get start germinating during next crop cycle.

Field system

This is a new system of Makhana cultivation, which has been standardized by the institute. In this system, Makhana cultivation is carried out in agricultural fields at a water depth of 1 ft. (Kumar *et al.,* 2011). This system is very easy to operate and provides opportunities of cultivate the same fields in a year for cereals and other field crops. The Makhana seedlings are first raised as a nursery and then transplanted in the main field at the optimum time. Depending upon the availability of field and nursery, the transplanting can be done in between first week of February to the third week of April. Through this system, the duration of Makhana crop is reduced up to the four months. The details of field cultivation of Makhana is depicted below:

Well developed Makhana crop in field condition

View of Makhana crop in the fields

Nursery

Being a purely aquatic crop, it thrives well on high water retentive clayey soil rich in organic matter. Thus, clay or clay loams soils are most suited for its cultivation. For sowing, the field is well prepared by two-three deep ploughing, however, before ploughing, for the proper nourishment of seedlings, fertilizers @ 100:60:40/ha, respectively, of N, P & K is applied. Thereafter, the levelling of field is carried out and earthen bund of about two feet height is made around the field. The field is filled with water up to the 1.5 ft height of bund and the seeds are sown in the month of December. An

amount of 20 kg of healthy seeds is broadcasted uniformly in the entire field. For transplanting in one hectare area, about 500 m^2 of nursery is found to be sufficient. A water level of 1 ft height is maintained throughout the growing period of seedling, i.e., from December to April. It has also been observed that the seedling at young stage may be affected by aphids. However, the aphids can be controlled effectively by spraying a 0.2% solution of Endosulphan. By the end of March, the seedling are ready for transplanting.

Makhana nursery at the transplanting stage

Uprooting of Makhana plantlets for transplanting

Land preparation

Land is prepared by two-three deep ploughings, followed by planking with tractor drawn implements or desi plough. Depending upon the availability of the field, the operation can be done from first week of February to the second week of April.

Preparation of main field for Makhana transplanting

Before transplantation, to retain the sufficient water level, an earthen bund of 2 ft height is made around the field and water is filled up to the 1 ft height of the bund. The field is puddled by 2-3 runs of tractor based puddler. For Makhana cultivation, puddling is very essential because it is helpful to check the downward percolation of water to the lower layer of the field.

Manure and fertilizers

Makhana is not manured or fertilized, when grown in pond condition. In field condition, however, manuring and fertilizer application is very essential so as to provide the proper nourishment to the heavy feeder Makhana plants. Being an aquatic crop and possessing large and heavy leaf size, the requirement of nutrients of Makhana crop is very high. On an average, a good crop of Makhana requires 100:60:40 kg of NPK, approximately. To meet out the above nutrient requirements, the application of both organic (15 t/ha) and inorganic fertilizers is essential.

Transplanting

The healthy seedlings are uprooted from nursery and immediately transplanted in the well prepared fields. On the basis of availability of the field, the crop can be transplanted from 1st week of February to the 2nd week of April. It has been recorded that 1.5 m^2 is an ideal spacing for proper growth and development of Makhana plants. Therefore, a distance of 1.20 m and 1.25 m, is maintained from plant to plant and row to row, respectively.

Water management

An assured supply of irrigation is a prerequisite for Makhana cultivation. The transplanted Makhana seedlings take 4 month's period for gaining its full maturity. Since transplanting is done in the month of April, the main growing period (April to August) could make use of monsoon rains. Nevertheless, farmers need to apply 4-5 irrigations depending on the requirement, particularly when rainfall is erratic.

Transplanting of Makhana in field condition

Weed management

The infestation of weeds takes place rapidly in the initial stage of de-

velopment of Makhana crop. Therefore, regular weeding is essentially required at the initial stage of establishment of the seedlings. On account of luxurious vegetative growth of Makhana leaves, i.e., after 30-40 days of transplantation, the infestation level of weeds, however, starts getting reduced. In integrated farming system, combining Makhana with fish and water chestnut, weed menace is reduced due to netting during harvesting of the fishes in the month of December-January.

Flowering and fruiting

The flowering and fruiting starts from the month of May and it continued up to the month of October-November. After 35-40 days of flowering, the fruits become fully developed and matured. In Makhana, it has been observed that the flowering and fruiting are of unsynchronised nature. Upon maturity, the fruits start rupturing, and as a result of this, all the seeds appeared to be floating on the upper surface of water and after 2-3 days, get settled in the bottom surface of the pond/fields. The process of bursting of fruits and accumulation of seeds continue by the end of crop period.

Makhana crop at flowering stage

Harvesting

Harvesting refers to the collection of scattered seeds, either from bottom of the pond or shallow water fields. In pond (traditional) system, harvesting is done in the month of August to October, while in case of field system, it is carried out in the month of August. The apparent reason of earliness in field system is the low depth of water, *i.e.*, 1-2 ft. Generally, harvesting is carried out in the morning

Seed collection of Makhana

hours (6.0 am to 11 am), which is an age old traditional practice. On average, a group of 4-5 people start collecting seeds from the bottom of the pond. The time required for collection depends upon the amount of seeds lying in the bottom of the pond or the fields. However, in field system, due to shallow depth of water, collection of seeds is very simple and less time consuming.

Cleaning and storage

The collected seeds are put in a crescent shaped container locally known as *Gaanja*, which is then swung as well as shaken repeatedly by touching water surface, until all the seeds get cleaned. This practice removes all the wastes adhered with the seeds. The seeds are again poured into a cylindrical container locally known as *Auka* or *khanjhi*, which is rolled over ground so as to rub seed coat, which get smoothen afterwards. The nuts are normally threshed by feet in order to remove mud and other materials and thoroughly washed. After proper cleaning, the seeds are put in gunny bags. Sprinkling of water is done at regular intervals to maintain the optimum moisture in seeds until process of popping starts.

Seed yield

Depending upon the genetic potential of seed material, on an average, the seed yield in pond system is about 1.4-2.2 t/ha, while in field system, the yield potential of the same material has been recorded to be 2.6-3.0 t/ha. Till date, there is no improved variety of Makhana in the country. However, the work on varietal development is under progress and some pure lines have been developed with a yield potential of 2.8-3.0 t/ha

Seed yield of an individutal plant

Insect, Pests and Diseases

Like other crops, Makhana is also attacked by a number of insects-pests and diseases. It is mostly attacked by aphids (*Rhopalosiphum nymphaeae* L), caseworm (*Elophila crisonalis* W) and root borer (*Donacia delesserti*). Among these, aphids attack is observed in the initial stage of plant development in nursery field. While the attack of caseworm and root borer is observed in the fully developed plants of Makhana crop. Aphids attack is generally restricted to tender leaves of young plants, while caseworm and root borers have been found to cause the damage to flower and root organs, respectively (Mishra *et al.,* 2003).

Aphids and caseworm may be, however, controlled by spraying 0.3% aqueous solution of neem extract (neem oil) while damage caused by root borers can be easily controlled by applying 25 kg neem cake as basal dose during the final preparation of field.

Hypertrophy in Makahana leaf (left) and fruits (right)

Leaf blight has been observed as the serious fungal disease in Makhana. The causal organism has been identified as *Alternaria tenuis.* Generally, the disease appears in the fully developed plants of the main crop. The affected plants are characterized by the presence of dark brown or black, irregular, more or less circular dead areas upon the upper surface of leaves. It usually shows a concentric series of rings and ridges, giving the lesions a "target board" effect. Several such adjacent spots coalesce to each other forming large spots. In severe incidence of this disease, most of the leaves become completely blighted (Haider and Mahto, 2003).

Foliar sprays with Copper oxychloride, Dithane Z-78 or Dithane M-45 (0.3%) twice or thrice at fortnightly interval have been found very effective to check the disease.

Fruit rot has been observed as new occurrence in Makhana. The causal organism of the disease has not yet been identified. However, it seems to be a fungal disease

because a foliar spray with the mixture of 0.3% aqueous solution of systemic and contact fungicides (Carbendazim and Dithane M-45) has been found very effective to check the losses caused due to this disease. The entire organs of affected plants seems to be very healthy but in reality, the immature fruits get starts rotting, and as a result, the economic yield gets affected badly.

Few plants have also been observed to be affected by hypertrophy, however, it is not a serious disease in Makhana. The leaves and floral organs get badly distorted by unusual growth of the affected tissues in case of hypertrophy. On the basis of distortion, the affected plants can be identified easily. This disease is also caused by a fungal agent called *Doassansiopsis euryaleae.* The infection of the disease is not localized and usually extends from leaf lamina to petiole, peduncle of flower, thereby causing great distortion to the basal part of the flower. In turn, flowers become unable to set seeds (Verma *et al.,* 2003). No systematic study has been reported so far for the control of this disease. Thus, there is a need of initiating a systematic research work on this aspect.

Makhana Cultivation in Pond Ecosystem and Agricultural Fields

The detailed comparison of both the systems of Makhana cultivation is depicted below:

Parameter	Pond ecosystem	Agricultural fields
Water requirement	At least 4-6 feet	Just 1 feet
Seed requirement	80-90 kg/ha	20 kg/ha
Source of water	Natural water as perennial water bodies.	Irrigation water or any other perennial source of water
Fertilizers & manure	Not possible due to high depth of standing water	Can be applied very easily before and after the transplantation
Weed management	Very tedious	Very easy
Crop duration	Long to very long (8-10 months)	Short (4- 5 months)
Seed yield	1.8-2.0 t/ha	2.6-3.0 t/ha
Scope for grain and fodder production	Not possible	Water chest nut, rice, wheat, Barseem and other field crops can be grown in rotation
Possibility of maximum no. of crops in a year	Two	Three
Intensification of cropping system	Makhana with water chestnut	Makhana - Water chestnut, Makhana - Barseem, and Makhana-Rice-Wheat
Crop protection measures	Very tedious	Quite feasible
Cropping intensity (%)	In general, 100% in traditional system	200-300%
Net Income	Low to medium in traditional system	High to very high
Feasibility of harvesting	Very tedious. It can be done only by trained labourers	Very simple. It can be done even by unskilled labours
Capital investment	High to very high, depending on the situations	Invariably, medium to low
Scope of horizontal expansion of Makhana cultivation	Limited scope because it would depend upon the availability of natural water bodies	Wide scope

Makhana Cultivation in Cropping System Mode

In the field system, in addition to Makhana, various other crops including cereals and forages can be grown successfully. While 4-5 months are sufficient for Makhana cultivation, other crops could be cultivated during rest of the months. In general, Makhana is transplanted in the second week of April and harvested by the second week of August. Thereafter, short duration varieties of rice are cultivated in the same field. After harvesting of rice (November), wheat is sown by mid of December and harvested by the second week of April and the field is prepared for the subsequent crop of Makhana. Hence, cultivation of three crops per year is possible in field method of cultivation. In general, the Makhana based different cropping system include:

Makhana -Water chestnut,
Makhana - Barseem, and
Makhana - Rice - Wheat

Water chestnut (left) and Barseem cultivation (right) in Makhana growing fields

Rice (left) and wheat (right) cultivation in Makhana based cropping system

Integrated Farming System Mode of Makhana Cultivation

The basic principles involved in integrated farming are the utilization of the synergetic effects of inter-related farm activities, and the conservation, including the full utilization of farm waste. It is based on the concept that "there is no waste", and "waste is only a misplaced resource which can become a valuable material for another product". Integrated fish farming can also play a role in increasing employment opportunities, nutrition and income of rural populations. Composit fish culture or polyculture has been found to be the suitable inland pond aquaculture practice, although, modifications, particularly in species composition and ratio are inevitable, depending on the topography. Fish cultivation is also possible in association of Makhana. Hence, in pond system, to ensure higher income per unit area, fishes and water chest nut are integrated with Makhana. Maximization of water productivity was attempted through multiple uses of water integrating Makhana with fish and water chest nut as a concurrent crop, and crop rotation in order to utilize the water body throughout the year.

The recommended practices for makhana cum fish and water chestnut cultivations are timely cleaning of pond before emergence of makhana seedlings, removal of carnivorous fishes by application of mahua oil cake @ 2.5 t/ha, transplanting and gap filling for optimization of crop geometry (plant to plant & row to row spacing of 1 x 1 m, *i.e.*, 10,000 plants/ha), making refuge area of 10 % of total water body area, integration of different carp fingerlings @ 5000 nos./ha (40% Rohu and 20% each of Catla, common carp and Mrigal). Water chest nut, as a tertiary crop, is harvested in four pickings from November to December. Whereas, fishes are harvested in the month of December-January, i.e., before the emergence of makhana seedlings.

Makhana-Fish cultivation

Post Harvest Management

In general, the post-harvest technology involves sun drying, size grading, pre-heating & tempering, roasting & popping, polishing, and grading & packaging. Still entire system of Makhana processing is manual as till date no successful machine has been developed for its popping. The popping process is highly skilled, tedious, time consuming and pains taking. Most of the experts of this technology belong to the women population of a specific community of *'Mallah'* of north Bihar. The entire process is conventional, which is passed on to the generations from time immemorial. The natural distribution of these experts is limited to the some parts of north Bihar. Perhaps this is the only reason, that the processing of Makhana is restricted to Bihar only.

Sun drying

The removal of free moisture of the fresh seeds is the first step of Makhana processing. For this purpose, the fresh seeds are spread on a mat or cemented yard for 2-3 hrs under bright sun light. The moistures content of the sun dried seeds reduced to an extent of 25% (w.b.). From processing point of view, the optimum level of sun drying of the seeds is an important aspect.

Size grading

Sun dried seeds are sieved for grading. The process arranges seeds as per their size. The entire gradation process requires the sieves of 7 different sizes, marked with No. 1-7. While no. 1 devise have the largest diameter of pores (1.2 cm), no. 7 have the least diameter (0.4 cm). Gradation starts by using No. 1 sieve and ends with sieve 7. The entire process is operated manually.

Pre-heating

During this process, the sun-dried seeds are generally heated in earthen pitcher or cast iron pan by placing them over the fire and stirring them continuously. The time to be taken in this process is solely determined by the experience of the female workers engaged in this profession. The surface temperature of the pan varies from 250-300°C and required time is nearly 5 to 6 minute at the full capacity of the pan. After this activity, the moisture contain of the seeds reduces to approximately 20%.

Indigenous method of pre-heating of Makhana

Tempering

The storage of pre-heated seeds for duration of 48-72 hrs at the ambient condition is known as the tempering of the seeds. It acts upon a universal law of matters that upon heating the volume of matters increases and upon cooling, the volume of matters decreases. Based on this scientific principle, tempering of seeds is done purposefully to loosen the kernels within hard seed coat and helping the equilibrization of the moisture within the seeds.

Roasting and popping

It is the most important but laborious and pains taking operation. About 250g of pre-heated and tempered seeds are taken and roasted in a cast iron pan in single layer over the fire at 290-340°C surface temperature with continuous stirring. After about 1.5 to 2.2 min, a cracking of sound is heard from the seeds being roasted (Jha and Prasad, 2003).

Makhana popping

The roasted seeds (8-10 in nos.) are scooped quickly by hand from the pan and kept on a hard surface and beaten by the wooden hammer. As soon as the hard shell of the seeds break, the kernels pop come out in the expended form, which is called as *lawa*. Depending upon the quality of raw material, the yield of Makhana varies from 35-40% on raw seed weight basis

Polishing

The Makhana seed comprises of two layers within its shell. One thin, red colour membranous covering remains attached with the outer surface of the kernel. This layer of red pericarp; even after popping of Makhana seed is found on the outer surface of Makhana, which necessitates polishing. Makhana are thus polished by rubbing action among them in a basket made of bamboo splits. This operation facilitates more whiteness and lustre to Makhana. Polishing is being done immediately after popping since popped Makhana may absorb moisture and render polishing difficult, if done in the later stage.

Grading

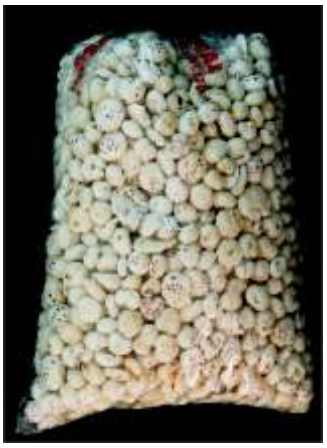
The popped Makhana *lawa* is generally graded in 2 grades at the producer level – *lawa* and *thurri*. The *lawa* is swollen and white with reddish spot whereas, *thurri* is semi-popped, hard and reddish in colour. At trader level, it is graded again into 5 grades. They are *lawa top*, *lawa*, *Murra*, *olwa* and *Thurri*. *Lawa top* and *lawa* are differentiated on specific demands of some traders of outside state. The grades in order of their quality are *Thurri* > *Murra* > *Olwa* > *Lawa* > *Lawa top*.

Packaging

Makhana unlike other agricultural commodity is less perishable. Therefore, ordinary gunny bags for local markets and gunny bags with polythene lining are used for distant markets. Due to the bulky size of the produce, one standard size of gunny bag can accommodate only up to 8 kg of high quality of *lawa* and up to 12 kg of medium quality of Makhana.

Storage

Makhana can be easily stored under ordinary storage conditions for long periods at the growers/processors level. But as a result of higher bulky volume, it occupies larger space. Therefore, the entire Makhana produce is sold mainly to the whole sellers. The whole sellers store the produce for price advantage in the off season.



Finished product of Makhana

Prices

Makhana *lawa* is sold at a price of ₹ 120- 150 kg in local market. The good quality of Makhana *lawa* is, however, priced to ₹ 200-250/kg. The traders get a demand price for *lawa* and *top lawa* which is in high demand from the outside state traders. This commodity also has international delicacy.

Marketing

No infrastructural and financial support is available for Makhana production, processing and marketing. The local marketing channel, however, has the following track-producer to processor to local trader / whole seller / commission agent → retailer→ consumer. The long distance marketing channel are as follows: producer → processer / whole seller of local market → commission agent of distant market → whole seller of distant market → retailer of distant market → consumer.

Commercial Cultivation of Makhana

At the global level, India is the only country where commercial cultivation of Makhana is carried out. Within India, Bihar is the leading state so far in Makhana production is concerned. Other Makhana producing states include Assam, West Bengal and Manipur etc. In Mithilanchal of Bihar, there are a huge number of natural ponds, tanks, land depressions and low lying areas. Hence, this region is known as the natural abode of Makhana production.

Latest information is not available about the area under Makhana cultivation. However, as per the data available, it is cultivated in an around 13000 ha area. The total seed production is estimated to be 23,400 tons, which could produce about 9360 tons of popped Makhana having a total cost of ₹ 1123.0 million in the domestic market.

Economics of Makhana Cultivation

Economics of the Makhana cultivation has been worked out and the net monetary returns (₹/ha) are depicted below:

1. Traditional methods (Stagnant water bodies)	
Makhana alone	₹ 48,960/-
2. Integrated farming system mode of Makhana production (Pond ecosystem)	
Makhana with fish and water chestnut	₹ 88,910/-
3. Cropping system mode of Makhana cultivation	
Makhana, followed by water chestnut	₹ 88,790/-
Makhana, followed by Barseem	₹ 98,465/-
Makahana, followed by rice and wheat	₹ 1,22,570/-

The details of economics of each method of Makhana cultivation is depicted in Table 1 - 3a-c.

Table 1. Economic analysis of Makhana cultivation in traditional methods

Name of the items	Rate per unit (₹)	Total cost (₹)
Input Cost (₹/ha)		
Rent of land for one year	15,000.00	15,000.00
Seed (80kg)	70.00	5,600.00
Weeding (12 Labours)	120.00	1,440.00
Harvesting of crop	15000.00 per ton	27,000.00
Transportation charges	1000.00	1,000.00
Total cost of Inputs		**50,040.00**
Output		
Average seed yield- 1.8 ton/ha	**55,000.00** per ton (@ ₹ 55.00 per kg)	**99,000.00**
Net monetary returns (₹/ha)		**48,960.00**

Table 2. Economic analysis of integrated farming system mode of Makhana production

Name of the items	Rate per unit (₹)	Total cost (₹)
Input cost (Makhana)		
Rent of land for one year	15000.00	15,000.00
Seed (80kg)	70.00	5,600.00
Weeding (12 Labours)	120.00	1,440.00
Harvesting of crop(1.6 ton)	15000.00 per ton	24,000.00
Transportation charges	1000.00	1,000.00
Sub-total		**47,040.00**
Fish integration		
5000 fingerlings	1.50 per fingerling	7,500.00
Fish harvesting including labour	2000.00	2000.00
Transportation charges	1500.00	1500.00
Sub-total		**11,000.00**
Water Chestnut		
2500 Plants	1.5/plant	3750.00
Transplanting	1500.00	1500.00
Insect and diseases control	3000.00	3000.00
4 Picking of nuts (harvesting)	1500.00 per ton	6000.00
Transportation charges for 2.5 ton	3000.00	3000.00
Sub-total		**17,250.00**
Total input cost		**75,290.00**
Output(s)		
Average seed yield of Makhana- 1.6 t/ha (@ ₹ 55.00 per kg)	55,000/- per ton	88,000.00
Fishes- 0.26 t/ha	120 per kg	31,200.00
Water chestnut- 15.0 t/ha	3.0 per kg	45,000.00
Total Output (₹/ha)		**1 ,64,200.00**
Net monetary returns (₹/ha)		**88,910.00**

Table 3. Economic analysis of Makhana cultivation in cropping system mode

(a) Makhana and water chestnut

Name of the items	Rate per unit (₹)	Total cost (₹)
Input cost (Makhana)		
Rent of land for one year	15000.00	15000.00
Seed (20kg)	70.00	1400.00
Nursery raising (in 500m) Charges	1500.00	1500.00
Ploughings, planking and puddling of the field (three times)	1500.00	4500.00
Bund making	500.00	500.00
15 tons FYM	600.00	9000.00
Fertilizer (125kg urea,100 DAP,60kg MOP)	5/kg urea, 11/kg of DAP and 11/kg of MOP	2385.00
Insect and diseases control	2000.00	2000.00
Irrigation (5)	2000.00	10000.00
30 Labours (nursery uprooting, transplanting, irrigation, weeding and plant protection etc.)	120.00	3600.00
Harvesting of crop (2.60 ton)	12000.00 per ton	31,200.00
Transportation charges	1000.00	1000.00
Other miscellaneous expenditures	5000.00	5000.00
Sub-total		**87,085.00**
Water Chestnut		
Field preparation	1500.00	1500.00
2500 Plants	1.50 per plant	3750.00
Transplanting	1000.0	1000.00
Fertilizer (100kg urea, 75kg DAP, 50kg MOP)	5/kg urea, 11/kg DAP 11/kg MOP	1875.00
Insect and diseases control	3000.00	3000.00
Irrigation (4)	1000.00	4000.00
4 Picking of nuts (harvesting)	1000.00 per ton	2000.00
Transportation charges of 20 ton nuts	5000.00	5000.00
Other miscellaneous expenditures	5000.00	5000.00
Sub-total		**27,125.00**
Total input cost (₹/ha)		**1,14,210.00**
Output(s)		
Average seed yield of Makhana- 2.6 ton/ha	55,000/- per ton (@ ₹ 55.00 per kg)	1,43,000.00
Water chestnut- 20.0 t/ha	3.0 per kg	60,000.00
Total Output (₹/ha)		**2,03,000.00**
Net monetary returns (₹/ha)		**88,790.00**

(b) Makhana, followed by Barseem

Name of the items	Rate per unit (₹)	Total cost (₹)
Total input cost (Makhana)		**87,085.00**
Barseem		
Seed (20kg)	140.00	2800.00
Ploughings, planking and puddling (twice)	1500.00	3000.00
Seed sowing	250.00	250.00
Bund making	1000.00	1000.00
Fertilizer (173 DAP)	11/kg DAP	1900.00
Irrigation (7)	1000.00	7000.00
100 Labours (for 5 cutting of crop).	120.00	12000.00
Transportation charges (for 5 cuttings)	2500.00	12500.00
Other miscellaneous expenditures	5000.00	5000.00
Sub-total		**45,450.00**
Total input cost (₹/ha)		**1,32,535.00**
Output(s)		
Makhana	**55,000.00 per ton**	**1,43,000.00**
Barseem - Total fodder yield- 44.0 t/ha	2000.00 per ton	88,000
Total Output (₹/ha)		**2,31,000**
Net monetary returns (₹/ha)		**98,465.00**

(c) Makhana, followed by rice and wheat

Name of the items	Rate per unit (₹)	Total cost (₹)
Total input cost (Makhana)	-	87,085.00
Rice crop		
Seed (25kg)	50.00	1,250.00
Nursery raising (in 500m)	800.00	800.00
Ploughings, planking and puddling of the field (twice)	1500.00	3,000.00
Fertilizer (100kg urea, 75kg DAP, 50kg MOP)	5/kg urea, 11/kg DAP & 11/kg MOP	1,875.00
Insect and diseases control	3000.00	3,000.00
Irrigation (3)	1000.00	3,000.00
30 Labours (nursery uprooting, transplanting, irrigation, weeding etc	120.00	3,600.00
Harvesting of crop	1200.00 /ha	1,200.00
Threshing of crop	2000.00	2,000.00
Transportation charges	1000.00	1,000.00
Other miscellaneous charges	5,000.00	5,000.00

Name of the items	Rate per unit (₹)	Total cost (₹)
Total input cost of Rice crop		**25,725.00**
Wheat crop		
Seed (100 kg)	30.00	3000.00
Herbicides	1000.00	1000.00
Ploughing, planking and of the field (three times)	1000.00	3000.00
Sowing of seed	1000.00	1000.00
Bund making	4000.00	4000.00
Fertilizer (167 kg urea, 130 DAP, 66 kg MOP)	5/kg urea, 11/kg DAP 11/kg MOP	3000.00
Irrigation (5)	1000.00	5000.00
12 Labour (for fertilizer and irrigation application)	120.00	1440.00
Harvesting of crop	1500.00	1500.00
Threshing of crop	2000.00	2000.00
Transportation charges	2000.00	2000.00
Miscellaneous expenditures	2000.00	2000.00
Total input cost of Wheat crop		**28,940.00**
Total input cost of all three crops		**1,41,750.00**
Output(s)		
Makhana	**-**	**1,43,000.00**
Rice		
Seed yield (Basmati Var.)- 4.00 t/ha	13,000.00 per ton	52,000.00
Straw yield- 4.00 t/ha	2,000.00 per ton	8,000.00
Sub-total of Rice		**60,000.00**
Wheat		
Grain - 4.20 t/ha	11,000.00 per ton	46,200.00
Straw - 5.04 t/ha	3,000.00 per ton	15,120.00
Sub-total of Wheat		**61,320.00**
Total Out put of all three crops (₹/ha)		**2,64,320.00**
Net monetary returns (₹/ha)		**1,22,570.00**

Uses of Makhana

Edible uses

From edible point of view, Makhana is considered a superior dry fruit, as it is endowed with several rich nutritional ingredients (Table 4). Edible parts of the seeds contain 12.8% moisture, 9.7% protein, 0.1% fats, 0.5% minerals, 76.9% carbohydrates, 1.4 mg/100g of iron and traces of carotene (CSIR, 1952). The calorific value of raw and popped seeds of Makhana is 362 and 328 K Cal/100g, respectively. From nutrition point of view, the quality of Makhana protein is very superior to a number of food plants and animal based diets.

Table 4. Amino acid profile of Makhana and egg protein

Amino acids	Makhana		Egg	FAO/WHO (1973)
	Raw	Fried		
Lysine	3.79	4.69	6.70	5.40
Histidine	3.15	3.12	3.50	2.50
Arginine	15.19	16.07	6.70	5.20
Aspartic acid	5.76	5.05	10.40	7.70
Threonine	3.34	3.51	5.10	4.00
Serine	5.05	5.64	6.00	7.70
Glutamic acid	16.64	17.06	25.20	14.70
Proline	4.00	3.24	-	10.70
Glycine	3.01	3.28	3.60	2.20
Alamine	5.50	5.84	3.50	6.10
Valine	5.18	5.49	7.50	5.00
Cystine	0.75	1.21	3.00	-
Methionine	3.06	2.95	2.30	3.50
Isoleucine	4.18	4.80	5.60	4.00
Leucine	8.34	8.85	8.90	7.00
Tyrosine	6.38	2.91	3.60	3.05
Phenylalanine	5.78	6.12	6.70	3.05
Tryptophan	-	n.d	1.50	1.00
Ammonia	0.90	1.16	-	1.00
Protein (%)	11.10	11.50	-	-

Source: Jha *et al.*, (1991)

Food items

Popped Makhana are used in the preparation of a number of delicious and rich sweet dishes like Makhana kheer, Makhana vermicelli and Makhana halva etc. It is used in pudding and milk based sweets. Dal makhani and vegetable curries become delicious when Makhana is mixed for taste and thickening object. Makhana raita is also tastier and digestive in nature.

Instant makhana kheer mix

Ready to constitute *makhana kheer* mix is mainly constituted by makhana, milk powder, sugar and a commonly available binder. Optional ingredients are cardamom powder, raisin and cashew nut. The proximate compositions of freshly prepared mix is shown in Table 5.

Table 5. Proximate composition of ready to constitute *Makhana kheer* mix

Constituents	Per 100 g
Energy (kcal)	405
Protein (g)	11.5
Carbohydrate (g)	64.7
Fat (g)	7.6
Cholesterol (g)	0.05
Moisture (g)	13.9
Minerals (g) (phosphorous, iron, calcium etc)	2.2
Saturated fatty acid (g)	4.36
Poly unsaturated fatty acid (PUFA, g)	0.16
Mono unsaturated fatty acid (MUFA, g)	1.7
Trans fatty acid (g)	0.24
Calcium (mg)	303

Snacks

The popped Ma]khana are roasted with a small amount of desi ghee, and some salt and spices are added to it. The snacks are served with tea/coffee.

Cuisines

In Manipur, Makhana is produced for its vegetable purpose, where, the well-developed and almost matured fruits are picked up before their bursting and sold as prime vegetable in the markets. Young fruits are also used as a salad called *'Singju'*. Seeds of matured fruits are used for the preparation of a number of local delicious cuisines like *Eronba* and *Morokmetpa*. In both "*Eronba*" (soup based) and "*Morokmetpa*" (soup less), fermented fish (locally called as "*Ngari*") and chilli are added.


Makhana fruits (left) and its marking with other vegetables in Manipur (right)

Medicinal uses

The medicinal properties of Makhana are well documented in Indian and Chinese ancient literature. According to these literatures, all the plant parts have tonic, astringent and de-obstruent properties (Dragendorff, 1898). The seed is analgesic and aphrodisiac. It is taken internally in the treatment of chronic diarrhoea, vaginal discharge, impotence, premature and involuntary ejaculation, nocturnal emissions and kidney weakness associated with frequent urination. The seeds of Makhana are used in the preparation of a number of Ayurvedic medicines. Makhana alleviates vat and pitta dosha. It is an important herbal preparation, used for erectile dysfunction (impotence). In China, its herbal seeds are used in traditional medicine to strengthen the male potency and retard aging. Das *et al.* (2006) demonstrated that Makhana has the cardioprotective properties and suggested that these properties may be linked with the ability of Makhana to induce TRB-32 and Trx-1 proteins and to scavenge ROS. The leaves are effective against rheumatism which may be attributed to the presence of an alkaloid "drummine" (Sokolov, 1952) and infusion of leaves was found to be effective against difficult parturition. Leaf ash cooked with fermented rice was found to have the capacity to restrain seminal gleets.

Industrial uses

Makhana seeds are very rich in carbohydrate content. From lusting point of view, the starch of popped Makhana seeds is of premium quality hence it is used for coating in the quality fabrics like Banarasi sarees and high quality cotton dresses.

Livestock feed

Makhana bran, a by-product of Makhana processing industry, is considered as a waste material. It constitutes about 4.98-5.46% of the popped Makhana. Makhana bran contains 89.2% dry matter, 7.1% protein, 0.62% fat and 94.4% organic matter. It has been observed that it can supplement the requirement of concentrate feed by 6% in poultry feed. Likewise, in case of goat and dairy cattle, Makhana bran can replace requirement of concentrate up to 40%. Feeding of Makhana bran to birds/livestock also resulted into higher growth rate, comparatively high milk yield and nutrients digestibility.

Use of Makhana bran as poultry feed

Religious uses

In every religion, Makhana is considered as the pious and divine food item. In Hindu religion, it is used in all the worshiping ceremonies, Hawan, Pooja etc. In addition to this, due to its heavenly nature, it is considered as the best offering to god and goddesses in temples. Being the non-cereal food, Makhana is a ideal staple food of devotees during their religious fast.

Crop Improvement

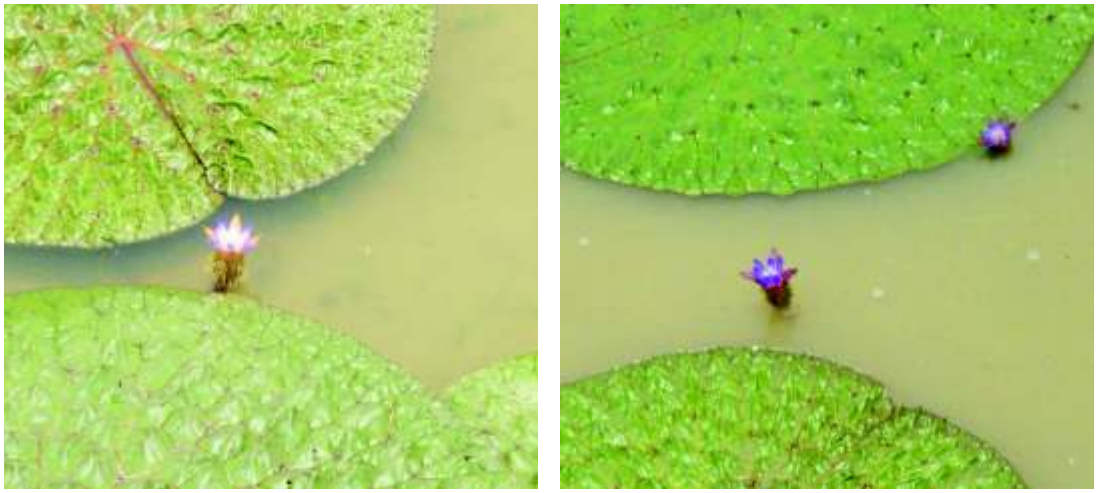
The various aspect of genetic improvement of makhana crop is given below:

Genetic diversity

The flowers of Makhana are large in size, purple in colour and of bisexual type. Makhana is an exclusively self pollinated plant and the fertilization in flowers takes place at a very early (hermetically sealed) stage under the surface water. Makhana is a monotypic genus and the available genetic variability is limited (Verma *et al.,* 2010). In the absence of genetic diversity, no improvement could be made in crop plants. Keeping this fact in view, studies on genetic diversity in makhana, using 36 germplasm (collected from different places of Bihar and Manipur) was conducted and the range of different quantitative traits is depicted as : Days to germination (28-35); Days to initiation of flowering (112-126); Days to fruit bursting (146-156); No. of effective fruits per plant (8-15); Fruit diameter (4-8 inch); No. of seeds per fruit (20-200); Seed yield per fruit (15-150g); Diameter of seed (0.4-1.5cm); 100-seed weight (40-130g); Seed yield per plant (150-1600g)

Breeding

Owing to peculiar characteristics of makhana buds, the artificial hybridization is not possible through conventional means in this crop. Therefore, artificial selection is the only possible way for genetic improvement in Makhana. Keeping this fact in view, pure line selection is being practiced and many promising lines (Sel-1, Sel-5, Sel-6, Sel-13 and Sel-14) have been developed and identified so as to increase the productivity.



A close view of white flowered genotype- Sel-5 (left) and purple flowered genotype - Sel-6 (right)

Researchable and Other Issues

Though suitable production technologies have been developed including Makhana based farming system mode of food production system, nevertheless, many core issues of importance are yet to be addressed. The same has been depicted below:

- Varietal development in Makhana.
- Nutrient requirement of Makhana crop including fertility status of Makhana growing water bodies and agricultural fields.
- Weed management in Makhana ponds.
- Studies on plant protection measures in Makhana.
- Technology assessment and refinement in integrated farming system mode of Makhana cultivation.
- Intergretion of cat fish (*Clerius batrichus*); Murrels (*Channa striatus* and *C. morlius*), *Anabas testeduneous*, *Ompak pabta* and *O. bimaculatus* with makhana.
- Development of harvester, seed grader and popping machines to reduce the drudgery of fisherman community.
- Harnessing the potential of waste water resources through Makhana cultivation.
- Relationship between seed size and seedling vigour.
- Seed viability in Makhana strains.
- Packaging and storage of Makhana.

Literature Cited

CSIR (1952). *The Wealth of India*. CSIR publication, New Delhi.

Das, S.; Der, P.; Raychaudhary, U.; Maulike, N. and Das, D.K. (2006). The effect of *Euryale ferox* Salisb. (Makhana), an herb of aquatic origin on myocardial ischemic repurfsion injury. *Molecular and Cellular Biochemistry,* **289** (12): 55-63

*Dragendorff, G. (1898). Die Heilflanzen der verschinen volver and zeiten. Stuttgart, pp. 885.

Haidar, M.G. and Mahto, Asharfi (2003). Fungal leaf blight and nematode diseases of Gorgon nut (*Euryale ferox*) and their management. In: Mishra, R.K.; Jha, Vidyanath and Dharai, P.V. (eds.) *Makhana*, ICAR, New Delhi, pp. 159-162.

Kumar, Lokendra; Gupta, V.K.; Khan, M.A.; Singh, S.S.; Jee, Janardan and Kumar, Askok (2011). Field based Makhana cultivation for improving cropping intensity of rice fields. *Bihar Journal of Horticulture*, **1**(1): 71-72

Mandal, R.N.; Saha, G.S. and Sarangi, N. (2010). Harvest and processing of Makhana (*Euryale ferox* Salisb.)– an unique assemblage of traditional knowledge. *Indian Journal of Traditional knowledge*, **9**(4): 684-688

Mishra, R.K.; Jha, V. and Jha, B.P. (2003). Associations of insects and gastropods on Makhana with reference to pests and their control. In: Mishra, R.K.; Jha, Vidyanath and Dharai, P.V. (eds.) *Makhana*, ICAR, New Delhi, pp. 124-144.

Jha, S.N. and Prasad, S. (2003). Post–harvest technology of gorgon nut. In: Mishra, R.K.; Jha, Vidyanath and Dharai, P.V. (eds.) *Makhana*, ICAR, New Delhi, pp. 194-214.

Jha, V.; Barat, G.K. and Jha, U.N. (1991). Nutritional evaluation of *Euryale ferox* Salisb (Makhana). *Journal of Food Science and Technology*, **28**(5): 326-328.

*Sokolov, V.S. 1952. *Alkaloid Plants of the USSR*. Akademiia Nauk, Moscow.

Verma, R.A.B.; Jha, V. and Devi, Santha (2003). Leaf and floral hypertrophy of Makhana caused by *Doassansiopsis euryaleae*. In: Mishra, R.K.; Jha, Vidyanath and Dharai, P.V. (eds.) *Makhana*, ICAR, New Delhi, pp. 163-168.

Verma, A.K.; Banerji, B.K.; Chakraborty, D. and Dutta, S.K. (2010). Studies on Makhana (*Euryale ferox* Salisbury). *Current Science,* **99** (6): 795-800.

***originals not seen**