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Sweet Sorghum in the Philippines: Status and Future

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International Crops Research Institute for the Semi-Arid Tropics
Patancheru 502 324, Andhra Pradesh, India

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Preface

Renewable energy as a means of reducing dependence on fast depleting fossil fuels and also as an appropriate mechanism to reduce greenhouse gas (GHG) emissions has attracted global attention. The urgency to mitigate the adverse effects of climate change is evident in legislation initiated by several developed and developing countries to commence research to diversify energy sources to include biofuels, and use them to reduce environmental pollution and alleviate the pressure on fossil fuels. However, supply issues and price volatility have made compliance with the ethanol mandate difficult in many countries.

On 12 January 2007, the Philippine government enacted Republic Act 9367 (RA 9367) or the Biofuels Act, which stipulates a target of 10% ethanol blending in gasoline by February 2011. The potential feedstocks for ethanol production in the Philippines are sugarcane, molasses, sweet sorghum and cassava. Currently, the country has only three ethanol production facilities (two with sugarcane and one molasses-based) with a combined annual production capacity of about 69 million liters (MLi). Even though another facility with a production capacity of 30 MLi is reportedly due to start commercial operation in 2011, local production will still remain significantly below the mandated demand.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has a BioPower initiative that aims to empower the dryland poor to benefit from, rather than be marginalized by, the biofuels revolution. The Institute has developed diverse and improved sweet sorghum varieties and hybrids that can be used as feedstock sources for bio-ethanol production. The multipurpose sweet sorghum also produces grain and fodder which is highly palatable and nutritious to livestock. As part of its strategy, ICRISAT builds partnerships to facilitate technology exchange, testing and adoption of varieties to benefit small-scale farmers. It is in this context that beginning 2004, sweet sorghum was successfully introduced and tested in the Philippines. Efforts by national organizations like DA-BAR, MMSU, DOST, PCARRD and SUCs in making research and development programs fully operational in the Philippines with ICRISAT's support have borne fruit.

Sweet sorghum has caught the attention of researchers, farmers and entrepreneurs in the Philippines as it provides grain for human consumption, stalks/leaves for animal fodder and the juice of the stalks is used for fuel. This use does not compete with the food basket or harm the environment. In addition, sweet sorghum has shown wide adaptability in different parts of the country and a few adapted cultivars have been identified for commercial cultivation. This has served as a strong foundation for the growth of agro-enterprises based on sweet sorghum and its by-products to meet diverse needs of Filippino society.

Sweet Sorghum in the Philippines: Status and Future chronicles sweet sorghum's introduction, testing and selection, seed system development, growth of the local breeding program besides the process of sensitizing government organizations and private sector players to the issue of biofuels. It also delves into the state-of-the-art on its R&D, multilocation trials conducted across the country, screening for biotic and abiotic stresses, breeding, agronomic management, post-harvest losses, utilization, by-product development and capacity building. Commercialization and marketing and the ethanol industry outlook are also discussed. So are the future scenario and public-private partnerships besides the role of ICRISAT in sweet sorghum research, development and commercialization in the Philippines in particular and in Asia in general.

Written by highly experienced scientists from ICRISAT, MMSU and PCARRD, this lucid and comprehensive publication is a valuable source of information on the genesis and progress of sweet sorghum research and development in the Philippines. It will serve as an important source of reference to researchers, students, entrepreneurs, policymakers and other stakeholders in the Philippines and in other countries as well.

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Abbreviations and Acronyms

ABI	Agri-Business Incubator
AIA	Anangui Irrigators' Association
AICSIP	All-India Coordinated Sorghum Improvement Project
APAARI	Asia Pacific Association of Agricultural Research Institutions
ASEAN	Association of South East Asian Nations
ATI	Advanced Training Institute
BAR	Bureau of Agricultural Research
BE	Bapamin Enterprises
BFC	Bapamin Farmers' Cooperative
BIARC	Bicol Integrated Agricultural Research Center
BPI	Bureau of Plant Industry
BRI	Biomass Resources Incorporated
BRSLFB	Bagasse Residue and Stripped Leaves-based Feed Block
BSPMC	Bungon Seed Producers' Multipurpose Cooperative
BSR	Bacterial Stalk Rot
CDM	Clean Development Mechanism
CEM	College of Economics and Management
CEY	Calculated ethanol yield
CFB	Commercial Feed Block
CFC	Common Fund for Commodities
CHED	Commission on Higher Education
CIMMYT	International Maize and Wheat Improvement Center
CLSU	Central Luzon State University
CMU	Central Mindanao University
DA	Department of Agriculture
DCU	Decentralized Crushing Unit
DDG	Distillers' Dried Grain
DOE	Department of Energy
DOST	Department of Science and Technology
ENA	Extra-Neutral Alcohol
FI	Fuel Incorporated

GGE	Genotype main effect plus Genotype Environment interaction
GHG	Greenhouse Gases
GSMI	Ginebra San Miguel Incorporated
ICAR	Indian Council of Agricultural Research
ICBA	International Centre for Biosaline Agriculture
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IEC	Information, Education and Communication
IFAD	International Fund for Agricultural Development
ILRI	International Livestock Research Institute
IMOD	Inclusive Market-Oriented Development
IPCC	Intergovernmental Panel on Climate Change
IRRI	International Rice Research Institute
ISSEVRT	International Sweet Sorghum Elite Varieties and Restorers Trial
ISSEHT	International Sweet Sorghum Elite Hybrids Trial
ISSHET	International Sweet Sorghum Hybrids Evaluation Trial
ISSVET	International Sweet Sorghum Varieties Evaluation Trial
ISU	Isabela State University
LGU	Local Government Unit
MAU	Marathwada Agricultural University
MMSU	Mariano Marcos State University
MSSBT	Multilocation Sweet Sorghum B-line Trial
MSSHT	Multilocation Sweet Sorghum Hybrids trial
MSSVT	Multilocation Sweet Sorghum Varieties Trial
NAIP	National Agricultural Innovation Project
NARS	National Agricultural Research System
NBB	National Biofuels Board
NBC	Negros BioChem Corporation
NEDA	National Economic and Development Authority
NPV	Nuclear Polyhedrosis Virus
OPTION-MPC	Organic Producers in the Island of Negros, Multi-Purpose Cooperative

PAC	Pampanga Agricultural College
PADCC	Philippine Council for Agricultural Development and Commercial Corporation
PCARRD	Philippine Council for Agriculture, Forestry and Natural Resources Research and Development
PCIERD	Philippine Council for Industry Energy Research and Development
PEP	Philippine Energy Plan
PRRI	Philippine Rice Research Institute
PSU	Pangasinan State University
QTLs	Quantitative Trait Loci
RCBD	Randomized Complete Block Design
RDC	Regional Development Council
RDE	Research Development and Extension
RMTU	Ramon Magsaysay Technological University
RUE	Radiation Use Efficiency
RSB	Rhizoctonia Sheath Blight
SAT	Semi-Arid Tropics
SCBI	San Carlos Bio-Energy Incorporated
SKPSC	Sultan Kudarat Polytechnic State College
SMEDI	Small and Medium Enterprise Development Institute
SRI	Sorghum Research Institute
SSGR	Sweet Sorghum Germplasm Resources
SSHT	Sweet Sorghum Hybrid Trial
SSP	Sweet Sorghum Progenies
SSPHT	Sweet Sorghum Preliminary Hybrid Trial
SSV	Sweet Sorghum Variety
SUC	State Universities and Colleges
TCA	Tarlac College of Agriculture
TSS	Total Soluble Solids
UPLB	University of the Philippines, Los Baños
USM	University of Southern Mindanao
VAT	Value Added Tax

Executive Summary

The ever increasing use of fossil fuels has contributed significantly to the rapid rise in greenhouse gas emissions. The United Nations Intergovernmental Panel on Climate Change (IPCC) had in its report concluded that most of the observed increase in global average temperature since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. Renewable energy is thus being considered the best option to mitigate climate change and to harness a wider array of economic and environmental benefits. Many governments have realized the potential of bioenergy and are actively promoting it without compromising on food security while at the same time keeping a close vigil on land use changes.

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) based in Andhra Pradesh in southern India envisions a prosperous, food-secure and resilient dryland tropics of Asia and sub-Saharan Africa (SSA). To achieve that vision, ICRISAT's mission is to reduce poverty, hunger, malnutrition and environmental degradation in the dryland tropics of Africa and Asia, through partnership-based international agricultural research for development that embodies Science with a Human Face. Since the last two decades, ICRISAT has been conducting research and development work on multipurpose smart crop sweet sorghum [*Sorghum bicolor* (L.) Moench] under its BioPower strategy, in order to improve the livelihood opportunities of smallholder farmers in its mandate region.

In 2004, ICRISAT Director General William D Dar initiated the process of generating greater awareness in the Philippines about the potential value of sweet sorghum, given the country's fertile heavy soils that are conducive to its cultivation throughout the year. Considering the country's present cropping pattern and food production requirements, the crop can be grown during the dry season after rainfed rice. Also, in the light of the huge demand for ethanol to be used to blend with petrol (gasoline), there is great potential to produce it using sweet sorghum; this can be done by supplementing feedstocks currently being used in the Philippines.

The use of sweet sorghum as a commercial biofuel source called for the identification of cultivars suitable for different agro-climatic conditions in the Philippines. This led in 2004 to an informal agreement on sharing improved breeding materials, sweet sorghum cultivars' testing and improvement

between ICRISAT, the Philippines Department of Agriculture-Bureau of Agricultural Research (DA-BAR), Philippine Council for Agriculture, Forestry and Natural Resources Research and Development (PCARRD), and Mariano Marcos State University (MMSU). The ties were fortified through visits by Dr Heraldo Layaoen (MMSU) to ICRISAT; exposure visits by key officials from DA-BAR, Commission on Higher Education (CHED) and PCARRD of the Department of Science and Technology (DOST) and University of the Philippines, Los Baños (UPLB); meetings on biofuels; training of Philippine personnel at ICRISAT; and evaluation and training visits of ICRISAT scientists to Philippine production plots.

On 12 January 2007, President Gloria Macapagal Arroyo signed the Biofuels Bill and Republic Act 9367 (RA 9367) which emphasized the development and utilization of indigenous renewable and sustainable clean energy sources to reduce dependence on imported oil and mandated 10% blending of ethanol in gasoline by February 2011.

Convinced about the potential benefits of ICRISAT's research, DA-BAR and MMSU signed a tripartite agreement with ICRISAT on 21 February 2007 to improve agricultural productivity and the welfare of smallholders through strategic research on hybrid technology development for pigeonpea and sweet sorghum.

To date, the collaborative projects have focussed on identifying appropriate sweet sorghum cultivars for different agro-climatic conditions; strengthening hybrid parents and hybrids development research; and on commercializing sweet sorghum stalk use as feedstock for ethanol production and grain use for food and feed in the Philippines.

This book covers at length the different aspects of sweet sorghum research in the Philippines. It describes future plans to take the research to greater heights for it to have impacts on small farmers and on the national economy of the Philippines. Also discussed are sweet sorghum's potential as a bio-energy feedstock in India and China.

I. Sweet Sorghum: The Crop

We can get fuel from fruit, from that shrub by the roadside, or from apples, weeds, sawdust—almost anything! There is fuel in every bit of vegetable matter that can be fermented. There is enough alcohol in one year's yield of a hectare of potatoes to drive the machinery necessary to cultivate the field for a hundred years. And it remains for someone to find out how this fuel can be produced commercially—better fuel at a cheaper price than we know now.

~ Henry Ford, 1925

1. Introduction

Renewable energy is a critical source of supply that contributes to energy security, reducing dependence on fossil fuels and reducing emission of greenhouse gases (GHG). It plays a major role in energy strategies of countries keen on staving off the adverse effects of global climate changes (FAO 2005 and Farrell et al. 2006). Henry Ford's seemingly prescient outlook is thus becoming much more relevant now after 85 years, as the sources he mentioned are virtually inexhaustible. Fossil fuels are a limited source of energy, depleting swiftly and non-renewable. With the world seeing greater depletion of non-renewable energy sources, the need to explore alternative renewable energy sources gains urgency. Biofuels have been considered such an alternative due to their capacity to offset reliance on oil imports and their potential ability to mitigate the impacts of climate change (Pacala and Socolow 2004). Another factor to be considered is the unprecedented and unpredictable price volatility of global crude oil. On 21 January 2008, the price of crude oil per barrel in the international market was $88.92, rising to a historic high of $147 by June 2008, and plummeting to $33 in December 2008 owing to global recession. May 2011 saw a resurgence in price instability with the cost per barrel going to over $115, forcing policymakers to consider renewable indigenous sources like biofuels as viable options for energy security. In short, a combination of volatile oil prices, national energy security compulsions, ethanol tax incentives, lower ethanol production costs with improved technology, and climate change concerns are driving the demand for ethanol as an alternative renewable fuel source (Srinivasa Rao et al. 2009 and Hardy 2010).

Since biofuels can be produced from diverse crops, each country is adopting a strategy that exploits the comparative advantages it holds with respect to such crops. For example, sugarcane and maize are the main feedstocks for ethanol in Brazil and the USA, respectively, while rapeseed in Europe and palm oil in Malaysia are the main feedstocks for biodiesel. Many nations in Asia such as China and India have launched national policies on biofuels. In the Philippines, the National Policy on Biofuels (NPB) encourages the use of renewable energy resources as alternate fuels to supplement gasoline and diesel in the transport sector (NPB 2009 and Corpuz 2010).

2. Utilization

A. Characteristics

The term sweet sorghum is used to distinguish between varieties of sorghum (*Sorghum bicolor* (L) Moench) with high concentration of soluble sugars in the plant stalk sap or juice. Sweet sorghum is a C_4 species plant with wide flat leaves and a rounded head full of grain at maturity. It is similar to grain sorghum that has been under cultivation for nearly 3000 years. Also known as the 'sugarcane of the desert', sweet sorghum can grow and survive successfully in the semi-arid tropics, where other crops fail to thrive. It is highly suitable for tougher dryland areas and can produce very high yields with irrigation. During very dry periods, sweet sorghum can go into dormancy, with growth resuming when sufficient moisture levels resume (Gnansounou et al. 2005). It is easily grown on all continents, in tropical, sub-tropical, temperate, semi-arid regions as well as in poor quality soil. The grain stalk juice and bagasse (the fibrous residue after juice extraction) can be used to produce food, fodder, ethanol and in cogeneration of power. Owing to these favorable attributes, it has often been referred to as a "smart crop" (Table 1).

Table 1. Traits of sweet sorghum as a biofuel feedstock (Reddy et al. 2005; Reddy et al. 2008 and Srinivasa Rao et al. 2010).

As crop	As ethanol source	As bagasse	As raw material for industrial products
• Growing period of 3–4 months • C_4 dryland crop • Greater resilience • Farmer-friendly • Meets fodder/food needs • Non-invasive species • Low soil N_2O/CO_2 emission • Seed propagated	• Eco-friendly process • Superior quality • Less sulphur • High octane • Automobile friendly (up to 25% of ethanol-petrol mixture)	• Higher biological value • Rich in micronutrients • Used as feed/ for power cogeneration/ bio-compost • Good for silage making	• Cost-effective source of pulp and paper making • By-products produce fermentation dry ice, acetic acid, fusel oil, and methane • Butanol and beverages can be manufactured

Sweet sorghum juice is better suited for ethanol production because of its higher content of reducing sugars compared to other sugar sources including sugarcane juice. It is a promising crop for biomass production due to its high yield and potential to generate high value added products like ethanol, Distillers' Dried Grain (DDG), electricity and heat. After harvesting, it can be separated into grain (used for food or ethanol and DDG production), stalk sugar juice (used for syrup or ethanol production) and bagasse (used to generate electricity, heat, animal feed or bio-compost). Its other by-products (Chiaramonti et al. 2004) include carbon dioxide from the fermentation process, paper from bagasse and compost from leaves (Fig. 1).

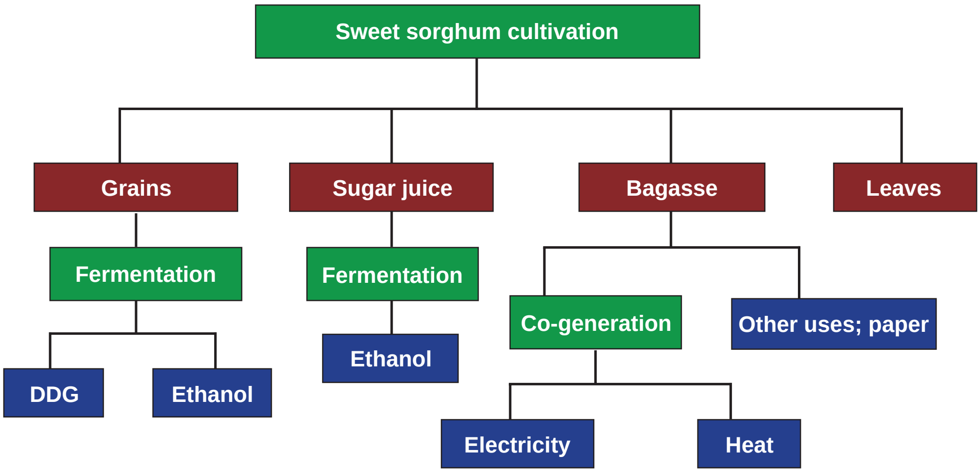


Figure 1. *Alternative processes to convert sweet sorghum into energy fuels (Girase 2010).*

These important characteristics of sweet sorghum, along with its suitability for seed propagation, mechanized crop production and ethanol producing capacity compared to sugarcane and sugar beet, make it a viable alternative source for ethanol production (Table 2).

Table 2. A comparison of sweet sorghum and other bio-ethanol feedstocks rich in raw sugars (Reddy et al. 2008; Srinivasa Rao et al. 2009; and Girase 2010).

Characteristics	Sugarcane	Sugar beet	Sweet sorghum
Crop duration	12–13 months	5–6 months	3–4 months
Growing season	One season	One season	All seasons (if water is available)
Propagation	Setts (40,000 ha^{-1})	Seed (3.6 kg ha^{-1}; pellet)	Seed (8 kg ha^{-1})
Soil requirement	Grows well in drained soil	Grows well in sandy loam; also tolerates alkalinity	Grows in all types of drained soil
Water management	Requires water throughout the year (36,000 m^3 ha^{-1})	Requires 40–60% water compared to sugarcane (18,500 m^3 ha^{-1})	Needs less water; can be grown as a rainfed crop (10,000 m^3 ha^{-1})
Crop management	Requires good management, 250–400 N 125 P and 125 K	Requires moderate management, 120 N, 60 P and 60 K	Easy management; low fertilizer, 90 N and 40 P
Yield (t ha^{-1})	60–85	85–100	45–65
Sugar content on weight basis (%)	10–12	15–18	7–12
Sugar yield (t ha^{-1})	5–12	11.25–18	3–7
Ethanol yield from juice (l ha^{-1})	4,350–7,000	7,100–10,500	2,000–5,500
Harvesting	Mechanical	Mechanical	Predominantly manual and mechanical at pilot scale

B. Food-fuel Trade-off

It is often stated that sweet sorghum cultivars do not produce much grain yield or very less compared to grain sorghum. Studies at ICRISAT have shown that sweet sorghum hybrids have higher stalk sugar yield (11%) and higher grain yield (5%) compared to grain types, and sweet sorghum varieties have 54% higher stalk sugar yield and 9% lower grain yield compared to non-sweet stalk varieties in the rainy season. On the other hand, higher stalk sugar yield was evident in both sweet sorghum hybrids (50%) and varieties (80%) and lower grain yields (25% and 2%, respectively) in the postrainy season. Thus, there is little trade-off between grain and stalk sugar yields in sweet sorghum hybrids in the rainy season while the trade-off is less in both hybrids and varieties in the postrainy season (Srinivasa Rao et al. 2010).

Zhao et al. 2009 further support this by showing that there are significant soluble sugars in the stalks (79–94%) during post-anthesis period; that hybrids exhibit significantly high soluble sugars over varieties with the same maturity period and that the effects of year, harvest time and genotype on calculated ethanol yield (CEY) are highly significant. Experimental data on the relationship between stalk sugar traits and grain yield shows that the regression coefficient of stalk sugar yield on grain yield is not significant; thereby indicating that grain yield is not impacted when selection is done for stalk sugar yield. Hence selection programs can concentrate on improving both traits simultaneously.

C. Whole Plant Utilization

Sweet sorghum bagasse has higher biological value than bagasse from sugarcane when used as cattle feed. Laboratory studies on fodder quality traits in sweet sorghum bagasse and stripped leaves from a wide range of hybrids and varieties have revealed that both have almost similar fodder quality than unextracted (grain) sorghum stover. The International Livestock Research Institute (ILRI) and ICRISAT conducted intake and growth trials on cattle using sweet sorghum Bagasse Residue and Stripped Leaves-based Feed Block (BRSLFB). No significant differences were found between BRSLFB and commercially produced sorghum Commercial Feed Blocks (CFB) (Fig. 2). In other words, sweet sorghum bagasse and stripped leaves provide a valuable, tradable feed resource that will potentially add considerable value to a sweet sorghum biofuel value chain (Blümmel et al. 2009). This was confirmed further in the growing seasons of 2009 and 2010 when fodder traders and sweet sorghum crushing units were linked. Fodder traders' demand for sweet sorghum bagasse and stripped leaves was higher than the potential supply in Andhra Pradesh, India, and prices of sweet sorghum bagasse and stripped leaves could exceed those for whole sorghum stalks.

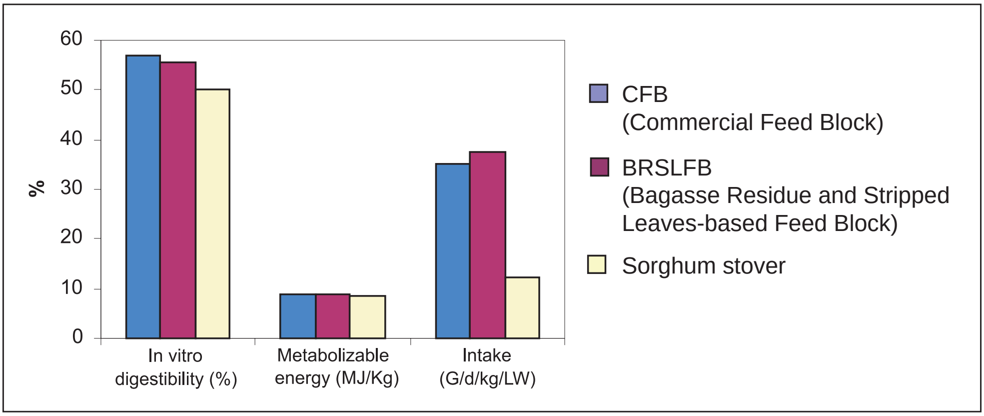


Figure 2. *Key properties of different types of diets vis a vis livestock feed.*

3. Distribution and Climatic Conditions

Sorghum is the fourth major cereal crop of the world in production and fifth in acreage after wheat, rice, maize and barley. It is mostly grown in the semi-arid tropics (SAT) where production is constrained by poor soils, low and erratic rainfall and low inputs resulting in low productivity. The largest sorghum grower in the world is India (7.8 m ha), followed by Nigeria (7.6 m ha) and Sudan (6.6 m ha). India is the third largest producer after USA and Nigeria. The crop is well adapted to the SAT and is one of the most efficient dryland crops to convert atmospheric CO_2 into sugar (Schaffert and Gourley 1982). Following is a brief description of the climatic conditions under which it can be grown:

Latitude. Sorghum is grown between 45°N and 45°S latitude.

Altitude. It can be found at elevations between sea level and 1500 m. Most East African sorghum is grown between 900 m and 1500 m, and cold-tolerant varieties are grown between 1600 m and 2500 m in Mexico.

Temperature. Sweet sorghum can be grown in the temperature range of 12°C and 37°C. The optimum temperature for growth and photosynthesis is 32°C to 34°C. The day length required is 10–14 h, with optimum rainfall of 550–800 mm and relative humidity between 15% and 50%.

Soils. Alfisols (red) or vertisols (black clay loamy) with pH 6.5 to 7.5, organic matter >0.6%, depth >80 cm, bulk density <1.4 gcc, water holding capacity >50% field capacity, available N>260 kg ha^{-1}, available P>12 kg ha^{-1} and available K>120 kg ha^{-1} are ideal for sweet sorghum.

Water. Sorghum can survive on less than 300 mm of water over a season of 100 days and responds well to additional rainfall or irrigation water. Sweet sorghum needs 500–1000 mm of water (rain and/or irrigation) to achieve good yields of 50–100 t ha^{-1} above ground biomass (fresh weight). Though sorghum is a dryland crop, sufficient moisture availability for plant growth is critically important for high yields. The crop has the ability to become dormant under adverse conditions in the vegetative stage and resume growth after a relatively severe drought. Early drought stops growth before panicle initiation and the plant remains vegetative; it resumes leaf and flower development when conditions again favor growth. Mid-season drought stops leaf development. Sorghum is susceptible to sustained flooding, but can survive temporary water logging much better than maize.

Radiation. Being a C_4 plant, sweet sorghum has a high radiation use efficiency (RUE) of about 1.3–1.7 g MJ^{-1}. Taller sorghum types possess higher RUE because of better light penetration through the leaf canopy.

Photoperiodism. Most hybrids of sweet sorghum are relatively less photoperiod sensitive. Traditional farmers, particularly in West Africa, use photoperiod-sensitive varieties, in which flowering and grain maturity occur almost simultaneously regardless of planting date. So even with delayed sowing, plants mature before soil moisture is depleted at the end of the season.

4. Crop Phenology

Sorghum is a short day photoperiod sensitive crop. Flowering is accelerated when day length decreases. An understanding of the crop phenology and growth stages will facilitate systematic crop genetic enhancement and the development of crop management technologies to maximize yield (in this case sugar yield). Crop phenology is primarily influenced by growing conditions like temperature, photoperiodism and moisture, etc. This information helps identify critical stages of weed control, water stress, other biotic (shootfly, stem borer, midge, grain mold, rust, etc) and abiotic stresses (salinity, temperature, photoperiodism, etc). Growth stages in temperate sorghums have been classified on a 0−9 scale (Vanderlip and Reeves 1972) which is inadequate for tropical sorghums that grow under different conditions. Growth stages in tropical sorghums have been classified on a ‘0’ (emergence) to ‘9’ (physiological maturity) scale (Table 3), mostly in line with the earlier classification. The duration of these growth stages may vary with planting date, genotype and location (latitude) (Rao et al. 2004). Based on available research, critical traits that need the immediate attention of researchers for a significant bearing on sweet sorghum's bio-ethanol productivity are given in Figure 3 (Gibson 2010).

Table 3. Phenological stages and characteristics of sorghum.

Growth stage	Days from emergence	Duration (days)	Identification characteristics
0	0	0	Emergence: Coleoptile is visible on soil surface. (First leaf is visible with a round tip.)
1	6	6	3-leaf stage: Collar of the 3rd leaf is visible.
2	16	10	5-leaf stage: Collar of the 5th leaf is visible.
3	32	16	Growing point differentiation (panicle initiation): Approximately 9-leaf stage by previous criteria.
4	50	18	18 flag leaf visible: Tip of the flag leaf (final leaf) is visible in the whorl.
5	60	10	10 boot: Head extends into the flag leaf sheath.
6	68	8	50% flowering: Half of the plant has completed pollination from the tip downward.
7	80	12	Soft dough: Squeezing kernel between fingers results in little or no milk.
8	96	16	Hard dough: Seed cannot be compressed between fingers.
9	106	10	Physiological maturity: Black layer (spot) appears on the hilum, at the base of the seed.

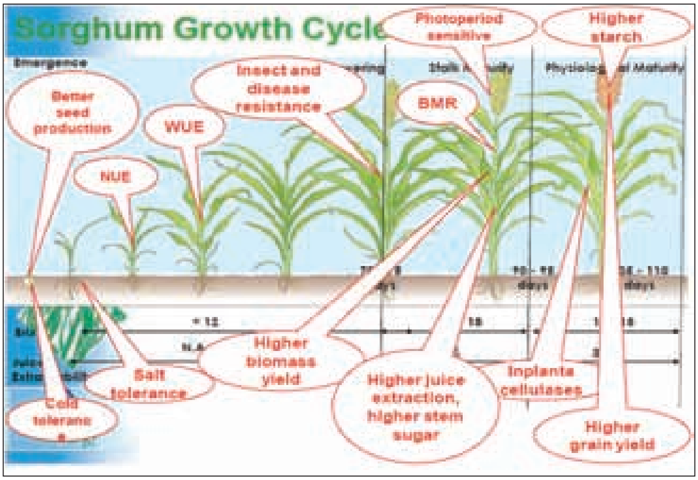


Figure 3. *Critical phenological traits at different stages that have a significant bearing on sweet sorghum's bio-ethanol productivity (Gibson 2010).*

5. Sweet Sorghum Research and Development at ICRISAT

A. Improving Stalk and Sugar Yields

Sweet sorghum research at ICRISAT was initiated in 1980 to identify lines with high stalk sugar in part of the sorghum germplasm collection maintained at its gene bank. Changing donor perceptions and National Agricultural Research Systems (NARS) needs led to its discontinuation in the late 1990s. However, ICRISAT renewed its sweet sorghum research to contribute its share to the biofuel revolution.

The Institute's current breeding strategy revolves around developing hybrid parental lines in partnership with the NARS. In the pipeline are 27 B-lines and 68 R-lines for rainy season adaptation and 19 B-lines and 35 R-lines for postrainy season adaptation. The hybrid cultivar CSH 22SS, developed and released in India by the Indian national program, had the female parent from ICRISAT. ICRISAT variety ICSV 93046 was tested in the All-India Coordinated Sorghum Improvement Project (AICSIP) from 2005–07 and was found superior to control varieties SSV 84 and CSV 19SS and identified for national release. Over the last two years, two more promising lines have been identified from ICRISAT by India: ICSV 25274 and ICSSH 58 (Figs. 4 and 5). Thousands of hybrids and segregating populations are under evaluation for stalk sugar traits (Srinivasa Rao et al. 2010).

Figure 4. *ICRISAT-bred promising sweet sorghum variety ICSV 25274.*

Figure 5. *ICRISAT-bred sweet sorghum hybrid ICSSH 58 (ICSA 731 x ICSV 93046).*

Developing sweet sorghum hybrids is receiving high priority since photo- and thermo-insensitivity are essential to facilitate planting at different dates to ensure the continuous supply of stalks to distilleries for ethanol production. This will lead to the production of more feedstock and grain yield per drop of water and unit of energy invested. Genotype main effect plus genotype environment interaction (GGE) analysis of experimental data has revealed finer details on principal components 1 and 2 accounting for more than 80% of the interaction for both the traits. Based on these biplots, ICSSH 24 and ICSSH 30 were found to be suited for the rainy season while ICSSH 39 and ICSSH 28 were best for sugar yield. ICSSH 30 is suitable for both the seasons for grain yield (Srinivasa Rao et al. 2011). Similarly, season specificity of improved genotypes was observed as the best performers in the rainy season did not perform in a similar fashion in the postrainy season and vice versa. Therefore, the sweet sorghum breeding program was oriented towards producing improved cultivars with season specific adaptation.

B. Breeding for Abiotic Stress Tolerance

ICRISAT's research involves improving and imparting drought tolerance in elite sweet sorghum material as mid-season moisture is predominant in the rainy season crop while terminal stress is frequent in postrainy sorghum in both Asia and Africa. Preliminary data has shown the existence of substantial variability for all the traits. Lines such as IS 23573, IS 23537, IS 20963, SP 93089, SP 54457-2, SP 2061-1, and hybrid ICSA 324 x SSV 74 are tolerant to mid-season stress while ICSV 93046, ICSV 25286 and ICSV 25289 are tolerant to terminal stress.

Among the entries tested for salinity tolerance, five varieties — SP 4504-1, IS 2331, RSSV 106, SP 4511-3 and ICSV 93046 — were superior over the control S 35. Hybrids ICSA 24001 x ICSR 93034, ICSA 724 x SPV 422, ICSA 474 x NTJ 2, ICSA 38 x SPV 422 and ICSA 702 x ICSV 93046 showed superior grain and fodder yields over the national control CSH 22SS.

C. Breeding for Biotic Stress Tolerance

Sweet sorghum is susceptible to many insects and diseases. Sowing time considerably influences the extent of insect and disease damage. Among insect pests, stem borer (*Chilo partellus*) and shootfly (*Atherigona soccata*) cause severe crop damage. Among diseases, grain mold (*Fusarium spp, Phoma spp*), anthracnose (*Colletotrichum spp*), rust (*Puccinia spp*), leaf blight (*Exserohilum turcicum*) and downy mildew (*Peronosclerospora sorghi*) are worth mentioning owing to their prevalence and intensity of damage.

Screening for insect tolerance. Several hybrid parents, hybrids and varieties have been identified for shootfly and stem borer tolerance through established screening protocols. These parents are used to incorporate shootfly tolerance in improved material.

Screening for disease resistance. A total of nine hybrids (ICSA 731 × NTJ 2, ICSA 38 × SPV 422, ICSA 502 × SPV 422, ICSA 724 × SPV 422, ICSA 702 × SPV 422, ICSA 344 × AKSV 22, ICSA 344 × RSSV 106, ICSA 702 × ICSR165 and ICSA 702 × SSV 53) were resistant (score ≤3.0) to anthracnose. They also exhibited moderate resistance to grain mold (score<6). Among varieties and R-lines, five lines (SPV 422, RSSV 106, IS 23526, Ent 64DTN and S 35) showed resistance to anthracnose (score<2) and depicted moderate to high levels of resistance to grain mold (score<4). The tolerant hybrid parents identified are used to incorporate grain mold and anthracnose tolerance.

ICRISAT envisions a prosperous, food-secure and resilient dryland tropics. To achieve that vision, its mission is to reduce poverty, hunger, malnutrition and environmental degradation in the dryland tropics of Africa and Asia through partnership-based international agricultural research for development that embodies Science with a Human Face. Towards this, ICRISAT has been striving to popularize the utilization of sweet sorghum in partnership with the Philippines NARS.

II. The Philippines and ICRISAT

1. Climate Suitability for Sweet Sorghum

The Philippines possesses a tropical and maritime climate characterized by relatively high temperature (mean temperature above 15°C), high humidity and abundant rainfall (Fig. 6). Its fertile clayey to black soils are conducive to sweet sorghum cultivation throughout the year. Sweet sorghum can be grown during the dry season after rainfed rice.

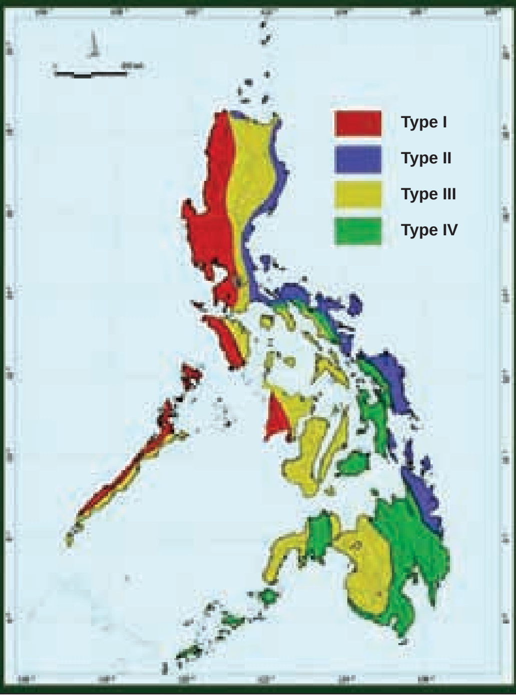
Temperature. The mean annual temperature in the Philippines based on the average of all weather stations, excluding Baguio, is 26.6°C. The coolest days fall in January (mean temperature 25.5°C) while the warmest month is May (mean temperature of 28.3°C). Latitude is an insignificant factor in temperature variability while altitude shows greater contrast with temperature. Thus, the mean annual temperature of Baguio (18.3°C) which is situated at 1,500 m and known as the country's summer capital, is comparable with that in the temperate region. The difference between the mean annual temperature of the southernmost station in Zamboanga and that of the northernmost station in Laoag is insignificant. In other words, there is essentially no difference in the mean annual temperature of places in Luzon, Visayas or Mindanao measured at or near sea level.

Humidity. Due to high temperature and surrounding water bodies, the Philippines has high relative humidity. The average monthly relative humidity varies between 71% in March to 85% in September. From March to May, temperature and humidity attain maximum levels.

Rainfall. Rainfall is the most important climatic element in the Philippines. Distribution varies with region, the direction of moisture-bearing winds and the location of the mountain systems. Mean annual rainfall varies from 965–4,064 mm. Baguio City, eastern Samar and eastern Surigao receive the greatest amounts of rainfall while the southern part of Cotabato receives the least. At General Santos City in Cotabato, the average annual rainfall is only 978 mm.

The Philippines has 1,088,014 ha of rainfed rice lands (Table 4). Under the Implementing Rules and Regulations of the Republic Act (RA) 9367, marginal lands under hybrid corn or sugarcane, idle pasture lands and areas that are not used for food production have been notified as suitable for sweet sorghum cultivation.

Climate Map of the Philippines based on the Modified Coronas Classification



Description

Type I– Two pronounced seasons, dry from November to April and wet during the rest of the year. Maximum rain occurs from June to September.

Type II– No dry season with a very pronounced maximum rain period from December to February. There is not a single dry month. Minimum monthly rainfall occurs between March and May.

Type III– No very pronounced maximum rain period with a dry season lasting only from one to three months, either between December and February or from March to May. This type resembles type I since it has a short dry season.

Type IV– Rainfall is more or less evenly distributed throughout the year. This type resembles type II since it has no dry season.

Figure 6. *Climate map of the Philippines.*

Table 4. Rainfed rice areas (ha) in the Philippines.

Region	Area (ha)
Ilocos	117,447
Cagayan Valley	47,517
Central Luzon	79,177
Southern Tagalog	133,736
Western Visayas	287,779
Eastern Visayas	125,214
Western Mindanao	43,265
Northern Mindanao	3,194
Southern Mindanao	26,667
Central Mindanao	54,508
ARRM	133,331
Caraga	36,179
Total	1,088,014

Source: Philippine Rice Research Institute (PRRI 2005).

2. The Drivers of Change

The International Crops Research Institute for the Semi-Arid Tropics has been instrumental in creating awareness about the potential value of sweet sorghum, its cultivation, the initiation of research on sweet sorghum and its use as a feedstock for bio-ethanol production in the Philippines. The Institute is headed by its Director General, William D Dar, formerly Secretary of the Department of Agriculture (DA), Republic of Philippines, who has shared his insights into the potential of sweet sorghum, which he refers to as a "smart" crop.

Sweet sorghum is the only crop that provides grain and sugary juice at the same time, which can be used to produce ethanol, syrup, jaggery, flour and other food items (Bennett and Anex 2009; Collins et al. 2005 and Bitzer 1997). The use of sweet sorghum as feedstock for ethanol production will generate employment in several sectors and eventually boost rural economies and farm income (Dahlan and Singh 2003). It can also be considered a staple food since its grains can be processed into several food items. Thus there is ample opportunity to position it as a complimentary crop to rice in the Philippines.

Following are some steps ICRISAT has taken to help facilitate sweet sorghum research in the Philippines.

Discussions with scientists and officials. The Philippine Council for Agriculture, Forestry and Natural Resources Research and Development and universities facilitated the visit of Heraldo L Layaoen, vice-president of MMSU, Batac, Ilocos Norte to ICRISAT's sorghum breeding program at Patancheru, India, in 2004. Layaoen was the focal point coordinating Philippine's activities on sweet sorghum along with Jocelyn E Eusebio, Director, PCARRD-CRD and Director, Nicomedez P Eleazar, Bureau of Agricultural Research of the Department of Agriculture (DA-BAR). Belum V S Reddy, Principal Scientist (sorghum breeding), ICRISAT, strengthened the partnership by providing information and technologies, facilitating seed exchange, research and capacity building activities.

Sweet sorghum introductions. Sweet sorghum was introduced in the Philippines in October 2004 through PCARRD. Seventeen cultivars were initially provided by ICRISAT and planted for preliminary evaluation trials on 27 October 2004 at MMSU, followed by further introductions (Annexure I) between 2004 through 2010.

A significant event in this effort occurred on 4 February 2006, when accompanied by ICRISAT Director General WD Dar, the then Indian President APJ Kalam formally handed over seeds of sweet sorghum variety NTJ 2 to Gloria Macapagal Arroyo, then President of the Philippines (Fig. 7).

Study tours and visits. ICRISAT Director General WD Dar and scientists from the Institute paid visits to organizations in the Philippines. In turn, Philippines' scientists, administrators and entrepreneurs visited ICRISAT's sweet sorghum program and Rusni Distilleries Pvt Ltd in Andhra Pradesh, India, from 2004 onwards. WD Dar also met Secretary of Agriculture and the President of the Philippines, Gloria Macapagal Arroyo (Fig. 8) and conveyed to them the research advances made in sweet sorghum at ICRISAT, emphasizing the crop's suitability for the Philippines. ICRISAT's scientists have served as resource persons during seminars and discussed the relevance of sweet sorghum in the biofuel program of the country and its importance in its livelihood programs. From 13–24 January 2007, Belum VS Reddy, AR Palaniswamy, Managing Director of Rusni Distilleries Pvt Ltd, along with Australian investor Ron Valentine, visited various agricultural universities, MMSU and DA-BAR (Fig. 9).

Figure 7. *Sweet sorghum seeds being formally handed over to Gloria Macapagal Arroyo, President of the Philippines, by APJ Kalam, President of India.*

Figure 8. *WD Dar with President Gloria Macapagal Arroyo.*

Figure 9. *(L to R) KB Saxena (ICRISAT), H Layaoen (MMSU), Santiago R Obien (DA-BAR consultant), Belum VS Reddy (ICRISAT), AR Palaniswamy (Rusni Distilleries Pvt Ltd), WD Dar (DG, ICRISAT), Rodolfo Galang, Senior agriculturist (DA-BAR) and investor Ron Valentine from Australia at a techno-demonstration in the Philippines.*

Visits to universities in the Philippines from 25 August to 1 September 2007 and 10–15 March 2008 led to further exchange of experiences on sweet sorghum research.

Pilot studies. Pilot studies were conducted at MMSU with 17 cultivars initially supplied by ICRISAT, and planted on 27 October 2004. Of these, 5 were selected for their sweet and juicy stalks and high grain yield. In 2005, multilocation trials were conducted with the selected varieties in strategic areas in the country to evaluate their performance and adaptability under different agro-ecological zones.

The seed crop was grown at MMSU (Fig. 10) during the peak of the dry season, characterized by no rainfall, 76.5% RH and daytime temperature of 34.6°C. On the other hand, the ratoon was grown at the peak of the rainy season when typhoons are prevalent. The ratoon crop was hit by one of the most devastating typhoons during 9–12 July 2006. While the crop lodged and was continuously flooded for 7 days, the plants survived to maturity (Fig. 11). This demonstrates the versatility of sweet sorghum as a crop, surviving both extremes of water regime. In 2006, all these studies clearly established sweet sorghum's very high productivity in the Philippines (in fact, higher than in India), reinforcing the need to initiate research on the crop.

Sensitizing policymakers. Efforts have been made by WD Dar to sensitize policymakers to the importance of sweet soghum as a biofuel crop. This has involved meetings with the President of the Philippines, the Secretary of the Department of Agriculture, the Secretary of the Department of Science and Technology (DOST), the Secretary of the Department of Energy (DOE), members of Congress, print and broadcast media, funding agencies such as DOST-PCARRD and DA-BAR, regional directors of line agencies, the private sector, oil companies, presidents of State Universities and Colleges (SUCs) and entrepreneurs. Business and technology meetings/workshops were organized at several locations spearheaded by the Philippine Council for Agricultural Development and Commercial Corporation (PADCC) and co-sponsored by DA-BAR and the regional office of Department of Agriculture.

Feasibility study. In March 2006, DA-BAR funded a scoping study on the "Feasibility study on sweet sorghum", presented at a conference attended by top executives of oil companies, foreign and local investors, members

Figure 10. *Sweet sorghum crops raised from the seeds of NTJ 2 received by the President of the Philippines.*

Figure 11. *A ratoon crop of NTJ 2 (a) lodged during floods and (b) later recovered.*

of the Philippine Congress, executives and scientists of Research Development and Extension (RDE) organizations, to which Belum Reddy and AR Palaniswamy were invited as resource persons. This was followed by small group meetings and visits to techno-demonstration sites with investors to prepare business plans as a prelude to establishing sweet sorghum bio-ethanol distilleries.

Technology fora/seminars/workshops have been organized from time to time to discuss the potential of sweet sorghum in the country, such as the one in San Carlos City, Negros Occidental, attended by the members of the board of directors of San Carlos Bio-energy Incorporated (SCBI), composed of Ramon V Valmayor, former Executive Director of PCARRD, land owners, farmers, researchers, local government executives and agriculturists and the technology forum organized at a local university (La Salle-Bacolod) targeting academia, local investors, entrepreneurs and researchers of sugar mills in Negros Occidental. Seminars and other events organized during 2006 in the Philippines are summarized in Table 5.

Table 5. Seminars, technology fora, training and workshops organized across the Philippines towards increasing awareness about sweet sorghum, 2006.

Event	Duration	Target beneficiaries
Investment conference-cum-business matching of the 2006 Isabela Day celebrations	7–9 May 2006	Researchers, technical representatives and investors
Annual Town Fiesta of Flora, Apayao	26–27 May 2006	Municipal officers, farmers and agriculturists
Meeting with the President of Basic Petroleum, DA-BAR, Metro Manila	20–22 June 2006	President, technical representatives, investors and policymakers
Investment forum of the province of Cagayan, Tuguegarao City	28–30 June 2006	Researchers, directors and technical representatives
Emergency issues on sweet sorghum production and utilization, DA-BAR, Quezon City, Metro Manila	11–12 July 2006	Researchers and technical representatives
Orientation seminar on the Production of pigeonpea and sweet sorghum, RMTU, Iba, Zambales	31 July 2006	Researchers, technical experts, investors and farmers
19th BAR Anniversary on the theme BAR at 19: Transforming Philippine agriculture and fisheries R&D into global responsiveness, Quezon City	7–8 August 2006	Stakeholders, agencies, government and non-government institutions, local government unit, private sector and researchers
Seminar-workshop on Research properties and concerns on bio-energy, BSU	12 September 2006	Researchers and technical experts
Agrilink/foodlink with the theme Genetics: Vital to agribusiness competitiveness, World Trade Center, Metro Manila	4–7 October 2006	Stakeholders of government and non-government institutions, local government unit, private sector and researchers
PCARRD Governing Council meeting, DOST, Bicutan, Taguig City	25–27 October 2006	Researchers and policymakers
DOST Executive Committee meeting, DOST, Bicutan, Taguig, Metro Manila	21 December 2006	Researchers and policymakers

3. Philippines' Biofuels Act of 2006

On 12 January 2007, President Gloria Macapagal Arroyo signed the Biofuels Bill and Republic Act 9367 (RA 9367), otherwise known as the Biofuels Act of 2006. RA 9367 took effect on 6 February 2007. The corresponding Implementing Rules and Regulations were released on 17 May 2007 in Circular No. 2007–05–0006 of the Department of Energy (DOE). The Act directed DOE to take the lead in preparing the Philippines Biofuel Program consistent with the Philippine Energy Plan (PEP).

RA 9367 states that the policy of the State is to reduce dependence on imported fuels with due regard to the protection of public health, the environment, and natural ecosystems consistent with the country's sustainable economic growth that would expand opportunities for livelihood by mandating the use of biofuels as a measure to:

- Develop and utilize indigenous renewable and sustainably sourced clean energy sources to reduce dependence on imported oil;
- Mitigate toxic and greenhouse gas emissions;
- Increase rural employment and income; and
- Ensure the availability of alternative and renewable clean energy without any detriment to the natural ecosystem, biodiversity and food reserves of the country.

The Act specified that two years after taking effect (February 2009), the annual total volume of gasoline sold and distributed by oil companies in the country would be subject to the requirement that all ethanol-blended gasoline shall contain a minimum of 5% ethanol by volume (DA-BAR 2009). Within four years of the law taking effect, the NBB would determine the feasibility and recommend to DOE raising the ethanol blend volume in all gasoline fuel distributed and sold by oil companies in the country to a minimum of 10%. It was decided that by February 2011, all gasoline fuel sold in Philippines must contain a minimum of 10% bio-ethanol, which is approximately 482.30 MLI, requiring the operation of 16 distilleries. By 2014, projected bio-ethanol demand is slated to be 537.16 MLI, requiring the operation of 18 distilleries (DOE 2009).

RA 9367 provides the following incentives to encourage investments in the biofuels industry:

- Zero specific tax per liter on local and imported biofuels;
- The sale of raw material used in the production of biofuels shall be Value Added Tax (VAT) exempt;
- All water effluents considered as "reuse" are exempt from wastewater charges; and
- Government financial institutions shall, in accordance with their respective charters or applicable laws, accord high priority to extending financial support.

In support of RA 9367 and its Implementing Rules and Regulations, the Joint Administrative Order No. 2008–1 detailing the guidelines governing biofuel feedstock production, biofuels and biofuel blends production, distribution and sale, was signed on 8 October 2008. The Act stipulates that agricultural lands under food crops are not to be utilized for biofuels feedstock production.

4. National R&D Initiatives

In cooperation with SUCs, line government agencies in the Philippines embarked on several biofuel production development programs. At MMSU, a study was conducted to determine the viability of growing sweet sorghum as a source of bio-ethanol. Field trials showed that it is technically feasible to grow sweet sorghum and produce high yields. However, doubts about the commercial viability of growing the crop and processing it into bio-ethanol needed to be addressed if prospective venture capitalists were to be invited to invest. This called for inter-agency RDE work on sweet sorghum.

The first research for development project titled *Sweet sorghum commercial production and utilization* was approved in March 2006 and implemented on 11 August 2006, funded by DA-BAR, focused in North Luzon, and covering the provinces of Ilocos Norte Ilocos Sur, La Union, Pangasinan, Nueva Ecija, Isabela and Cagayan. Under this project, 17 sweet sorghum varieties acquired earlier were further tested and evaluated for juice yield and quality, stripped stalk and grain yield. Of these, five were selected for their favorable traits (Table 6) and elevated for evaluation

Table 6. Five promising dual and sweet stalk sorghum cultivars from ICRISAT selected for further evaluation in the Philippines.

Variety	Stripped stalk yield (t ha^{-1})			Grain yield[1] (t ha^{-1})		
	Seed crop	First ratoon	Second ratoon	Seed crop	First ratoon	Brix (%)
NTJ 2	45–50	48–55	51–60	3.62	4.40	18.5
SPV 422	55–60	57–65	62–73	3.28	3.92	19.0
ICSV 700	43–48	45–50	47–54	3.46	4.11	18.0
ICSV 93046	47–52	48–55	52–59	3.40	4.08	15.0
ICSR 93034	46–52	47–53	50–55	3.46	4.25	18.0

[1] Grain yield from the second ratoon crop was not recorded as the crop was severely damaged by birds.

under different agro-ecological zones in coordination with different regional field units of the Department of Agriculture. The results confirmed that SPV 422 performs well in almost all the areas in the Philippines.

The other activities undertaken were the development and commercialization of low external input production technologies of sweet sorghum cultivars; cultural management and pest management studies; product development, packaging and commercialization; promotion, advocacy and market development; institutional development; training of project staff and farmer cooperators; study tours and continuing training and delivery of extension services. Results of trials at MMSU were used to package a production technology to initially commercialize and utilize sweet sorghum, intended for a cropping system in a rainfed sweet sorghum-sweet sorghum (ratoon)-rainfed rice cropping pattern.

In January 2007, the National Economic and Development Authority (NEDA) in Region I funded the project on *Establishment of a Barangay-based techno-demo on sweet sorghum production for ethanol, food, feed, and forage,* to assist farmers in growing the crop after rainfed rice. This cropping pattern does not displace lands planted to corn, tobacco and other vegetables. The introduction of sweet sorghum slightly modified the cropping system in the Barangay.

At Barangay Bungon, Batac, Ilocos Norte, Bapamin Enterprises in collaboration with MMSU set aside area for its sweet sorghum stalk crushing and processing facilities. Residents were trained to grow sweet sorghum and process it for food and feed. To ensure the project's sustainability, the farmers' association was linked with a private sector integrator to provide the production inputs and marketing assistance needed. The private sector partner's specialized grain thresher for sweet sorghum led to better grain recovery. The setting up of a village-level bio-ethanol distillery is being undertaken to produce bio-ethanol for household use such as disinfectants, moisturizers, stove fuel, etc.

DOST-PCARRD funded a mega-project on *Integrated R&D program on biofuels: Sub-program on utilization of sweet sorghum and cassava as feedstocks for ethanol production.* For sweet sorghum, the following sub-projects are being undertaken (PCARRD-DOST 2008; 2009; and 2010):

Project 1. Germplasm collection, characterization and conservation, varietal improvement and seed system

Project 2. Performance evaluation of sweet sorghum lines for bio-ethanol and grains under different ecological zones

Project 3. Development/adaptation of appropriate production technologies

Project 4. Participatory integrated nutrient and water management for maximum bio-ethanol production from sweet sorghum grown in different agro-ecological zones

Project 5. Development of management strategies against insect pests of sweet sorghum *Sorghum bicolor*

Project 6. Assessment of major diseases in commercial sweet sorghum varieties and development of management strategies

Project 7. Pest dynamics in sweet sorghum under different agro-ecological zones

Project 8. Enhancing capability for sustained ethanol production and utilization.

Likewise, DA-BAR funded the following projects (March 2006 – December 2010):

Project 1. Sweet sorghum commercial production and utilization in North Luzon

Project 2. Scaling-up technology commercialization and utilization of sweet sorghum for bio-ethanol, food, feed and forage

Project 3. Development of sweet sorghum food products and delicacies

Project 4. Regional adaptability trials of promising sweet sorghum varieties (conducted in all regional field units of DA)

Project 5. Promotion and adaptation of sweet sorghum technologies in CPAR areas.

The Commission on Higher Education funded a project titled *Sweet sorghum for bio-ethanol and food* implemented by selected SUCs in the Philippines.

III. Sweet Sorghum Research in the Philippines

1. Introduction

Technology-demonstrations in pilot studies (2004–06) in the Ilocos and Cagayan Valley in the Philippines have clearly shown that sweet sorghum can be cultivated in dry areas with minimum water. The crop needs between 700 mm and 1000 mm of water (rain and/or irrigation) for a good stalk yield (50–70 t ha^{-1}). On idle land, it can be grown year-long provided there is a source of irrigation. Sorghum is not a major food or fodder crop in the Philippines. However, in the light of the huge demand for ethanol for blending with petrol (gasoline), there is great potential to produce ethanol using sweet sorghum-based feedstock to supplement feedstock currently being used. Using sweet sorghum as a commercial biofuel source necessitates large-scale development and production of sweet sorghum and distilleries that operate throughout the year. Since Philippines is a new sweet sorghum adopter, it needs cultivars suitable for different agro-climatic conditions to meet this feedstock need and information on ways of using sweet sorghum grain in food and feed systems (Fig. 12).

The North Luzon Super Region has been identified as a suitable area for large-scale sweet sorghum cultivation. It is composed of four regions namely: Cordillera Administrative Region, Region I (Ilocos Region), Region II (Cagayan Valley) and Region III (Central Luzon). Ironically, the farms here are relatively small, irregularly-shaped and on a rolling terrain. The dry areas in northwest Philippines too were identified by the Regional Development Council (RDC) since previous efforts made to develop/ identify drought-tolerant crops met with low success.

2. Crop Research

Research collaboration between ICRISAT, BAR and MMSU on testing and improving sweet sorghum cultivars started informally in 2004–06 but on a project basis after a tripartite agreement between DA-BAR, MMSU with ICRISAT on 21 February 2007, which aimed to:

- Identify appropriate sweet sorghum cultivars for different agro-climatic conditions;

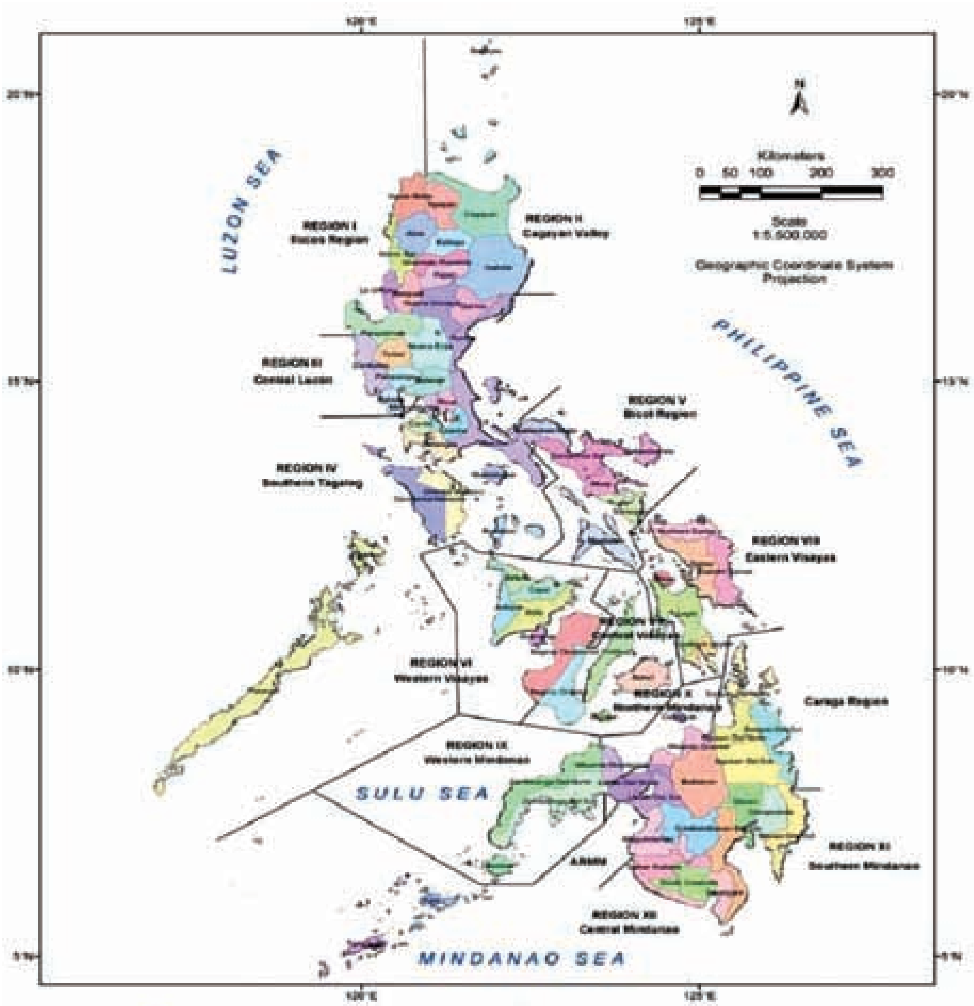


Figure 12. A Philippines map showing the different agro-regions of the country.

- Strengthen hybrid parents and hybrids development research; and
- Commercialize sweet sorghum stalks as feedstock for ethanol production and its grain for food and feed in the Philippines.

Heraldo Layaoen, Vice-President, MMSU, was appointed as Program Leader of a mega program on sweet sorghum titled *Integrated R&D program on biofuels: Sub-program on utilization of sweet sorghum and cassava as feedstock for ethanol production* funded by DOST-PCARRD and implemented in collaboration with selected universities in the Philippines. The mega-program consists of the following projects:

- **Project 2.1.** Sweet sorghum varietal improvement
- **Project 2.2.** Performance evaluation of sweet sorghum lines for bio-ethanol and grains under different ecological zones
- **Project 3.1.** Development of production technology protocol for sweet sorghum.

In addition, a BAR-funded two-year project (2007–09) was started with UPLB. PCARRD is funding projects on the development of hybrid parents/ varieties of sweet sorghum adapted to local conditions. MMSU was also a partner in the 3-year (2008–10) ICRISAT-International Fund for Agricultural Development (IFAD) project on *Linking the poor to global markets: Pro-poor development of biofuel supply chains*. Additional research sub-projects funded by DOST, DA-BAR and PCARRD have been implemented since July 2009 (Table 7).

To fully develop sweet sorghum as a multi-purpose crop in the Philippines, a seminar-workshop attended by key researchers from SUCs, DA Regional Field Units, ethanol distillers, chemical and fertilizer companies, traders, oil companies, including policymakers, was conducted at MMSU in March 2008 to identify and prioritize studies to be conducted. Some of these were implemented starting 2009 (Table 7), the results of which are discussed later in this chapter. Projects in the pipeline are given in Table 8.

3. Participating Organizations and Research Areas

This section describes the major research and development organizations participating in the projects and their project activities.

The University of the Philippines, Los Baños, College Laguna, leads the studies on development of sweet sorghum hybrids and varieties as well as more efficient micro-organisms and processes to improve fermentation and distillation to obtain higher bio-ethanol yield per unit of juice. It is also conducting studies on mechanization and development of small-scale tandem mill to improve juice extraction efficiency in a village-level sweet sorghum facility.

Mariano Marcos State University based in Batac, Ilocos Norte, is closely collaborating with ICRISAT and UPLB in developing sweet sorghum hybrids and varieties. It leads the national cooperative trials of promising hybrids and varieties. Basic studies on water use efficiency, nutrient management, pest and disease management, harvesting and post-harvest management, fermentation, agricultural mechanization and food products development and processing will be conducted. The University regularly conducts training for trainers in production technology in northwest Luzon.

Isabela State University (ISU) based in Echague, Isabela, is working on product development and as a cooperating agency, on national cooperative trials of promising hybrids and varieties, nutrient/pest management and water use efficiency. It is also involved in training trainers in production technology in northeastern Philippines.

Central Luzon State University (CLSU) in Munoz, Nueva Ecija, leads in post-harvest management studies and the scope to use sweet sorghum as feed and forage for small ruminants and buffaloes.

Pampanga Agricultural College (PAC) in Magalang, Pampanga, is working on food products development, nutrient and water management studies and development of hybrids and varieties and serves as the main testing station for the provinces of Pampamga, Tarlac, Bataan and Zambales.

Pangasinan State University (PSU) in Sta Maria, Pangasinan, Tarlac College of Agriculture (TCA), Camiling, Tarlac, and Ramon Magsaysay Technological University (RMTU) in San Marcelino, Zambales, are the cooperating stations involved in national studies under different agro-ecological environments. These SUCs will cover drought- and flood-prone strategic areas in Central Luzon.

Central Mindanao University (CMU) in Musuan, Bukidnon; University of Southern Mindanao (USM) in Kabacan, North Cotabato and Sultan Kudarat Polytechnic State College (SKPSC) in Sultan Kudarat are the cooperating stations in the island of Mindanao under the SUC umbrella.

Table 7. Ongoing sub-projects on sweet sorghum in the Philippines.

Project title/researchers	Objectives	Fund source	Budget (PhP)
Germplasm collection, characterization, conservation and varietal improvement (Artemio M Salazar, UPLB; Consortia E Reano, UPLB and Gerardo Burgos, UPLBCA).	• To evaluate different sweet sorghum lines available locally and internationally in terms of sugar/ethanol yield, agronomic characteristics and their reaction to naturally-occuring pests and diseases • To develop genetically segregating populations as sources for improved lines	DOST-PCARRD	1,208,088
Performance evaluation of sweet sorghum lines for bio-ethanol and grains under different ecological zones (Heraldo L Layaoen, MMSU; Consortia E Reano, UPLB; Gerardo Burgos, UPLBCA; Cesar G Della, PSU; Danie T Sayo, ISU; Tessie E Navarro, TCA and Delfin M Vallador, Sr, CMU).	• To acquire sweet sorghum varieties developed by international and local government research centers and private seed companies • To conduct performance tests on different sweet sorghum lines for ethanol production and grains · • To determine their agronomic characteristics in relation to total fermentable sugar • To identify and recommend varieties that are suitable for ethanol in given ecological zones	DOST-PCARRD	2,773,749.20
Development of production technology protocol for sweet sorghum (Domingo E Angeles, Felicito Rodriguez and Emmanuel G Samson, UPLBCA and Louella M Cabahug, CMU).	• To establish the appropriate time of planting of sweet sorghum in different growing environments· • To evaluate the performance of sweet sorghum varieties in different growing environments • To determine the optimum planting density of different varieties of sweet sorghum • To establish the relationship between nutrient concentration and yield • To determine the crop's fertilizer requirements	DOST-PCARRD	1,641,765.60

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Project title/researchers	Objectives	Fund source	Budget (PhP)
Participatory integrated nutrient and water management for maximum bio-ethanol production from sweet sorghum grown in different agro-ecological zones (NE dela Cruz, CLSU).	• To characterize prospective areas for commercial production of bio-ethanol from sweet sorghum and identify production constraints in the different agro-ecological zones of Central Luzon • To calibrate soil test values for determining soil nutrient supply • To develop specific fertilizer (optimum N, P and K) recommendations based on soil test values in both rainfed and irrigated growing areas in each agro-ecological zone and validate the recommendations under farmer's field • To pilot test the fertilizer recommendations in other potential sorghum-growing areas in the region	DOST-PCARRD	695,554.50
Development of management strategies against insect pests of sweet sorghum (VR Ocampo, UPLB).	• To identify insect pests of sweet sorghum and their natural enemies • To establish insect-pests succession in sweet sorghum • To develop mass-rearing techniques for important natural enemies of major insect pests • To evaluate promising biological control agents against major insect pests • To evaluate insecticides for their efficacy against major insect pests • To identify selective insecticides • To determine agronomic practices to aid management of arthropod pests of sweet sorghum • To evaluate combination(s) of agronomic practices in terms of their effect on the population of major insect pests • To identify a combination of approaches that will result in better management of major insect pests of sweet sorghum • To study the implications of management approaches on the sweet sorghum complex	DOST-PCARRD	1,291,175.08

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Project title/researchers	Objectives	Fund source	Budget (PhP)
Assessment of major insect pests in commercial sweet sorghum varieties and development of management strategies (RG Bayot, UPLB).	• To collect, isolate, preserve and identify pathogens infecting sweet sorghum in the Philippines • To determine the damage potential of isolated pathogens in major commercial varieties under optimum moisture and temperature regimes • To evaluate the effectiveness of selected fungicides and microbial antagonists against virulent pathogens of sweet sorghum	DOST-PCARRD	834,788
Pest dynamics in sweet sorghum under different agro-ecological zones (Thelma Z Layaoen, MMSU; Mary Ann S Silvestre, ISU; Oliver Caasi, PSU; Nora P Lucero, PAC; Lilibeth Laranang, TCA; Janice Baysa, RMTU; Frederick Corey, CMU and Emmanuel Samson, UPLBCA-LG).	• To identify common and major pests attacking sweet sorghum seed and ratoon crops in two growing seasons under different agro-ecological zones • To establish the succession of pests of sweet sorghum seed and ratoon crops under different agro-ecological zones • To determine and identify the common, important and naturally-occurring control agents of major pests of sweet sorghum in different agro-ecological zones • To observe infestation/infection rates of major pests and relate them with juice yield and juice sweetness • To compare the performance of five promising cultivars for their resistance/tolerance to major insect pests and diseases under different ecological zones	DOST-PCARRD	2,627,106
Technology upscaling project for sweet sorghum in Isabela Region 2/R (Quilang E Macaballug, C Mangabat, R Albano and R Pallaje, ISU).	• To promote the sustainable production of sweet sorghum and to develop food and by-products to increase livelihood opportunities and farm income in rural areas	DA-BAR	500,000

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Project title/researchers	Objectives	Fund source	Budget (PhP)
Testing and evaluation of sweet sorghum varieties for ethanol and grains (Victotia L Leynes and Brigida G Mercado, DA-Lipa Agricultural Experiment Station).	• To test and evaluate the performance of sweet sorghum varieties developed by ICRISAT for grain and juice production	DA-BAR	500,000
Sweet sorghum food products and delicacies (Estrella Zabala, Zosimo M Battad and Norman G de Jesus, PAC).	• To promote the production and utilization of sweet sorghum for human food purposes in Region III	DA-BAR	1,000,000
Sweet sorghum commercialization program in Bicol Region (Elena B de Los Santos, Romulo C Cambaya, Ailyn G Rafer, Rodel P Tornilla, Ailyn R Adante and Arlene I de Asis, DA-RFU 5 and Salvador T Albia, Tropics Agro-Industries, Naga City).	• To evaluate sweet sorghum lines/varieties from ICRISAT for feed and ethanol production • To develop appropriate production, product and by-product technologies • To analyze the cost and benefits of developed, production and post-production showcased technologies	DA-BAR	1,000,000
Adaptability trial of sweet sorghum varieties in Central Visayas (Ronnie B Jamola, Senador S Ponce Jr and Ninfa P Davis, DA-7).	• To test the adaptability and performance of different varieties for ethanol production and for grain • To determine the agronomic characteristics of sweet sorghum varieties • To identify and recommend varieties that are suitable for ethanol production in the region	DA-BAR	500,000,000
Adaptability of five varieties of sweet sorghum in Eastern Visayas (Lordes M Calleja, Nilda M Robin, Glicerio N Pernito, Pio P Tuam and Loriel Alo (DA-RFU 8).	• To evaluate the growth and yield of sweet sorghum under Eastern Visayas conditions • To identify the variety suited for regional commercialization • To determine the pests and diseases associated with sweet sorghum • To assess cost and returns in producing sweet sorghum	DA-BAR	500,000,000

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Project title/researchers	Objectives	Fund source	Budget (PhP)
Evaluation of sweet sorghum varieties as sources of feed and biofuel in Northern Mindanao (AS Tumapon, AP Bahia, CA Dumayaca, CR Lapoot and JV Salvani, DA-10 and NOMIARC).	• To evaluate sweet sorghum lines/varieties from ICRISAT for feed and ethanol production· • To develop appropriate production, product and by-product technologies· • To analyze the cost and benefits of developed, production and post-production showcased technologies	DA-BAR	500,000
Sweet sorghum varietal evaluation and by-product utilization development in region XI (MB Gordo, MA Provido, JC Lupiba, FM Agustin, MS Cantila, and AI Telabangco, DA-SMIARC, Region XI).	• To evaluate sweet sorghum lines/varieties from ICRISAT for feed and ethanol production· • To develop appropriate production, product and by-product technologies· • To analyze the cost and benefits of developed, production and post-production showcased technologies	DA-BAR	524,000
Performance evaluation of five promising sorghum varieties under Davao City conditions	• To determine which of the five varieties is best suited under Davao conditions • To determine which varieties produces better yield • To determine which varieties yields more juice extract • To determine the sweetness of their juices		500,000
Promotion and adaptation of sweet sorghum technologies in CPAR areas	• To conduct capacity building for organized farmers in CPAR areas in disseminating the sweet sorghum package of technologies for the adoption of organic fertilizers, animal feed and other potential by-products •To facilitate community-based and managed promotion and participatory approaches in sweet sorghum product and by-product technologies • To identify information needs for different by-products of sweet sorghum		500,000

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Project title/researchers	Objectives	Fund source	Budget (PhP)
Adaptability trial of four sweet sorghum cultivars under ARMM condition (SB Belongan, MS Macabago and O Kasin, DA-ARMM).	• To determine the agronomic characteristics of four cultivars in terms of growth and development, yield and yielding ability· • To identify and recommend best performing varieties for production under different ecological zones of ARMM	DA-BAR	500,000
Utilization of dual/sweet stalk sorghum products and by-products in the production of food and beverages (JF Torres, DA-RXII CEMIARC).	• To utilize sorghum grains as raw material in cake and pastry • To produce vinegar and wine from sorghum juice and syrup through biotechnology	DA-BAR	100,000
Adaptability trial of different sweet sorghum varieties in the Cordillera Administrative Region (BT Pekas and D Africano, DA-CAR).	• To determine the yield and growth of different varieties of sweet sorghum· • To determine the pest and diseases of varieties· • To determine the sugar content of the different varieties	DA-BAR	500,000
Social preparation and further capability building for the promotion of sweet sorghum utilization (FT Rivera, CLSU-LGU Cabiao).	• To train farmers and other stakeholders on sweet sorghum crop management	DA-BAR	1,000,000
Sweet sorghum validation trials in collaboration with ethanol producers in Negros Occidental (R Demafelis, UPLB and HL Layaoen, MMSU).	• To determine the yield and growth of different varieties of sweet sorghum· • To determine the sugar content of the different varieties	DA-BAR	1,500,000

Table 8. Proposed RDE projects to fully develop sweet sorghum in the Philippines.

Project title/researchers	Objectives	Expected output	Budgetary need (PhP M/year)
Varietal improvement and characterization (ME Pascua, MI Remolacio, HI Layaoen, MMSU and AT Salazar, UPLB).	• To develop, characterize and recommend varieties of sweet sorghum for juice and grain for bio-ethanol, food, feed and forage. To include activities like non-conventional and genetic engineering; conventional breeding and genetics; preliminary, general and advanced tests and multilocation tests	To come up with climate/season- and location-specific varieties adaptable to adverse conditions, requiring low external inputs and those resistant to pest and diseases that produce good quality juice and grain	1.5
Developing appropriate cultural management practices			
Varietal response to time of planting, fertilizer and irrigation (H Layaoen and SR Pascua, MI Remolacio/MMSU).	• To develop a technology package that produces the best yield of sweet sorghum grain and stalk, taking into account time of planting, fertilizer and irrigation	A technology matrix indicating the effect of time of planting, fertilizer input and irrigation frequency/level to attain maximum yield	2
Varietal response to population density and row spacing (H Layaoen and SR Pascua, MI Remolacio/ MMSU).	• To determine optimum population density and row spacing for maximum yield of juice and grain	Establishing a planting management that indicates optimum population density of sweet sorghum to attain maximum yield of juice and grain	1.5
Effect of different irrigation schedules and nitrogen and potassium levels (H Layaoen and SR Pascua, MI Remolacio/MMSU).	• To determine the level of nitrogen, potassium and irrigation management on juice and grain yield	A matrix of the interaction of nitrogen and potassium application levels and irrigation management on juice and grain yield	2

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Project title/researchers	Objectives	Expected output	Budgetary need (PhP M/year)
Effects of time of nitrogen/potassium application and irrigation schedule on the performance of ratoon (H Layaoen and SR Pascua, MI Remolacio/ MMSU).	• To establish a fertilizer and irrigation management of sweet sorghum ratoon for maximum juice and grain yield	A system of applying and managing fertilizer and water to attain maximum yield of sweet sorghum juice and grain	2
Response of sweet sorghum to different moisture regimes (H Layaoen and SR Pascua, MI Remolacio/ MMSU).	• To determine the growth and yield performance of sweet sorghum in different moisture regimes to optimize irrigation water	A planting management system that will allow maximum yield of juice and grain of sweet sorghum under certain water stresses	3
Response of sweet sorghum to varying duration of water stresses at different growth stages (H Layaoen and SR Pascua, MI Remolacio/MMSU).	• To know the response of sweet sorghum growth, juice yield, quality and grain yield to certain water stresses	Determining the performance of sweet sorghum at different moisture levels (flooding and drought) and different growth stages	1.5
Determining the ecological factors that influence the presence of diseases in sweet sorghum (H Layaoen and SR Pascua, MI Remolacio/MMSU).	• To determine the agro-ecological and climatic factors affecting the occurrence of sweet sorghum diseases	The agro-climatic factors that affect the occurrence of sweet sorghum disease identified	1
Harvesting and post-harvest management			
Optimum time of harvest with reference to time of the day (SS Franco).	• To determine the time of harvesting sweet sorghum in relation to juice quality	A harvesting schedule that considers juice brix content	1.45

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Project title/researchers	Objectives	Expected output	Budgetary need (PhP M/year)
Optimum time of harvest (if juice is the priority; if grain is the priority, if both grain and juice will be used as feedstock for bio-ethanol) (SS Franco).	• To determine the optimum harvest time of sweet sorghum for bio-ethanol	A harvesting scheme that maximizes bio-ethanol yield from juice, grain and for both juice and grain	1.75
Effect of cutting panicle at full bloom, soft dough and hard dough stages on biomass and juice quality (SS Franco).	• To determine the effect of sweet sorghum juice brix on the time of panicle harvesting	The level of brix sugar in sweet sorghum as influenced by the time of panicle removal	1.25
Industrial research			
Characterization of sweet sorghum components in relation to bio-ethanol production (SQ Barroga).	• To determine and characterize the different components of sweet sorghum which have an effect on the production of bio-ethanol	Characterizing the following components and their effects on bio-ethanol production: sugars, starches, cellulose, lignin, gums, gelatin, monosaccharide; hexose sugars, disaccharides, amino acids; proteins (particularly those that can be derived from sugars)	5
Determining the most cost-efficient feedstock source (from the perspective of the farmer and the distillery) (SQ Barroga).	• To compare different parts of sorghum as fermentable sources	The most efficient part of sorghum will be recognized as feedstock	0.5

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Project title/researchers	Objectives	Expected output	Budgetary need (PhP M/year)
Screening and genetic manipulation of promising micro-organisms to ferment raw/pasteurized sweet sorghum juice, syrup and jaggery (PFR Franco, AFC Llaguno).	• To identify the most efficient strain to ferment sweet sorghum juice/grain and genetically modify it to further hasten efficiency	Identify the most efficient microbe to ferment sweet sorghum and clone a genetically modified microbe	5
Comparison of syrup and jaggery as feedstocks in terms of cost and water use in the distillery (SQ Barroga).	• To determine the differences in sweet sorghum syrup and jaggery in bio-ethanol production	A techno-economic matrix of the differences between sweet sorghum juice and jaggery in bio-ethanol production as regards to cost, water use and wastewater generation	0.7
Utilization			
Effect of cooking time and temperature on the quality of syrup and jaggery (SS Franco).	• To determine the impact of heat treatment on the quality of sweet sorghum syrup and jaggery	The level of temperature and time of heat applied in juice pasteurization and jaggery production in relation to quality required for bio-ethanol production	1.25
Characterizing the sugar profile of sweet sorghum juice at different durations after crushing (SQ Barroga).	• To characterize the sweet sorghum juice sugar profile after harvesting and crushing	A sugar profile of sweet sorghum juice established	0.45
Determining the sugar content of sweet sorghum between time of cutting and time of crushing (SS Franco).	• To determine the variation in sugar brix content of sweet sorghum juice after harvest	The level of brix content in sweet sorghum juice after harvest and exposure to the environment	1

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Project title/researchers	Objectives	Expected output	Budgetary need (PhP M/year)
Cellulosic (2nd generation) bio-ethanol production from sweet sorghum (SC Agrupis).	• To determine and develop micro-organisms to convert sweet sorghum to bio-ethanol through cellulosic and enzymatic action	Organisms identified and modified by genetic engineering to convert sweet sorghum to bio-ethanol	5
Evaluation of sweet sorghum grain as a component of poultry and livestock feed (R Sair).	• To determine the nutrient content of sweet sorghum grain and its use as a component of ration for poultry	Amount of sweet sorghum grain in the formulation of ration for poultry and livestock quantified	1
Integrated Pest Management (IPM)			
Survey on insect pests of sweet sorghum (TZ Layaoen, MMSU).	• To determine the different insect pests attacking sweet sorghum	Insect pests and their ecology identified	1.5
Determining the ecological factors that influence the presence of insect pests in sweet sorghum (TZ Layaoen, MMSU).	• To identify the agro-climatic and ecological factors affecting the occurrence of insect pests in sweet sorghum	The climatic and environmental conditions that affect occurrence of insect pests in sweet sorghum identified	1.5
Screening of pesticides (TZ Layaoen, MMSU).	• To identify an effective but low-cost insecticide to control insect pests of sweet sorghum	A list of insecticides to control insect pests of sweet sorghum without harming beneficial insects and organisms	1.5
Development of biological control method of insects attacking sweet sorghum (TZ Layaoen, MMSU).	• To develop a biological control scheme for insect pests of sweet sorghum as a substitute for chemical pesticide use	Biological control system for insect pests of sweet sorghum to substitute chemical pesticides	1
Survey on diseases of sweet sorghum (TZ Layaoen, MMSU).	• To determine the different diseases affecting sweet sorghum	The diseases, causal organisms and secondary hosts identified	1.5

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Project title/researchers	Objectives	Expected output	Budgetary need (PhP M/year)
Agricultural mechanization			
Sweet sorghum seeder-cum-fertilizer applicator for small and large plantings (AF Dumaoal).	• To design and develop a sweet sorghum seeder-cum-fertilizer applicator for small or large landholdings	A low-cost but efficient sweet sorghum seeder-cum-fertilizer applicator	2.5
Design and develop a mechanical sweet sorghum stalk harvester for small landholdings (AF Dumaoal).	• To design and develop a sweet sorghum stalk harvester	A sweet sorghum stalk harvester that is appropriate for small landholdings	3
Design and development of a sweet sorghum combined harvester-crusher for small landholdings (AF Dumaoal).	• To design and develop a sweet sorghum combined harvester and crusher	An operational sweet sorghum stalk harvester and crusher	5.5
Total			73.6

4. Exchange of Breeding Materials

A total of 1014 samples of sorghum lines/hybrids were supplied by ICRISAT to partners under different projects in the Philippines (Annexure I): 762 for MMSU; 163 for UPLB; 44 for Bureau of Plant Industry (BPI), Los Baños; 42 for the DA-Integrated Agricultural Research Station, Ilagan, Isabela; and 3 for the Advanced Training Institute (ATI), Caraga.

5. Early Varietal Trials

The first sweet sorghum trial in the Philippines was conducted as part of pilot studies at MMSU, Ilocos Norte, from October 2004 to February 2005. The 17 varieties screened were ICSV 1, ICSV 112, ICSV 745, S 35, ICSV 145, ICSV 96056, ICSV 96101, PVK 801, PSV 16, A 2267-2, ICSV 239, IRAT 204, ICSV 93046, ICSV 700, ICSR 93034, NTJ 2 and SPV 422 (Table 9). Juice quality was not evaluated quantitatively due to lack of instruments like a crusher and refractometer. Entries A 2267-2, PSV 16 and PVK 801 were found to be superior for grain yield. Juiciness and sweetness were observed by chewing and tasting. Based on qualitative tests, five varieties – ICSV 93046, ICSV 700, ICSR 93034, NTJ 2 and SPV 422 – were chosen and tagged as “dual type”. They were evaluated for Brix percentage and grain yield. Juice was extracted using a heavy duty plier at the lower, middle and terminal parts of the stalk to measure total soluble solids with a hand refractometer.

In 2007, 230 improved sweet sorghum lines were provided by ICRISAT. In evaluating these lines during the dry season of 2007, 12 lines were found to be promising (Table 10). In 2008, 341 lines/progenies were obtained from ICRISAT under the ICRISAT-IFAD biofuels project on *Linking the poor to global markets: Pro-poor development of biofuel supply chains* and another 360 lines/progenies/hybrids were imported and evaluated for sugar yield (Annexure I). These preliminary screenings resulted in the identification of 44 promising lines (Table 11) that are ready for advanced trials in different agro-ecological zones in the Philippines.

Table 9. Agronomic characteristics of 17 ICRISAT sorghum varieties screened in MMSU, Batac, Ilocos Norte, the Philippines, October 2004 – February 2005.

Variety	Plant height (m)	Days to heading	Days to maturity	Panicle length (cm)	Grain color	Seed size (gm 1000^{-1} seed)	Grain yield (t ha^{-1})
ICSV 1	1.41	64	119	34.9	Cream	29.83	4.02
ICSV 112	1.54	65	119	32.3	Cream	31.80	4.04
ICSV 745	1.60	59	106	24.6	Cream	39.67	3.50
S 35	1.63	63	119	26.2	Cream	48.93	3.96
ICSV 145	1.95	62	119	22.3	Cream	32.30	2.60
ICSV 96056	1.76	70	119	27.5	Brownish	32.90	3.52
ICSV 96101	1.14	57	106	29.1	Dull white	25.37	2.74
PVK 801	1.52	69	119	31.1	White	41.90	4.32
PSV 16	2.25	66	119	27.7	Cream	36.85	4.44
A 2267-2	2.16	70	119	25.5	Cream	36.80	5.04
ICSV 239	1.51	68	119	27.8	Cream	37.90	3.68
IRAT 204	0.98	47	99	29.0	Cream	28.90	2.18
ICSV 93046	2.41	78	129	20.7	Cream	37.43	3.40
ICSV 700	2.70	73	119	20.9	Cream	34.70	3.46
ICSR 93034	1.94	60	119	25.6	Dull white	50.60	3.46
NTJ 2	1.79	60	119	25.1	Dull white	48.87	3.62
SPV 422	1.91	65	119	23.8	Dull white	43.97	3.28

Table 10. Promising sweet sorghum lines selected in 2007 trials at MMSU, Batac, Ilocos Norte, the Philippines.

Variety/line	Unstripped stalk (t ha^{-1})	Stripped stalk (t ha^{-1})	Juice yield (t ha^{-1})	Brix (%)
SPC 14-11	88.5	49.0	36.9	18.0
SP 6511-2	72.0	42.7	27.5	18.0
SPC 511-3	90.0	69.0	19.7	17.7
SP 4511-3	78.8	70.7	26.7	17.5
RSSV 106	93.0	64.1	26.9	17.0
IS 2331	93.0	83.1	26.0	17.0
SS 2016	72.4	64.5	21.9	16.9
SP 4504-1	93.8	83.3	30.2	16.8
SP 4487-3	85.8	76.5	25.3	16.0
SP 4511-2	87.2	78.8	27.9	15.4
SP 6504-2	96.0	68.1	26.1	15.3
SP 4482-1	87.8	77.3	24.7	15.2

Table 11. Promising lines/progenies[1] selected in preliminary evaluation conducted at MMSU, Batac, Ilocos Norte, the Philippines, 2008–10.

Variety/line/ progeny	Days to heading	Days to maturity	Plant height (m)	Stalk diameter (cm)	Unstripped stalk yield (t ha^{-1})	Stripped stalk yield (t ha^{-1})	Juice yield (t ha^{-1})	Bagasse weight (t ha^{-1})	Brix (%)
ENO 01-1001	62	127	1.37	1.59	42.2	33.6	18.3	15.3	18.4
ENO 02-1002	61	125	2.36	1.12	73.9	66.9	42.3	24.6	15.6
ENO 02-2007	66	130	2.80	1.34	47.1	34.3	19.3	15.0	20.7
ENO 02-2026	62	125	2.65	1.84	69.4	57.6	36.8	20.8	16.5
ENO 02-2036	62	124	2.18	1.90	83.9	74.9	43.9	31.0	16.4
ENO 04-1004	55	127	2.40	1.62	66.9	44.7	23.1	21.6	15.2
ENO 04-1004	61	130	2.43	1.57	66.9	45.5	20.3	25.3	19.7
ENO 04-2038	55	130	2.52	1.56	51.3	42.4	22.6	19.8	17.9
ENO 04-3003	55	130	2.37	1.73	69.6	39.5	21.5	18.0	16.1
ENO 04-3008	61	126	2.79	1.61	69.6	55.7	30.3	25.4	15.9
ENO 05-3011	71	130	1.99	1.41	48.8	35.8	18.7	17.1	20.9
ENO 06-2001	62	125	1.96	1.08	66.6	59.4	23.5	35.9	17.7
ENO 07-2014	56	125	2.63	1.98	84.9	60.0	33.4	26.6	16.6
ENO 07-3002	62	125	2.82	1.82	61.6	54.9	27.8	27.1	14.5
ENO 07-3013	61	125	2.64	1.75	69.8	48.8	23.1	25.7	20.1
ENO 08-2009	61	126	2.54	1.63	64.7	56.9	28.6	28.2	16.9
ENO 12-3006	62	125	2.95	1.66	58.5	54.5	37.2	17.3	13.9
ENO 14-1014	61	126	2.69	1.58	61.8	49.7	27.1	22.7	16.3
ENO 15-1015	56	130	2.63	1.64	66.5	62.0	25.6	36.4	17.8
ENO 15-2032	56	127	2.70	1.67	79.1	61.8	33.5	28.4	15.0

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Variety/line/ progeny	Days to heading	Days to maturity	Plant height (m)	Stalk diameter (cm)	Unstripped stalk yield (t ha^{-1})	Stripped stalk yield (t ha^{-1})	Juice yield (t ha^{-1})	Bagasse weight (t ha^{-1})	Brix (%)
ENO 16-1016	61	130	2.44	1.70	95.1	65.3	31.8	33.5	19.7
ENO 16-2002	63	130	2.58	1.57	84.6	59.2	30.0	29.1	19.9
ENO 16-3004	54	130	2.33	1.53	64.1	51.6	26.6	25.1	20.9
ENO 17-1017	61	127	2.59	1.46	62.2	49.2	26.7	22.5	15.2
ENO 17-2017	58	130	2.56	1.57	65.4	47.7	26.0	21.8	16.9
ENO 17-3022	60	130	2.54	1.62	67.9	47.2	24.0	23.2	17.1
ENO 21-2015	61	130	2.45	1.73	82.9	41.7	30.2	11.5	18.9
ENO 21-3008	61	130	2.45	1.59	67.9	45.7	24.0	21.7	18.9
ENO 22-2013	63	127	2.39	1.77	53.7	45.2	23.1	22.1	18.8
ENO 26-1026	61	127	2.51	1.62	64.2	49.2	24.1	25.1	17.3
ENO 26-2039	61	130	2.41	1.69	71.4	61.3	22.7	38.5	18.9
ENO 28-2005	59	127	2.60	1.77	72.5	50.4	25.5	24.9	14.7
ENO 29-2023	61	127	1.97	2.04	70.1	51.0	25.0	25.9	18.7
ENO 32-2012	61	127	1.90	2.20	67.7	55.4	28.6	26.7	16.2
ENO 32-3033	62	127	1.84	1.80	73.2	62.4	15.8	46.6	16.6
ENO 35-2034	62	127	2.89	1.67	55.7	47.4	27.6	19.8	16.7
ENO 35-3088	53	127	2.56	1.71	69.4	59.3	35.3	24.0	18.1
ENO 39-1039	61	127	2.78	1.75	85.4	45.5	29.6	15.9	18.6
ENO 39-2008	61	127	2.60	1.91	83.6	70.0	34.8	35.2	18.7
ENO 41-1041	69	127	2.180	2.05	91.5	55.2	27.4	27.8	14.8
ENO 41-2024	66	127	2.28	1.83	75.2	58.0	32.1	25.9	17.1
SP 4511-2	-	-	2.90	1.60	83.7	52.2	26.2	26.0	21.7
SP 4504-2	-	-	3.17	1.80	73.9	41.2	25.4	15.8	18.9
SPV 1411	-	-	3.16	2.00	79.7	48.7	25.9	22.8	15.9

[1]Selection was done on the basis of high sugar content (at least 15% Brix) and juice yield of at least 18 t ha^{-1}. ENO 12-3006 was selected because of its high juice yield.

6. Multilocation Varietal Trials

Two sets of multilocation trials were conducted. One set under the project on *Performance evaluation of sweet sorghum lines for bio-ethanol and grains under different ecological zones* supported by DOST-PCARRD was conducted by seven SUCs. The second set was funded by DA-BAR and the trials were conducted by IARCs of regional field units of DA. The DOST-PCARRD trials were coordinated by MMSU as lead agency. The collaborators were:

- University of the Philippines Los Baños, College of Agricuture – La Granja
- (UPLBCA-LG)/La Carlota City, Negros Occidental
- Pangasinan State University (PSU), Maria, Pangasinan
- Isabela State University (ISU), Echague, Isabela
- Tarlac College of Agriculture (TCA), Camiling, Tarlac
- Central Mindanao University (CMU), Musuan, Bukidnon
- University of the Philippines Los Baños (UPLB), College, Laguna

SPV 422 recorded the highest stalk yield at MMSU, UP La Granja and TCA while ICSV 700 was best at UPLB and PSU. ICSV 93046 performed better at ISU. Stalk yield of over 40 t ha^{-1} was recorded at three locations, namely, PSU, TCA and ISU, making it the best suited to these regions. SPV 422 recorded the highest juice yield at MMSU (26.33 t ha^{-1}), UP La Granja (7.93 t ha^{-1}) and TCA (22.51 t ha^{-1}). While ICSV 93046 performed better at UPLB (8.41 t ha^{-1}), ISU (18 t ha^{-1}) and CMU (11.24 t ha^{-1}), ICSV 700 was best at PSU (43.49 t ha^{-1}). SPV 422 recorded the highest Brix at UP La Granja (12.05%) and TCA (21.82%), while ICSV 93046 performed better at PSU (22.27%) and ISU (16.3%). ICSV 700 recorded the best Brix at MMSU (14.95%), UPLB (15.32%) and CMU (16.63%). In the case of grain yield, SPV 422 performed better at UP La Granja (4.05 t ha^{-1}), PSU (3.23 t ha^{-1}) and TCA (4.05 t ha^{-1}), while ICSR 93034 stood first at MMSU (5.55 t ha^{-1}) followed by CMU (4.05 t ha^{-1}) and UPLB (3.98 t ha^{-1}). The location mean for grain yield was best at MMSU. Table 6, described in the Chapter II, summarizes the varietal performance for stripped stalk yield (t ha^{-1}) and grain yield in main and ratoon crops. SPV 422 was found to be the highest stalk-yielding line in both main (55−60 t ha^{-1}) and ratoon crops (57−65 t ha^{-1}) with a Brix of 19%, exceeding all the tested entries. All the varieties evaluated in the study recorded highest stalk yield in the ratoon crop, probably due to coincidence of dry season with more degree days and differential temperatures. ICSV 93046 recorded the lowest Brix of 15% among the tested lines. Aphids among insect pests and leaf blight among diseases were the most important biotic stresses that affected the varieties. Also, the varieties tended to lodge due to tallness, heavy rains and wind.

Since SPV 422 consistently recorded high stripped stalk yield and Brix (Layaoen et al. 2007 and 2009), it can be considered a promising sweet sorghum variety adapted to the Philippines, pending confirmation of data from large-scale trials in 2010–11.

The International Sweet Sorghum Elite Varieties and Restorers Trial (ISSEVRT) consisting of 20 varieties/R-lines was evaluated in three replicated trials. Sugar yield among the varieties ranged from 1.64 to 3.58 t ha^{-1} (mean 2.59 t ha^{-1}). ICSV 700 was the best performing variety for sugar yield (3.58 t ha^{-1}) followed by SP 4495 (3.26 t ha^{-1}), SP 4484-2 (3.10 t ha^{-1}), NTJ 2 (3.04 t ha^{-1}) and Ent 64DTN (3.03 t ha^{-1}). Among these top five varieties, plant height ranged from 2.4–3.1 m, Brix ranged from 12.9% to 17.9% and grain yield ranged from 3.25–4.76 t ha^{-1}. However, ICSV 700 was highly susceptible to lodging (Table 12).

7. Early Hybrid Trials

The trials were undertaken by UPLB in collaboration with ICRISAT. Three sets of hybrids were evaluated in this project: (1) 19 first sent by ICRISAT; (2) 53 sent later by ICRISAT as part of its regular international trial; and (3) 62 produced by UPLB from A- and R-lines imported from ICRISAT.

Initially, 19 sweet sorghum hybrids obtained from ICRISAT were evaluated in wet and dry seasons of 2007 and 2008 in UPLB and Tayug, Pangasinan. In UPLB, the experiment was laid out in a Randomized Complete block design (RCBD) in single rows. Standard crop management practices were followed. Observations were recorded on days to flowering, plant height, stalk weight, stripped stalk weight, stalk diameter, panicle length, 100-seed weight, fresh grain weight, moisture content, juice volume, juice weight and Brix. Highly significant variation among hybrid cultivars was observed for plant height, stalk weight, stripped stalk weight, juice volume, juice weight, grain yield, bagasse yield, Brix and sugar yield. In terms of panicle length, stalk diameter, 100-seed weight and moisture content, no significant variation was observed.

Table 12. Performance of ICRISAT varieties in the International Sweet Sorghum Elite Varieties and Restorers Trial (ISSEVRT) at MMSU, Ilocos Norte, the Philippines, 2008.

Variety	Stripped stalk weight (t ha^{-1})	Juice weight (t ha^{-1})	Plant height (m)	Stalk diameter (cm)	Brix (%)	Stillage weight (t ha^{-1})	Lodging score*	Grain yield (t ha^{-1})	Sugar yield (t ha^{-1})
ICSV 700	48.67	25.38	3.14	1.20	14.1	23.29	5	3.35	3.58
SP 4495	46.00	21.17	3.01	1.25	15.4	24.83	3	3.35	3.26
SP 4484-2	49.33	24.00	3.09	1.40	12.9	25.34	4	3.25	3.10
NTJ 2	36.33	17.60	2.53	1.12	17.3	18.73	2	4.76	3.04
Ent 64DTN	36.00	16.92	2.42	1.19	17.9	19.08	2	3.37	3.03
S 35	39.33	19.66	2.48	1.28	15.2	19.67	1	5.86	2.99
ICSV 93046	39.00	19.43	2.89	1.18	14.9	19.57	5	-	2.90
ICSR 165/ SPV 42	42.33	19.66	2.89	1.23	14.1	22.67	2	4.91	2.77
SP 4511-2	35.67	16.37	2.80	1.11	16.2	19.29	3	2.91	2.65
SP 4487-3	47.00	21.49	3.05	1.27	12.3	25.51	5	6.29	2.64
SS 2016	39.67	17.83	2.76	1.23	14.2	21.83	4	3.55	2.53
E 36-1	28.00	13.26	2.17	1.04	17.9	14.74	1	3.74	2.37
SP 4504-1	41.67	20.12	3.37	1.19	11.5	21.55	4	3.90	2.31
SP 4511-3	31.67	15.09	2.76	1.06	14.5	16.58	3	3.02	2.19
ICSR 93034	36.33	17.37	2.66	1.06	12.1	18.96	4	4.72	2.10
104 GRD	37.67	10.75	3.27	1.23	19.4	26.92	1	3.60	2.09
SP 4484-3	40.67	18.75	3.08	1.13	10.6	21.92	4	4.15	1.99
IS 23526	39.33	16.23	2.86	1.14	11.9	23.10	4	2.81	1.93
IS 2331	33.33	13.71	3.01	1.11	14.0	19.62	4	3.04	1.92
SPV 1411	24.67	11.34	2.73	0.99	14.5	13.33	4	-	1.64
Mean	38.63	17.81	2.85	1.17	14.5	20.83	3	3.92	2.59

* Measured on a 1-5 scale, where 1=no lodging and 5=severe lodging.

ICSA 24001 × SPV 1411 was tallest at 3.9 m while ICSA 24001 × SPV 422 was the shortest at 2.6 m. Thirteen of the 19 hybrids were taller than 3 m. Stalk diameter showed no significant differences among sweet sorghum hybrids tested. The highest diameter, however, was observed for ICSA 24001 × SPV 1411 (2.3 cm) while ICSA 89002 × ICSV 700 had the lowest stalk diameter (1.2 cm). Seven of the hybrids had greater value than the mean stalk diameter of 1.6 cm. The five highest grain-yielding hybrids were ICSA 89002 × SSV 74 (5.1 t ha^{-1}), ICSA 702 × SSV 74 (5.1 t ha^{-1}), ICSA 675 × Ent 64DTN (5 t ha^{-1}), ICSA 511 × SSV 74 (4.2 t ha^{-1}) and ICSA 502 × SPV 422 (4 t ha^{-1}) (Table 13). Ten of the hybrids had grain yield greater than the mean grain yield at 2.9 t ha^{-1}. Very high coefficient of variation (33.5%) for grain yield was due to bird damage and continuous heavy rains at the time of harvest. Highly significant differences were observed for stalk yield and stripped stalk yield. ICSA 502 × ICSV 700 had the highest stalk yield of 75 t ha^{-1} and stripped stalk yield of 65.5 t ha^{-1}. Ten of the hybrids recorded stalk and stripped stalk yield greater than the mean at 45.9 and 38.6 t ha^{-1}, respectively.

The same trend was observed for bagasse yield. Juice weight ranged from 5.0 to 33.0 t ha^{-1}. Eleven of the hybrids showed juice weight greater than the mean at 18.9 t ha^{-1}. Brix reading showed significant difference among sweet sorghum hybrids. It varied from 3.9% in ICSA 502 × SSV 74 to 12.8% in ICSA 511 × ICSV 700. Nine of the hybrids showed higher Brix readings than the mean at 7.6%. Sugar yield ranged from 0.34 t ha^{-1} (ICSA 24001 × SSV 74) to 2.42 t ha^{-1} (ICSA 511 × ICSV 700). The six highest sugar yielders were ICSA 511 × ICSV 700 (2.42 t ha^{-1}), ICSA 502 × ICSV 700 (2.24 t ha^{-1}), ICSA 675 × ICSV 700 (2.01 t ha^{-1}), ICSA 38 × ICSV 700 (1.67 t ha^{-1}), ICSA 89002 × SSV 74 (1.38 t ha^{-1}) and ICSA 675 × SSV 74 (1.23 t ha^{-1}). Studies on character association indicated that traits that were very strongly correlated with sugar yield were stalk yield (0.83), stripped stalk yield (0.81), bagasse yield (0.82) and juice weight (0.81). Grain yield and panicle length showed negative correlation with sugar yield but it was not significant. Moderate positive correlation was observed with plant height. Stalk diameter had weak positive correlation with sugar yield. Sugar yield was moderately positively correlated (0.56) with Brix.

The International Sweet Sorghum Elite Hybrids Trial (ISSEHT) consisting of 53 hybrids was planted in the first week of September 2008 and harvested in the last week of December 2008. Sugar yield in the 53 hybrids

Table 13. Performance of sweet sorghum hybrids evaluated for sugar yield and related traits, UPLB, College Laguna, the Philippines, 2008.

Cultivars	Plant height (m)	Stalk yield (t ha^{-1})	Stripped stalk yield (t ha^{-1})	Bagasse yield (t ha^{-1})	Juice weight (t ha^{-1})	Brix (%)	Sugar yield (t ha^{-1})	Grain yield (t ha^{-1})
ICSA 38 × ICSV 700	3.6	59	48.8	23.4	23.5	9.8	1.7	1
ICSA 102 × SPV 422	2.9	41.5	33.2	15.7	16.7	4.9	1	3.7
ICSA 502 × SSV 74	3.4	44	39.2	16.7	20.3	3.9	0.8	3.9
ICSA 502 × SPV 422	2.8	50.3	42.5	19.7	22	5.1	1.1	4
ICSA 502 × ICSV 700	3.7	75	65.5	31	32.8	10.5	2.2	2.5
ICSA 511 × ICSV 700	3.5	71.3	64	28.8	31.3	12.8	2.4	2.2
ICSA 511 × SSV 74	3.3	47.3	39.5	17.3	19.7	5.2	1.1	4.2
ICSA 675 × SPV 1411	3.1	30.5	26.5	12.8	11.7	9.3	0.9	3.8
ICSA 675 × ICSV 700	3.3	58.8	50.8	22.8	25.2	11.8	2	0.8
ICSA 675 × Ent 64DTN	2.9	46.2	38.7	17.5	19.7	5.1	1.2	5
ICSA 675 × SSV 74	3.5	43.3	38.3	18	21	4.9	1.2	3
ICSA 702 × SSV 74	3.3	52	43.5	19	22.5	4.9	1.1	5.1
ICSA 24001 × ICSR 93036	3.5	40.2	30.7	15.2	13.5	9.5	1	1.5
ICSA 24001 × SSV 74	2.7	14	11.3	5.5	5	8.5	0.3	1.5
ICSA 24001 × SPV 422	2.6	40	29.3	14.5	13.2	7.3	0.7	2.2
ICSA 24001 × SPV 1411	3.9	47.8	37.3	19.2	17.2	8.3	0.8	1.5
ICSA 89002 × ICSV 700	3.2	34.3	28.8	14.3	13	10.3	1	1.8
ICSA 89002 × SPV 422	3.3	31.2	26.5	12.5	12.2	5.8	0.6	3
ICSA 89002 × SSV 74	3	45.8	38.7	18	19.3	6.2	1.4	5.1
Mean	3.2	45.9	38.6	18	18.9	7.6	1.2	2.9
CV%	6.9	19	19.3	22.4	21.7	31.6	37	33.5

ranged from 1.46–4.05 t ha^{-1} (Table 14). Nine hybrids yielded above 3.0 t ha^{-1}. The best performing hybrid for sugar yield was ICSA 516 × SPV 422 (4.05 t ha^{-1}) followed by ICSA 675 × ICSV 93046 (3.84 t ha^{-1}) and ICSA 95 × E 36-1 (3.59 t ha^{-1}). ICSA 675 × ICSV 93046 recorded the highest grain yield (6.72 t ha^{-1}) followed by ICSA 702 × SSV 84 (6.70 t ha^{-1}) and ICSA 731 × NTJ 2 (6.52 t ha^{-1}). The top nine hybrids matured in 92–114 days, reaching a height of 2.78–3.14 m. Brix among them varied from 12.6% to 16.4%.

Sixty-two preliminary hybrids produced by UPLB involving crosses of A- and R-lines from ICRISAT were evaluated in a preliminary hybrid trial with two replications between September and December 2009. The trial was hit by two typhoons, Pepe and Santi. The latter struck during the plant's vegetative phase, affecting crop stand. However the hybrids recovered well. The best performing entries for sugar yield were ICSA 749 × ICSV 93046, ICSA 84 × ICSV 93046, ICSA 502 × ICSV 700, ICSA 95 × SPV 1411, ICSA 38 × ICSV 93046 and ICSA 675 × SPV 1411.

8. Screening for Pests and Diseases

The materials received from ICRISAT were screened for several pests and diseases. Sixty varieties received from ICRISAT were screened for phalacrid beetle (*Phalacrinus rotundus*), corn sap beetle (*Carpophilus dimidiatus*) and maize weevil (*Sitophilus zeamais*) at MMSU in 2006–07 (Table 15). Majority of the entries were found to be tolerant to these pests. ICSV 93046, ICSV 700, S 35, SSV 53629, RSSV 106, GD-65081 and Ent DTN64 were free from infestation of the three insect pests.

The same set of varieties were screened for Fusarium blotch, Helminthosporium leaf blotch, rust and kernel mold. Seven entries did not show any symptoms of Fusarium and Puccinia spp. infection. Seven lines were not infected with Helminthosporium leaf blotch and 9 were free from mold (Table 16). The resistant lines against Fusarium blotch and rust were IS-21260, IS-2331, NSS 254 622, SS 20163 837, SP 6506-1 637, and SP 6511-2 614. The identified tolerant lines against Helminthosporium leaf blotch were M35-1, SP 6506-3 612, ICSR 93034, IS-23526 620, ICSR 56, GD-65080, and ICSV 86020. Those not infected with kernel mold were IS-21260, ICSV 700, SPC 511-3 615, Ent 64DTN, SP 6685610, SP 506-3 612 and NTJ 2.

Table 14. Performance of ICRISAT hybrids in the International Sweet Sorghum Elite Hybrids Trial (ISSEHT), MMSU, the Philippines, 2008.

Hybrid	Days to maturity	Plant height (m)	Cane weight (t ha^{-1})	Juice weight (t ha^{-1})	Brix (%)	Panicle length (cm)	Grain yield (t ha^{-1})	Lodging score[1]	Sugar yield (t ha^{-1})
ICSA 516 × SPV 422	92	2.97	52.67	25.10	16.1	24.80	5.90	3	4.05
ICSA 675 × ICSV 93046	113	2.98	60.33	23.89	16.1	26.32	6.72	5	3.84
ICSA 95 × E 36-1	114	2.89	48.33	22.18	16.2	22.77	3.10	5	3.59
ICSA 749 × NTJ 2	93	2.83	47.67	22.00	15.7	28.00	4.27	5	3.46
ICSA 475 × SSV 84	103	3.12	48.00	20.36	16.4	21.17	4.07	5	3.34
ICSA 24001 × ICSR 93034	103	2.80	43.67	26.17	12.6	23.59	6.17	4	3.30
ICSA 285 × SSV 74	103	2.78	47.33	21.09	14.9	24.04	5.12	4	3.14
ICSA 731 × NTJ 2	113	2.78	45.33	19.16	16.3	22.38	6.52	4	3.13
ICSA 502 × SSV 84	101	3.14	47.33	18.63	16.4	20.86	4.18	5	3.05
ICSA 731 × ICSV 700	103	3.14	46.67	21.95	13.4	19.35	5.41	4	2.94
ICSA 702 × SSV 84	112	3.02	48.67	19.68	14.9	24.94	6.70	3	2.93
ICSA 475 × Ent 64DTN	102	3.17	45.00	20.59	14.0	22.03	4.44	4	2.88
ICSA 324 × NTJ 2	93	2.99	45.33	19.12	14.9	25.56	5.40	5	2.84
ICSA 502 × SSV 74	90	2.93	40.67	18.06	15.6	24.16	5.25	5	2.82
ICSA 702 × E 36-1	92	2.67	35.00	15.90	17.2	23.85	3.93	4	2.73
ICSA 474 × SPV 422	112	2.97	38.83	15.44	16.9	19.81	3.81	5	2.60
ICSA 502 × ICSV 700	123	3.20	43.67	18.34	13.8	19.04	3.97	4	2.53
ICSA 731 × ICSV 93046	102	3.05	46.00	18.26	13.7	21.70	4.22	5	2.50
ICSA 749 × SSV 74	91	3.04	38.00	15.69	15.7	26.12	5.01	5	2.47

Contd...

Contd...

Hybrid	Days to maturity	Plant height (m)	Cane weight (t ha^{-1})	Juice weight (t ha^{-1})	Brix (%)	Panicle length (cm)	Grain yield (t ha^{-1})	Lodging score[1]	Sugar yield (t ha^{-1})
ICSA 479 × Ent 64DTN	91	3.06	42.33	18.82	12.9	22.87	4.73	4	2.43
ICSA 749 × ICSV 93046	102	3.15	40.67	16.81	14.5	25.05	6.03	5	2.43
ICSA 324 × SSV 74	104	2.93	43.33	16.68	14.5	24.78	5.93	5	2.41
ICSA 102 × SSV 84	112	3.14	38.50	16.15	14.5	22.63	4.82	5	2.34
ICSA 675 × SPV 1411	102	2.98	40.67	15.68	14.7	23.75	5.08	5	2.30
ICSA 38 × ICSV 93046	102	2.99	36.00	15.14	15.1	22.26	5.18	4	2.28
ICSA 95 × SSV 74	113	3.12	38.50	14.25	15.7	22.49	4.39	4	2.23
ICSA 724 × SPV 422	92	2.94	39.33	17.44	12.7	21.86	4.38	4	2.22
ICSA 89002 × SPV 422	92	2.85	39.33	15.77	13.8	25.41	6.19	5	2.18
ICSA 702 × SSV 74	92	3.03	39.33	16.44	13.1	24.64	5.84	5	2.16
ICSA 474 × SSV 74	93	2.65	35.00	14.95	14.4	23.65	4.97	4	2.15
ICSA 24001 × SSV 74	91	3.12	36.00	15.19	13.9	22.86	4.94	5	2.11
ICSA 474 × NTJ 2	92	2.91	35.33	14.58	14.4	24.80	5.62	5	2.10
ICSA 344 × E 36-1	89	2.74	33.67	15.00	13.7	23.64	5.27	4	2.06
ICSA 102 × E 36-1	92	2.78	32.67	14.80	13.5	23.16	5.18	5	2.00
ICSA 38 × NTJ 2	93	3.05	39.00	16.82	11.9	24.58	5.26	5	2.00
ICSA 475 × E 36-1	93	2.84	32.00	15.55	12.7	24.45	4.60	5	1.98
ICSA 474 × E 36-1	94	2.95	36.33	16.89	11.7	23.94	4.73	5	1.97
ICSA 702 × ICSV 93046	105	2.83	35.17	14.64	13.2	24.44	6.16	5	1.93

Contd...

Contd...

Hybrid	Days to maturity	Plant height (m)	Cane weight (t ha^{-1})	Juice weight (t ha^{-1})	Brix (%)	Panicle length (cm)	Grain yield (t ha^{-1})	Lodging score[1]	Sugar yield (t ha^{-1})
ICSA 479 × SPV 422	92	2.96	39.00	17.59	10.9	23.94	5.55	5	1.92
ICSA 479 × SSV 84	91	3.16	38.67	15.98	11.9	24.89	4.27	4	1.91
ICSA 502 × SPV 422	102	2.74	38.50	17.32	10.9	25.79	4.78	3	1.89
ICSA 479 × SSV 74	102	3.02	34.67	13.39	13.9	24.26	3.27	5	1.87
ICSA 675 × ICSV 700	112	3.28	36.00	13.78	13.1	21.06	4.49	3	1.81
ICSA 84 × Ent 64DTN	91	2.96	33.67	14.66	12.1	21.86	5.14	5	1.78
ICSA 38 × SSV 74	103	2.92	29.67	12.62	13.9	22.55	3.79	5	1.76
ICSA 95 × SPV 1411	103	2.99	37.33	14.35	11.5	23.96	6.19	5	1.65
ICSA 38 × SPV 422	93	2.87	36.17	15.30	10.1	23.33	4.36	5	1.55
ICSA 95 × ICSV 700	123	3.20	40.00	13.42	11.4	20.48	3.83	3	1.53
ICSA 38 × ICSV 700	112	2.99	34.00	14.04	10.7	21.85	3.04	5	1.51
ICSA 84 × ICSV 93046	103	2.88	31.00	14.47	10.4	22.86	4.93	3	1.50
ICSA 84 × E 36-1	92	2.84	30.00	12.60	11.9	24.38	4.50	5	1.50
ICSA 38 × E 36-1	103	2.83	31.33	12.79	11.5	22.75	5.09	4	1.47
ICSA 474 × ICSR 93034	91	2.79	28.33	12.52	11.7	24.68	4.61	4	1.46

[1] Measured on a 1-5 scale, where 1=no lodging and 5=severe lodging.

Table 15. Population density of the phalacrid beetle (*Phalacrinus rotundus*), corn sap beetle (*Carpophilus dimidiatus*) and maize weevil (*Sitophilus zeamais*) in ICRISAT-bred varieties, MMSU, the Philippines, 2006–2007.

Varieties	Insect pest			Varieties	Insect pest		
	Phalacrid beetle	Corn sap beetle	Maize weevil		Phalacrid beetle	Corn sap beetle	Maize weevil
CSV 15	0	22.00	1.33	SP 6685610	20.33	17.00	0
CSV 79	3.33	14.67	0.67	CSV 17	0	1.33	0
SSV 84	15.00	0	0	SP 6506-3 612	0	6.33	0
SP 6681-1 602	0	0	0	NTJ 2	0	11.00	0
ICSV 93046	0	0	0	SP 6506-1 637	0	6.00	0
SP 6686-1 606	0	0	0	SP 6511-2 614	9.33	4.67	0
IS-21260	17.67	0	5.00	ICSR 83034	0.67	5.00	0
S 35	0	0	0	IS-23526 620	0	3.00	0
IS-2331	4.33	0	1.33	ICSR 186	0	2.00	0
SP 6687-1 608	9.33	0	0	GD-65052	0	12.00	0
ICSV 700	0	0	0	ICSR 56	3.33	4.00	0
NSSH 104	2.33	0	0	GD-65080	0	0.67	2.00
SP 6686-3 607	0.67	0	0	GD-65081	0	0	0
M35-1	10.67	0	0	ICSV 700	0.67	3.67	0
E 36-1	0	13.33	0	ICSR 88015	0.67	13.67	1.00
NSS 254 622	0	6.00	2.00	ICSR 88010	1.00	4.33	0
ICONDEE	0.67	1.00	0	ICSR 83001	0	0	0.33
SP 6682-1 604	3.33	0	0.33	ICSV 86004	0.67	1.67	1.00
SP 6686-2 636	0	0	1.67	ICSB 383	7.00	16.67	3.33
SSV 53629	0	0	0	ICSV 112	0	11.33	1.33
SPC 1411	0.67	0.33	0.33	ICSV 85032	0	0.33	0.33
SPC 511-3 615	0.67	2.00	0	ICSV 86135	0	10.33	1.33
SP 6 504-2 611	10.67	0	0	ICSV 86020	4.00	13.33	1.00
SP 6687-3 609	1.00	0	0.33	ICSR 88058	0	0.67	1.33
SP 4481-2 603	7.33	15.00	0	ICSB 627	0	0	1.67
SP 6682-2 605	0	2.67	1.33	E 36-1	1.33	14.67	0
ICSR 165 617	8.33	0	0	A2267-2	0	3.00	0
SS-20 163 837	0	0	1.67	ICSV 861 36	0.67	4.33	0
IS-7266 151	2.00	0	0	ICSB 81002	11.67	10.00	6.33
RSSV 106 621	0	0	0	Ent 64DTN	0.33	0	0

During February-May 2008, UPLB evaluated the disease reaction of 19 sweet sorghum hybrids to four diseases – Rhizoctonia sheath blight (RSB), tar spot, Helminthosporium leaf spot (HLS) and bacterial stalk rot (BSR). Ten hybrids exhibited moderate resistance to RSB while the rest were moderately susceptible (Table 17). Only one hybrid, ICSA 502 × SSV 74, showed moderate resistance to tar spot while 7 others were susceptible. In terms of resistance to HLS and BSR, 6 and 7 hybrids, respectively, were moderately resistant and the rest were moderately susceptible. ICSA 502 × SSV 74 was moderately tolerant to RSB, BSR and tar spot but moderately susceptible to HLS. Further evaluation of newly generated hybrids is necessary to identify high sugar-yielding hybrids with moderate resistance to prevailing diseases.

A poster on insect pests and diseases of sweet sorghum was presented in an R&D review meeting held at MMSU (Fig. 13). Two handbooks on pest management: *A field guide in identifying diseases infecting sweet sorghum* and *A field guide in identifying insect pests infesting sweet sorghum* were published by MMSU-PCARRD to guide researchers and farmers (Fig. 14).

Figure 13. A poster on sweet sorghum pests and diseases.

Figure 14. Field guides for the easy identification of pests and diseases in sweet sorghum.

Table 16. Disease incidence in ICRISAT sweet sorghum varieties, MMSU, the Philippines, 2006–2007.

Varieties	Disease				Varieties	Disease			
	Fusarium blotch	Helminthosporium leaf blotch	Rust	Kernel mold		Fusarium blotch	Helminthosporium leaf blotch	Rust	Kernel mold
CSV 15	60	0	0	1	SP 6685610	90.5	0	0	0
CSV 79	80	0	0	12.2	CSV 17	50.5	0	0	0
SSV 84	80	0	0	0.6	SP 6506-3 612	20	0	0	0
SP 6681-1 602	80	0	0	8.2	NTJ 2	40	0	0	0
ICSV 83046	60	0	0	2	SP 6506-1 637	0	90.5	0	0.4
SP 6686-1 606	80	0	0	8.2	SP 6511-2 614	0	25.5	0	8.2
IS-21260	0	80	0	0	ICSR -83034	5.5	0	0	1
S 35	80	0	0	10	IS-23526 620	10	0	0	6.4
IS-2331	0	80	0	0.4	ICSR 186	5.5	0	0	14.4
SP 6687-1 608	90.5	0	0	2.8	GD 65052	70.5	0	0	4.6
ICSV 700	80	0	0	0	ICSR 56	5.5	0	0	6.4
NSSH 104	80	0	0	14.6	GD 65080	25.5	0	0	16.2
SP 6686 -3 607	80	0	0	8	GD 65081	10	0	0	18.2
M35-1	0	0	90.5	16	ICSV 700	40	0	0	1
E 36-1	0	60	90.5	1	ICSR 88015	30	0	0	10.2
NSS 254 622	0	70.5	0	2.8	ICSR 88010	30	0	0	50

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Varieties	Disease				Varieties	Disease			
	Fusarium blotch	Helminthosporium leaf blotch	Rust	Kernel mold		Fusarium blotch	Helminthosporium leaf blotch	Rust	Kernel mold
ICONDEE	90.5	0	0	0.8	ICSR 83001	30	0	0	1
SP 6682 -1 604	90.5	0	0	2.8	ICSV 86004	60	0	0	80
SP 6686 -2 636	50.5	0	0	34.2	ICSB 383	40	0	0	1
SSV 53629	40	0	0	0.6	ICSV 112	25.5	0	0	18.4
SPC 1411	90.5	0	0	0.4	ICSV 85032	10	0	0	66
SPC 511-3 615	90.5	0	0	0	ICSV 86135	20	0	0	38.2
SP 6504 -2 611	90.5	0	0	0.2	ICSV 86020	20	0	0	10.2
SP 6687-3 609	90.5	0	0	10.4	ICSR 88058	35.5	0	0	26.2
SP 4481-2 603	25.5	90.5	0	46	ICSB 627	60	0	0	48
SP 6682 -2 605	90.5	0	0	3.4	E 36-1	0	50.5	0	1
ICSR 165 617	40	0	0	6.2	A2267-2	10	0	0	0
SS-20 163 837	0	70.5	0	1	ICSV 861 36	50.5	0	0	92
IS-7266 151	0	60	50.5	4	ICSB 81002	90.5	0	0	86
RSSV 106 621	50.5	0	0	10	Ent 64DTN	90.5	0	0	0

Table 17. Reaction of hybrids to diseases[1] under natural infection at UPLB, College of Agriculture, Laguna, the Philippines, 2008.

Hybrid	Rhizoctonia sheath blight	Tar spot	Helminthosporium leaf spot	Bacterial stalk rot
ICSA 38 × ICSV 700	3	3	2	2
ICSA 102 × SPV 422	2	3	-	3
ICSA 502 × SSV 74	2	2	3	2
ICSA 502 × SPV 422	3	3	2	3
ICSA 502 × ICSV 700	3	4	3	2
ICSA 511 × ICSV 700	2	4	3	-
ICSA 511 × SSV 74	2	3	2	-
ICSA 675 × SPV 1411	3	3	2	2
ICSA 675 × ICSV 700	2	3	3	2
ICSA 675 × Ent 64DTN	3	4	3	-
ICSA 675 × SSV 74	2	3	3	2
ICSA 702 × SSV 74	3	3	3	-
ICSA 24001 × ICSR 93034	3	4	2	3
ICSA 24001 × SSV 74	2	3	3	2
ICSA 24001 × SPV 422	3	4	3	-
ICSA 24001 × SPV 1411	2	4	3	-
ICSA 89002 × ICSV 700	3	3	3	3
ICSA 89002 × SPV 422	2	3	3	3
ICSA 89002 × SSV 74	2	4	2	-

[1]Disease score: 1=resistant, 2=moderately resistant, 3=moderately susceptible, 4=susceptible, and 5=highly susceptible.

9. Juice Extraction and Fermentation Studies

A tandem mill/crusher is required to fully extract juice and sugars from sweet sorghum stalks. Those currently available in the country are used in sugar processing plants and are too expensive to operate for small-scale studies such as evaluating individual varieties/hybrids. Hence, a three-roller crusher was developed at the College of Engineering and Agricultural Technology of UPLB in cooperation with MMSU, suitable for village-level sweet sorghum processing. Matured stalks were harvested and immediately crushed to extract juice. Brix was measured using a refractometer; it ranged between 16 and 21%. The juice obtained was pasteurized at 60°C for 30 minutes and was either fermented at once or heat treated to form jaggery. Heat treatment at 100°C lasted an hour for the juice to form jaggery. The amount of alcohol produced as first generation ethanol from the juice and jaggery ranged from 9–12% v/v using locally isolated micro-organisms. Though all the varieties used are potential sources of ethanol, it is of paramount importance to consider the initial Brix of the juice as it determines the amount of fermentable sugars and eventually the amount of ethanol produced.

Bagasse was also used as raw material for second generation (cellulosic) bio-ethanol production (Hicks 2007). Micro-organisms isolated locally were used in the first step to degrade the bagasse and later subjected to fermentation by *Saccharomyces cerevisiae* to realise 1–2% alcohol v/v yield. When a consortium of the isolates was used, 4–5% alcohol v/v was obtained and there was no need for more *Saccharomyces cerevisiae* inoculation. The consortia of organisms can effectively convert biomass to bio-ethanol without a separate saccharification process and the yield ranges from 4–5% alcohol v/v compared to 1–2% for the two-step process that consists of degradation of bagasse and fermentation. The bio-ethanol was separated using a rotary evaporator in series in the laboratory. The system has a recovery of 78–85% hydrous ethanol. Passing the bio-ethanol through a locally available molecular sieve system produced ethanol with 99.5% purity.

Overall, the results showed that sweet sorghum juice, syrup and bagasse can be used as feedstock for bio-ethanol production.

10. Agronomy

The project on *Development/adaptation of appropriate production technologies* was implemented by Domingo Angeles of the UPLB, College of Agriculture, focussing on the development of production technology for sweet sorghum under different agro-ecological zones and conducted at three sites: UP Los Baños, Laguna; La Granja Experiment Station in Negros Occidental, and Central Mindanao University, Musuan, Bukidnon. A total of 15 experiments were conducted.

Periodic planting: 3 trials in Negros Occidental, 2 in Laguna and 2 in Bukidnon. The treatments were: early planting (August–November); medium (December–March) and late planting (April–July).

Planting density: 2 trials in Laguna and 2 in Bukidnon. Treatments: S1 –133,868 (90 cm × 8.3 cm); S2 – 176,366 (90 cm × 6.3 cm); S3 – 160,642 (75 cm × 8.3 cm) and S4 – 211,640 (75 cm × 6.3 cm).

Fertilizer experiment: Two trials each on fertilizer rate in Laguna and Bukidnon (critical N, critical P and critical K). The treatments were:

N1 – 0N	K1 – 0K	P1 -0P
N2 – 30 kg ha^{-1} N	K2 – 20 kg ha^{-1} K	P2 – 20 kg ha^{-1} P
N3 – 60 kg ha^{-1} N	K3 – 40 kg ha^{-1} K	P3 – 40 kg ha^{-1} P
N4 – 90 kg ha^{-1} N	K4 – 60 kg ha^{-1} K	P4 – 60 kg ha^{-1} P
N5 – 120 kg ha^{-1} N	K5 – 80 kg ha^{-1} K	P5 – 80 kg ha^{-1} P
N6 – 150 kg ha^{-1} N	K6 – 120 kg ha^{-1} K	P6 –120 kg ha^{-1} P

Varieties NTJ 2, ICSV 93046, ICSR 93034, SPV 422 and ICSV 700 were used in periodic planting and plant density experiments while SPV 422 was used in fertilizer experiments.

Region IV is in the island of Luzon and composed of Calabarzon (Region IV-A) and Batangas, Cavite, Quezon, Rizal, Laguna, Lucena City and Mimaropa (Region IV-B); Marinduque, Occidental Mindoro, Oriental Mindoro, Palawan and Romblon. The following activities were undertaken there:

Periodic planting trial: Varieties SPV 422 and ICSV 93046 were found to be promising for sugar yield while NTJ 2 was poor in it.

Plant density trial: Stalk weight, plant height, plant weight, panicle weight, stalk juice yield, stillage yield and juice extraction percentage were not significantly affected by planting distance. SPV 422, ICSV 700 and ICSV 93046 had higher stalk weight, juice volume, and total soluble solids (TSS). Highest Brix of 11.83% was observed in ICSV 700.

Fertilizer experiment: Higher levels of N and uniform levels of P and K consistently resulted in better plant height, stalk weight, juice and Brix. Application of 150 kg N improved Brix to 12.9%, but was not significantly different from 30, 60, 90, and 120 kg N. Critical N is yet to be determined. Phosphorus has no significant impact on plant growth and juice yield. K did not significantly affect plant growth and yield except for Brix.

Region VI is in the Visayas islands composed of the provinces of Aklan, Antique, Bacolod City, Capiz, Guimaras, Iloilo, Iloilo City and Negros Occidental. The following activities were undertaken there:

Periodic planting trial: Periodic planting trial during the wet season showed that ICSV 700 had highest stalk yield among other varieties but did not differ from ICSV 93046, SPV 422 and NTJ 2. Among the entries, NTJ 2 had the lowest Brix percentage. During the dry season, stalk yield was highest in ICSV 700 and ICSV 93046 and juice yield did not vary significantly among varieties. During the dry season, yield increased in late-maturing varieties such as ICSV 700 and ICSV 93046.

Region X is in Northern Mindanao composed of the provinces of Bukidnon, Cagayan de Oro City, Camiguin, Iligan City, Lanao del Norte, Misamis Occidental and Misamis Oriental. The following activities were undertaken there:

Periodic planting trial: ICSV 93046 and ICSV 700 varieties had high stalk yield, stripped stalk juice volume and weight with relatively higher grain yield. However, these varieties have delayed maturity, high lodging characteristics, relatively lower Brix and poor appearance. SPV 422 holds potential because of its least lodging due to its height. It has a short maturity period, good grain yield, higher juice weight and high sugar content.

Plant density trial: Growing sweet sorghum at a higher density of 211,640 plants ha^{-1} (75 cm × 6.3 cm) compared to 176,366 plants ha^{-1} (90 cm × 6.3 cm) increased stalk yield.

Fertilizer experiment: Application of 90–120 kg N ha^{-1} improved growth and yield parameters of sweet sorghum. NPK applied at 90:60:60 kg ha^{-1} may improve growth and yield. Tissue analysis of crops will determine the critical nutrient levels for sweet sorghum.

11. Seed Production

The Bungon Seed Producers' Multipurpose Cooperative (BSPMC) multiplied seeds during 2008–09. A total of 38,657 kg of SPV 422 was produced with the support of Anangui Irrigators Association (AIA). However, only 15,433 kg was accepted as seed grade by the DA-BAR/MMSU technical staff; the rest was rejected due to the presence of impurities. Seeds of other varieties were multiplied at MMSU and the same were used in multilocation trials conducted during 2007–08. Seed was treated with an insecticide-fungicide combination, packaged in one kg plastic bags, and stored in a cold room at MMSU.

Large-scale seed production of SPV 422 was done during the dry season of 2008–09 to meet the anticipated demand of investors interested in the commercial cultivation of sweet sorghum. The target area was 5,000 ha. An additional 30,799 kg of seeds was produced by farmer cooperators under the supervision of project staff to ensure varietal purity. Roughing was done at all the stages. Threshing was done by hand to make sure that the grains were not broken or damaged. The seeds were dried to 12% moisture content, treated with insecticide and fungicide, packed in 50-kg plastic bags and then bagged in gunny sacks. Repacking into 1 kg bags was done as per requirement. Planting in large-scale areas was not pursued because sweet sorghum distilleries had not been established as planned due to the global financial meltdown. The seeds were stocked and not sold as feed because they had been chemically treated. This led to a major loss to the cooperative. While large-scale planting did not materialize, seed materials were distributed to government agencies, researchers, farmers, investors, non-government organization and other walk-in clients for small-scale trials. The Provincial Government of Ilocos Sur was the largest recipient of seed, and the crop raised from these was used as fodder.

12. Alternative Uses

Sweet sorghum bagasse was evaluated by the Isabela State University as material for paper production. A study on the *Suitability of sweet sorghum varieties for pulp and paper based on fiber morphology* revealed that SPV 422, ICSR 93034 and NTJ 2 varieties were suitable as paper material based on properties such as fiber length, lustre and dyeability, cell wall thickness, fiber diameter, runkel, flexibility and rigidity ratios.

At the DA-Bicol Integrated Agricultural Research Center (BIARC) in Pili, Camarines Sur, sweet sorghum bagasse and stripped leaves were used to produce bio-organic fertilizer. The composition of the materials used was as follows: sweet sorghum bagasse/stripped leaves–80%; kakawate leaves–5%; chicken droppings–15%; CFA–5 packets and Bio-plus–4 kg.

A diverse array of food products was formulated by BIARC using sweet sorghum grain and juice. The PAC and Bapamin Farmers' Cooperative (BFC) led by Antonio Arcangel developed and promoted food products which were sold during DA-BAR's anniversary celebration (Fig. 15).

On 28 September 2009, Ilocos Sur Governor Hon Deogracias Victor B Savellano invited MMSU sweet sorghum experts to highlight the potential of sweet sorghum as a commercial/industrial crop. Impressed with its potential, Savellano convinced the mayors of sugarcane-producing municipalities in the province to use sweet sorghum juice to produce vinegar and "basi" (wine). The briefing-cum-demonstration of juice extraction and presentation of products was done in San Ildefonso, Ilocos Sur, on 30 September 2009.

Figure 15. Antonio Arcangel, sweet sorghum producer and trader, briefs DA-BAR Director Nicomedes P Eleazar and Assistant Director Teodoro S Solsoloy on sweet sorghum food products during the DA-BAR 2009 National Technology Commercialization Forum and Product Exhibition.

13. Reports and Publications

Reports and publications published by all the R&D organizations involved in sweet sorghum research, development and extension are given in Annexure II.

IV. Capacity Building

1. Workshops and Seminars

To strengthen and expedite institutional development in supporting the sweet sorghum value chain in the Philippines, training, technology promotion and commercialization activities were conducted on a regular basis. To facilitate understanding of sweet sorghum as a new crop, an information brief titled “Frequently Asked Questions” was developed by PCARRD and MMSU for dissemination during seminars, fora, meetings, conferences and other related activities.

In Bicol region, DA-BIARC spearheaded the following activities:

A *Regional sweet sorghum forum* was organized on 22–23 May 2008 to create awareness about sweet sorghum among prospective regional stakeholders. Attended by about 200 participants from local government units (LGUs), SCUs, lending institutions, government entities, representatives from Ateneo de Naga and farmers’ organizations, students and farmers, the forum culminated in the creation of a regional task force composed of representatives from various stakeholder groups in the region. Since then, several meetings and networking/collaborating activities have been organized.

Briefing/consultation seminars were organized to apprise the municipal LGUs of Albay and Camarines Sur. These activities led LGUs to commit to growing sweet sorghum on municipal land.

2. Training, Study Tours and Exploratory Visits to ICRISAT

To widen their horizons and gain a better understanding of the sweet sorghum value chain, sweet sorghum researchers from MMSU, ISU, PAC, UPLB and other institutions have undergone short-term training-cum-study tours at ICRISAT. Heraldo L Layaoen (MMSU) visited ICRISAT five times on various occasions to liaise with sweet sorghum scientists and also participated in the project development, launching and work plans progress review meetings of the ICRISAT-IFAD biofuels project on *Linking the poor to global markets: Pro-poor development of biofuel supply chains*.

Figure 16. *A delegation from the Philippines at Rusni Distilleries Pvt Ltd.*

He visited Rusni Distilleries Pvt Ltd and the Decentralized Crushing Unit (DCU) at Ibrahimbad, Medak district, Andhra Pradesh, India, which serves as a good model for village-level processing of sweet sorghum. Artemio Salazar too paid an exposure visit to ICRISAT to acquaint himself with sweet sorghum genetic enhancement work. Samuel S Franco (MMSU) visited Rusni Distilleries Pvt Ltd and ICRISAT's Agri-Business Incubator (ABI) to learn about the role of these organizations in the sweet sorghum value chain. Several delegations from the Philippines paid exposure visits to Rusni Distilleries Pvt Ltd (Fig. 16).

Thelma Z Layaoen was trained in the commercial production of nuclear polyhedrosis virus (NPV) and pest management research. Two project staff members, namely, Mario I Remolacio and Richard Dar dela Cruz were trained in sweet sorghum improvement, evaluation and seed multiplication at ICRISAT in 2009 (Fig. 17). Two more project staff (Odilon C Caraan and Valentin C Godoy) underwent training during September−October 2009 on screening techniques for pest and diseases and on post-harvest processing.

Odilon C Caraan (MMSU) and Er Marirowena C Tanquilit (PAC) attended the learning course on "Sorghum Hybrid Parents and Hybrids Development and Production" held at ICRISAT during 7–11 February 2011.

Figure 17. *Mario I Remolacio and Richard D dela Cruz being trained in seed multiplication and evaluation of sweet sorghum cultivars at ICRISAT.*

3. National and International Conferences

HL Layaoen attended an awareness workshop on *Clean Development Mechanisms (CDM) in biofuel production*, during 2–3 April 2009 at ICRISAT. He was also speaker at the Consultation on Biofuels (co-sponsored by the Asia Pacific Association of Agricultural Research Institutions (APAARI), International Rice Research Institute (IRRI), International Maize and Wheat Improvement Center (CIMMYT) and ICRISAT; 16th Association of SouthEast Asian Nations (ASEAN) Farmer's Week: Bioenergy and renewable fuel sources; and Biofuels development in Southeast and East Asia: Policy issues and research agenda, Makati Philippines. PCARRD, represented by its Crops Division Director, Jocelyn E Eusebio, participated in the International conference on sweet sorghum, Houston, Texas, in August 2008, where she presented a poster paper on *Sweet sorghum R&D initiatives: The Philippine experience.*

4. Training in Philippine Institutions

A strong promotion and advocacy program was launched by MMSU, PAC, ISU, UPLB, DA-BAR, DOST-PCARRD and other SUCs throughout the country to promote sweet sorghum as a "carbon neutral" crop and as a base material for village-level agri-industries. Several seminars, conferences and workshops were organized as part of this endeavor (Table 18).

Table 18. Seminars, conferences and workshops related to sweet sorghum organized in the Philippines 2006 onwards.

Events	Dates	Participants
Provincial Agriculture and Fishery Council, San Jose, Occidental Mindoro	6–9 February 2007	Representatives of different government agencies, LGUs and the private sector
Seminar on Sweet sorghum production for ARC, DAR Cagayan	26–27 February 2007	Provincial representatives, Municipal Agricultural Officers, DAR development facilitators, farmers from ARC and researchers
Forum on Potential of sweet sorghum as feedstock for bio-ethanol, Bago Distillery Negros Occidental, Ginebra San Miguel, and Crop Protection Association of Philippines – Philippine Integrated Crop Management and Crop Life	27–31 March 2007	Researchers and technical representatives
DOST Executive Committee meeting on Utilization of sweet sorghum and cassava as feedstock for ethanol production, Bicutan, Taguig, Metro Manila	16 April 2007	Researchers and policymakers
BAR seminar on Updates of sweet sorghum production for ethanol	20 April 2007	Researchers and technical representatives
DA-BAR 2008 National Technology Commercialization Forum and Product Exhibition: “Stronger technology-investment linkage for competitive agriculture and fisheries”, DA-BAR, Diliman, Quezon City	22–25 May 2007	Stakeholders from regional field units of the DA, state universities and colleges, government and non-government institutions, local government unit, and the private sector
DA-BAR National Technology and Product Exhibition	23–25 May 2007	Stakeholders in government and non-government institutions, local government unit, the private sector and researchers

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Events	Dates	Participants
6th Agraryo Trade Fair, SM Megamall, Mandaluyong City	6–10 June 2007	Stakeholders from government and non-government institutions, local government unit, the private sector and researchers
FCSSP 19th Scientific conference on Promoting innovations and entrepreneurship in agriculture, Department of the Academy of the Philippines, Tagaytay	12–16 July 2007	Researchers, farmers, agri-entrepreneurs, development workers and technical representatives
Biofuel seminar in Central Mindanao University, Musuan, Bukidnon	19–22 July 2007	Researchers, directors and technical representatives
3rd quarter meeting and Regional Convention of RDC-League of Local Planning and Development Coordinators, Region 1, San Fernando City, La Union	11 September 2007	Policymakers, researchers, directors and technical experts
Technology and Investment Forum, ISU Cabagan	3–4 October 2007	Researchers, stakeholders, investors and farmers
Conference on Pro-poor bio-power development program in Region 1	7–9 November 2007	Researchers and technical representatives
Roundtable discussion on Philippine sweet sorghum development, Philippine Agribusiness Lands Investment Center, Diliman, Quezon City	9 November 2007	Researchers, directors and technical representatives of investors
CFDP workshop and program launching, DA ITCAF Building, Diliman, Quezon City	20 November 2007	Researchers, investors and LGU officials
Special meeting/workshop for Municipal Agriculture Officers (MAOs), Diliman, Quezon City	21 November 2007	Researchers, provincial agriculturists and investors

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Events	Dates	Participants
Launching of Sweet sorghum in Oriental Mindoro	23–26 November 2007	Provincial agriculturists, inves tors and farmers
National Dryland Agriculture RDE Conference on Energizing research, development and extension for sustainable dryland agriculture in the Philippines, Oxford Hotel, Pampanga	16–19 April 2008	Researchers, policymakers, LGU officials and investors
Technology to People (T2P) media conference, Traders Hotel, Pasay City	12–14 May 2008	Researchers, LGUs and investors
Energy Forum, UPLB	27 June 2008	Researchers, academic faculty and students
30th scientific meeting of the National Academy of Science and Technology	9 July 2008	Researchers/scientists and policymakers
DA-BAR 2008 National Technology Commercialization Forum and Product Exhibition: Kabuhayan-Kaalaman-Kaunlaran sa Makabagong Agrikultura, Mandaluyong City	20–23 August 2008	Stakeholders, regional field units of the DA, state universities and colleges, government and non-government institutions, local government unit and the private sector
Sweet Sorghum Techno-Investment Forum, Bacolod and Davao	26–28 August and 16 –18 September 2008	Researchers, LGU officials, investors and cooperators
112th Nueva Ecija Day: Unang Sigaw ng Kalayaan-Unang Sigaw ng Kaunlaran	31 August – 3 September 2008	Researchers, LGU officials, investors and farmers
ICIERD 2nd Industry and Energy R&D symposium & competition, DMMMSU-MLUC, City of San Fernando	17–20 September 2008	Researchers, project leaders, LGU officials and investors
Sweet Sorghum Techno Investment Forum, Davao	25–27 September 2008	Investors, researchers and LGU officials

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Events	Dates	Participants
Northern Mindanao Sweet Sorghum Techno-Investment Forum, Cagayan de Oro City	2–4 October 2008	Investors, researchers and LGU officials
PSAI Biennial National Convention	12–14 October 2008	Researchers, investors and academe
Seminar on the Prospects of sweet sorghum, its cultural requirement and economic returns, DA-CVIARC, Ilagan, Isabela	23–25 October 2008	Managers of cooperatives under the auspices of DAR-Isabela and DAR personnel
Panata ARC Sweet sorghum field resting and demonstration farm, Bacarra, Ilocos Norte	7 November 2008	DAR officials, farmers and investors
Seminar on Bio-organic farming, Sta. Teresita, Cagayan	9–12 November 2008	Farmers, LGU officials and investors
Annual symposium of the FORESPI on Energy, food and water: Setting the forestry and natural resources research, development and extension agenda, PCARRD, Los Baños, Laguna	26–29 November 2008	Researchers, investors and academe
PHILDEVCOM 4th National Congress on Making waves 4: Reaffirming the role of development communication in sustainable agriculture for food security, UPLB, Laguna	13–15 December 2008	Students, faculty and researchers
Setting up of a Techno-demo farm in Clark, Pampanga	18–20 February 2009	Farmers and policymakers
First National Review of BAR-funded projects: Updates on sweet sorghum research, production and utilization	5–8 October 2009	Researchers, investors and LGU officials
2009 North Luzon Cluster Science and Technology Fair: Responding to Global challenge through science and technology, PSU Urdaneta Campus, Urdaneta City, Pangasinan	13–14 October 2009	Researchers, investors and LGU officials

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Events	Dates	Participants
First Biofuel Business Forum, Isabela State University, Echague, Isabela	19 November 2009	ISU, researchers, farmers/producers, investors and members of the industry
2009 North Luzon Cluster Science and Technology Fair: Responding to global changes through science and technology, PSU Urdaneta Campus	3–5 December 2009	DOST Councils and institutes, partner agencies, academe, small and medium enterprises and S&T stakeholders
Training workshop on proposal writing for CARASUC, Banaue, Ifugao	6–12 December 2009	SUCs and researchers
TRC at 33: Technology Partnering Forum 2010	22–24 February 2010	Stakeholders from state universities and colleges, government and non-government institutions and the private sector
Seminar on Sweet sorghum as fuel, feed, fertilizer and food, Central Bicol State University of Agriculture, Camarines Sur	25–27 February 2010	Farmers in the province, BSA and BSA engineering students, faculty researchers and extension workers
Sweet sorghum production, MVC Techno-Demo Farm, Brgy. Tangcarang Alaminos City, Pangasinan	8 April 2010	ARC, Municipality of Alaminos, farmers and agriculturists
Palayamanan model farm	21–22 June 2010	Farmers and local government officials
Second Biofuel Business Forum, ISU, Echague	19–21 August 2010	Farmers and investors
NAST Rountable on Biofuel: Fueling the nation's future alternative green energy sources, Roxas Boulevard, Pasay City	19 November 2010	Researchers and policymakers
Establishment of techno-demo farms in Negros	30 November– 4 December 2010	Bio-ethanol producers

V. Commercialization and Marketing

1. On-farm Demonstrations

The Philippine government through DA-BAR, financialy supported the first commercial production and utilization of sweet sorghum in the country. Technology demonstration farms were set up in Bantayan Island, Cebu; Tumauini, Isabela; Malasiqui, Sta Maria, Alaminos, Bani and San Nicolas in Pangasinan province; Sta Teresita and Gonzaga in Cagayan; Pili and Naga City in Camarines Sur; Alfonso Lista in Ifugao; Candaba and Floridablanca in Pampanga; Sta Maria and Sto Domingo in Ilocos Sur; Batac, Bacarra, Dingras and Pinili in Ilocos Norte; Koronadal and General Santos City in South Cotabato; San Carlos City, Sagay City, Binalbagan, Murcia and Bago City in Negros Occidendal; Naujan, Oriental Mindoro; Milagros, Masbate; Magsaysay, Occidental Mindoro; Mambusao, Capiz; and Cabiao, Nueva Ecija.

In Barangay Bungon, Batac, Ilocos Norte, DA-BAR granted a project on processing of sweet sorghum juice to vinegar or wine or basi. Sweet sorghum crop productivity is about 48 t ha^{-1} (Fig. 18). Heavy duty cane mills were used to extract the juice (Fig. 19) which was pasteurized in three

Figure 18. *A commercial crop of sweet sorghum variety SPV 422 in City of Batac, Ilocos Norte.*

sets of furnace-cum-vats (Fig. 20). The vinegar and wine produced were sold to walk-in customers and in public markets by the producers.

Large-scale processing of sweet sorghum juice was taken up by BFC which has a marketing arm called Bapamin Enterprises (BE). BFC acquired two mobile crushers (Fig. 21), one fitted with a 4-cylinder Isuzu diesel engine with a front-drive axle that can be used over a 30–60 km radius service area, and another fitted with a single piston Kirloskar diesel engine which can be operated over a radius of 3–5 km.

Figure 19. *A heavy duty cane mill in Bungon, City of Batac, Ilocos Norte.*

Figure 20. *The construction and use of semi-permanent furnaces to pasteurize sweet sorghum juice.*

Figure 21. *Mobile crushers of Bapamin Farmers' Cooperative (BFC).*

BFC converted a warehouse into a fermentation center. Hundreds of earthen jars housed in it (Fig. 22) are used to process sweet sorghum juice into vinegar. BFC also acquired an "acetator" (Fig. 23) to accelerate the processing of vinegar to meet the huge domestic demand as it is being sold by a chain of supermarkets across the country (Fig. 24). Currently, 1,000 litres of vinegar are being sold per month; and plans are afoot to increase this to 1,500 litres.

In Bicol region, the Ateneo de Naga University through its Small and Medium Enterprise Development Institute (SMEDI), has been cultivating several hectares of sweet sorghum, processing the grain to flour and marketing fresh sweet sorghum juice. Several big farmers in the region have shown interest in producing and processing sweet sorghum. To

Figure 22. *Earthen jars fermenting sweet sorghum juice into vinegar are housed in this warehouse-turned-fermentation center.*

Figure 23. *An acetator acquired by the Bapamin Farmers' Cooperative.*

Figure 24. *Processed sweet sorghum vinegar is now sold in supermarkets.*

date, 12 individuals have been trained in sweet sorghum cultivation and processing and supplied with seed. In addition, several foreigners and investors in the provinces of Sorsogon and Albay have expressed a strong desire to establish a sweet sorghum processing and ethanol distillery. The Long Life Ganoderma/Reishi Mushroom Production project is using sweet sorghum flour as the main ingredient in its growth medium.

The DA has supplied sweet sorghum seed to many farmers who had earlier undergone training in sweet sorghum cultivation and processing with MMSU and its partners. The DA popularized sweet sorghum technologies and products developed thus through publications and dissemination of Information, Education and Communication (IEC) materials, conducting in-house reviews, participation in product exhibits and conducting hands-on training in sweet sorghum production, post-harvest processing, bio-organic fertilizer production and food processing.

2. Food Uses

Fresh sweet sorghum juice is being marketed in trade fairs and schools, packed in plastic cups that are hygienically sealed with a “Plastic Cup Sealer” (Figs. 25a and b). The sealed plastic cups (250 ml) are chilled and sold at PhP 10.00/cup. This activity can be easily replicated by entrepreneurs or cooperatives all over the country.

In Bicol Region, a development program on the commercialization of sweet sorghum products and by-products was implemented through

Figure 25. *Many takers for the fresh sweet sorghum juice that is marketed in (a) plastic cups (b) that are sealed using a plastic cup sealer.*

public-private sector partnership. The program is anchored on the Biofuel Act of 2006 and the DA's goal of maximizing productivity in the marginal, underutilized or idle areas in the region. Sweet sorghum variety SPV 422 which was successfully grown in selected sites in the region was commercially produced and evaluated for its economic returns to simulate large-scale planting. Equipment for village-level sweet sorghum processing, such as a grain polisher, decorticator, flour mill, leaf stripper and cane crusher where manufactured by Tropics Agro-Industries. Three to five tons of polished grain of sweet sorghum can be obtained per hectare. When decorticated and milled, 90–99% of these grains can be recovered as sweet sorghum flour, which in turn can be used in processing food products such as cookies, cup cakes, *pandesal*, bread, crunchies, noodles, vinegar and syrup.

Nonita Badong, an entrepreneur of Naga City, Camarines Sur, set up an exclusive restaurant that serves sweet sorghum products. Named "Diet Secret" (Fig. 26), it caters to those who need high fiber and low calorie food intake, and is supported by the SMEDI unit of Ateneo de Naga in Region 5.

The PAC has worked extensively on developing diverse food products from sweet sorghum juice, syrup and grain. In 2009, it published an illustrated *Sweet Sorghum Food Products – A Compendium* with funding from DA-BAR (Fig. 27).

Figure 26. The Diet Secret Restaurant that serves baked delicacies made of sweet sorghum in Naga City, Camarines Sur.

Figure 27. *A compendium on sweet sorghum food products.*

3. Syrup Making

Due to the prohibitive cost of processing sweet sorghum juice into ethanol and the urgent need to use it to make vinegar and basi, juice was processed into syrup to position it in the market as an alternative to honey (Mandke and Kapoor 2003 and Mask and Morris 1991). Since village-produced syrup had a bitter taste traceable to poor processing, a short-term training on “Village level establishment and maintenance of sweet sorghum crushing-cum-syrup production” was conducted by Ch Ravinder Reddy, Scientist, ICRISAT, for 33 trainees from all over the country, including three from Mindanao and three from the private sector.

Sweet sorghum syrup is now sought by health-conscious people and village-level fruit manufacturers. As such, a more hygienic and energy saving system was jointly developed by UPLB and MMSU with financial support from DA-BAR. To date, the working model can process 60 L of sweet sorghum juice per hour.

4. Ethanol Production

The first commercial bio-ethanol distillery for fuel, San Carlos Bio-Energy Incorporated, was set up in Visayan island of Negros (Fig. 28). The distillery uses sugarcane as raw material and operates six months in a year. Sweet sorghum can be grown to extend the operation of the sugarcane distillery. The integration of sweet sorghum into the cropping system is feasible due to its early maturity. Upcoming sugarcane distilleries in the provinces of Bukidnon (Mindanao), Tarlac and Pampanga (Luzon), which have large tracts of idle land suitable for sweet sorghum cultivation, are exploring the possibility of using sweet sorghum as a complimentary feedstock.

Several entrepreneurs have been enthusiastic about learning about sweet sorghum use in ethanol production. However, it may take some time for them to set up distilleries that can use sweet sorghum along with other feedstock for ethanol production.

Figure 28. *San Carlos Bio-Energy Incorporated, Negros, processed sweet sorghum juice to ethanol on an experimental basis.*

5. Seed Business

Teresita L Madrid, a women farmer, has been actively engaged in the sweet sorghum seed business over the last five years in Bagong Sikat, Cabiao, Nueva Ecija province (Fig. 29). The local farmers are realizing

Figure 29. *Scientists from ICRISAT, PAC and MMSU with a sweet sorghum farmer -cum-businessman at Cabaio, Nueva Ecija.*

4.5 t ha^{-1} of grain yield from SPV 422 cultivation compared to 1.8 t ha^{-1} from traditional sorghum cultivars. The grain of sweet sorghum is purchased at a premium price of PhP 17 kg^{-1}.

VI. Lessons Learned, Major Challenges and the Way Forward

1. Lessons Learned

The collaboration between ICRISAT and DA-BAR, DOST, PCARRD, MMSU and PAC besides other public and private organizations in the Philippines in executing projects on sweet sorghum research and development has yielded substantial results since 2004. It has also taught us a few lessons.

It has shown that leadership and accessibility are of prime importance while exploring new options such as sweet sorghum. The resources of ICRISAT and their accessibility to the Philippine NARS, combined with the leadership shown by WD Dar in promoting the crop in the Philippines as the best option for dry and marginal areas, were instrumental in the success of the projects.

It was also realized that working with a multi-purpose crop such as sweet sorghum has its advantages, bringing with it greater acceptance from small-scale farmers as well as industry players. Feed millers are now using sweet sorghum grains as an ingredient in poultry and livestock feed. Small-scale farmers use the leaves as forage and the bagasse as fuel. Others use the bagasse for mushroom production and in vermiculture.

It has highlighted the fact that there are benefits when multi-government agencies work together with the private sector and LGUs to develop technologies for sweet sorghum as food, feed and feedstock for bio-ethanol. The full support of two government agencies tasked to develop science and technology in the Philippines enabled researchers and extension workers to promote and develop specific technologies in a given agro-ecological zone. While DOST-PCARRD provided RDE funds to SUCs, DA-BAR provided the same in the RIARCs. Capacity building and social networking were strengthened among research partners in the private and public sectors.

Aside from its use as feedstock for bioethanol production in answer to a very specific need to blend gasoline fuel with at least 10% ethanol, sweet sorghum also answers the need for alternative food sources in very dry areas in the country. Sweet sorghum grain is now processed into flour and the de-hulled grain is cooked like rice, which is the staple food of Filipinos.

With continued support from ICRISAT and increased R&D investment, sweet sorghum will be a very important crop that addresses the energy crisis in the Philippines by 2015.

2. Major Challenges

As sweet sorghum offers reasonable grain yields in addition to juice with high total soluble solids, its cultivation does not undermine food security in developing countries. The major constraints to its growth and production are similar to those of grain sorghum. However, based on ICRISAT's research experience, the following critical issues need to be taken into consideration with regard to sweet sorghum commercialization in the Philippines:

- Breeding short-mid-late and late-maturing sweet sorghum genotypes is necessary to widen the harvest window to provide an uninterrupted supply of raw material to distilleries. Planning the sowing of a mix of these cultivars in the catchment area of a distillery can help achieve more commercial stalk sugar/ethanol.
- G×E interactions are significant for sweet sorghum related traits; genotypes that perform well in the rainy season are not necessarily the top performers in the postrainy season and vice versa. Preliminary results indicate that non-allelic interactions are more predominant for stalk sugar and allied traits.
- As climate change leads to higher temperatures and sweet sorghum is bound to grow in new areas, thermo- and photo-insensitive, non-lodging cultivars that are resistant to multiple pests and diseases need to be developed.
- When cultivars with differing maturity durations are grown in an area, pests like shootfly and midge are likely to infest late-maturing cultivars, necessitating breeding for tolerance to these insects.
- Sorghum is traditionally challenged by marginal lands with poor fertility and poor moisture holding capacity; so is sweet sorghum. Sporadic water inundation due to excessive rains/floods is also an unforeseen constraint.

- The self fermentation of juice inside the stalk prior to extraction is a major concern, mainly when extraction is delayed after harvest due to distances between the factory and the field. Preliminary results indicate a 16.8% reduction in sugar yield due to a 24-hr delay in juice extraction (Srinivasa Rao et al. 2011*)*. Research should address post-harvest losses in terms of juice quality and quantity.
- Ensuring the long-term sustainability of the sweet sorghum value chain is a major challenge that needs to be addressed by:
  - Convincing and educating farmers to cultivate sweet sorghum for higher returns
  - Mechanization in cultivation and crushing activities
  - Supply chain innovations to reduce the time lag between harvesting and crushing of stalks both under centralized and decentralized models and ensuring the continuous supply of sweet sorghum stalk and syrup for the distillery to run at optimum capacity
  - Increasing juice storability and fermentation efficiency, increasing process efficiency and reducing investment and operational costs of syrup and ethanol production
  - Exploring alternative markets for syrup, like food additives, pharmaceuticals, beverages, bakery and confectionery units
  - Establishing institutional linkages for technical, financial and policy support.

3. Crop Research

The Philippine Council for Industry Energy Research and Development (PCIERD) of DOST has come up with a Bio-ethanol S&T Roadmap (Fig. 30) largely based on experimental data collected since 2004. Experts from the ethanol industry and scientists working on sweet sorghum together prepared a future plan on sweet sorghum for bio-ethanol based on the priorities set by PCIERD, exploiting the potential of sweet sorghum for diverse end uses, emphasizing Inclusive Market-Oriented Development (IMOD) in tune with ICRISAT's strategic plan to 2020.

In support of the roadmap, an integrated sweet sorghum research and development program was prepared, whose activities were discussed in Chapter III. There are nearly 30 sub-projects/ activities with research on

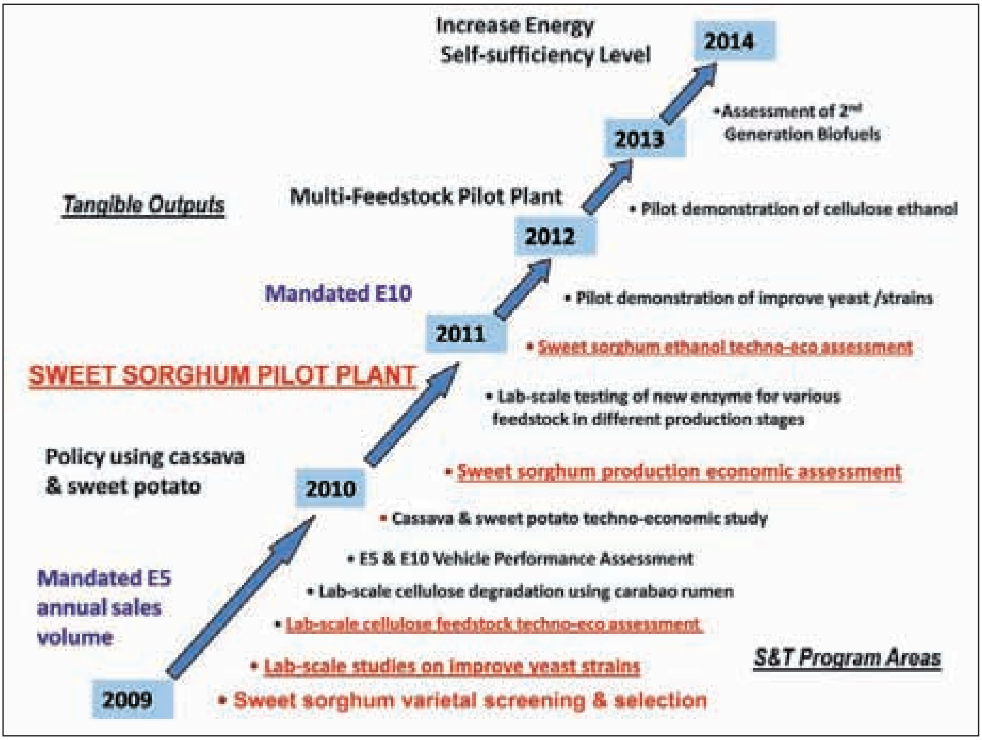

Figure 30. *The S&T roadmap prepared by PCIERD.*

till 2016, by which time it is expected to develop recombinant microbial organisms that convert cellulosic material of sweet sorghum to ethanol. A program of developing high-yielding sweet sorghum hybrids and high biomass sorghum until 2019 has been chalked out.

Large-scale screening and selection of sweet sorghum varieties, hybrids, parental lines and progenies were completed by bio-ethanol stakeholders in the Philippines, led by MMSU and UPLB-IPB in collaboration with private sector partners like Biomass Resources Incorporated (BRI), Negros BioChem Corporation (NBC), Fuel Incorporated (FI), Ginebra San Miguel Incorporated (GSMI) and First Biofuel Resources Incorporated. Studies to improve fermentation rate and efficiency were carried out at MMSU and UPLB. MMSU is undertaking a laboratory scale cellulose feedstock techno-eco assessment, one pertaining to cellulose degradation using carabao rumen and also testing of new enzymes for various feedstocks. By 2012, a pilot demonstration of improved yeast/strains together with a pilot demonstration of cellulosic ethanol will be done in cooperation with a commercial ethanol distillery.

Figure 31. ICRISAT Director General William D Dar hands over seeds of sorghum variety ICSV 93046 to Philippines Secretary of Agriculture Proceso J Alcala.

With the recent return of Filipino scientists (balik scientist) trained abroad through DOST, an assessment of 2nd generation bio-ethanol will be done in 2014 or earlier. A balik scientist hub is being established at MMSU with DOST-PCARRD, DA-BAR, DOST-PCIERD and CHED support.

To further fortify research efforts, improved sweet sorghum lines from ICRISAT are being introduced. Recently, WD Dar donated seed of sweet sorghum variety ICSV 93046, tested and chosen for release in India, to Proceso J Alcala, Secretary of Agriculture, Philippines (Fig. 31).

4. Commercialization and Marketing

A very significant development from the promising results of multilocation trials has been the establishment of technology demonstration farms in the island of Negros where DA-BAR-funded sugarcane-based ethanol distilleries are in operation. The partners involved are Biomass Resources Incorporated, Fuel Incorporated, Negros BioChem Corporation, Ginebra San Miguel Incorporated (GSMI), and the Sagay City-based Organic Producers in the Island of Negros, Multi-Purpose Cooperative (OPTION-MPC). Biomass Resources is a subsidiary of the San Carlos Bio-energy Incorporated (SCBI), the first company to produce fuel grade ethanol in

Philippines. Biomass Resources Incorporated is striving to produce high quality and reliable feedstock for the distillery. It conducted varietal trials on cassava and sweet sorghum, and identified sweet sorghum as the better feedstock. It also imported sweet sorghum hybrids from Australia and the USA, which are currently being evaluated along with ICRISAT-bred hybrids and SPV 422. Seeds of ICRISAT hybrids were produced by UPLB's Institute of Plant Breeding.

BRI is planning to grow sweet sorghum over 50 ha, to be later crushed and processed into fuel grade ethanol by SCBI. They plan to shift their operation for a day from sugarcane to sweet sorghum juice processing to demonstrate the crop's real potential in fuel grade ethanol production. A similar attempt is being made by Fuel Incorporated in Binalbagan, Negros Occidental. Fuel Incorporated is a partner of Sea Oil, one of the biggest independent oil companies in the Philippines with 170 retail outlets countrywide. Sea Oil was the first company to market 10% ethanol-blended gasoline (E10) long before the Biofuels Act of 2006 was signed into law.

Negros BioChem Corporation is a partner of Asian Alcohol Incorporated which is currently processing sugarcane molasses into ethanol. The company produces potable alcohol and will soon establish a distillery to produce fuel grade ethanol. GSMI whose current feedstocks are cassava and sugarcane molasses, is in the process of setting up techno-demo farms in three sites to evaluate sweet sorghum for grain productivity and ethanol production. These arrangements set the stage for the completion of trials in commercial-scale ethanol production using sweet sorghum as feedstock with SCBI using the juice and GSMI using the grains. GSMI is a sister company of PETRON, the country's biggest oil company. SCBI, on the other hand, sells its ethanol product to PETRON. The data generated by these firms will serve as a guide for future investors.

PAC and ISU, situated in different agro-ecological and socio-economic environments, will continue their work on food product development, varietal improvement and small-scale processing of ethanol for household and small farm engines. Together with MMSU, UPLB will upscale work on the development of hybrids and open pollinated varieties.

It was to support such commercial activities envisaged to improve sweet sorghum productivity through continuous breeding and management that MMSU as lead agency conducted the first sweet sorghum trial on

Figure 32. *(a) ICRISAT DG William Dar addressing a gathering at the inaugural of the MMSU Sweet Sorghum Experiment Station and (b) with Miriam E Pascua, President MMSU; Jocelyn E Eusebio, Director, PCARRD Crops Research Division; Rosanna Mula, ICRISAT; Thelma Z Layaoen, Professor MMSU and Heraldo L Layaoen at the station.*

27 October 2004 at its Sweet Sorghum Experiment Station that was inaugurated on 18 December 2009 (Fig. 32).

5. Policy Support

The high price of sugarcane, the current primary feedstock in distilleries, is responsible for the high cost of locally produced ethanol, making it noncompetitive in domestic and international markets. In fact, SCBI temporarily stopped distilling ethanol in the later half of 2010, concentrating instead on sugarcane juice that is shipped to factories for sugar production. BRI produces ethanol from other feedstocks like sweet sorghum and cassava. According to its Farm System and Operations Manager Carlos Ted Dela Torre, the company's priority is sweet sorghum based on SUC data and on developing a 3,500 ha plantation for sweet sorghum in the vicinity of San Carlos.

The College of Economics and Management (CEM) of UPLB is focusing on policy research and support systems development while the Department of Industrial Engineering of the College of Engineering and Applied Technology of UPLB is conducting research on supply/value chain management. MMSU, on the other hand, is working on socio-economic studies with an emphasis on small-scale farming in rainfed areas.

VII. Status and Commercialization in Other Asian Countries

Experiences with sweet sorghum in India, USA and China have shown that the crop has high potential as a bio-energy feedstock, with several opportunities for immediate use as a complementary feedstock and seasonal low-cost feedstock (mold-affected grain). Regions with a warm climate, large tracts of land and a system similar to sugarcane processing should work well for sweet sorghum. Further, the crop can be grown in regions of the world where sugarcane cannot be cultivated. A brief status report of sweet sorghum use as feedstock in ethanol production and other uses in some Asian countries follows.

1. India

Supply chain management is critical in commercializing sweet sorghum for ethanol production. The crop is seasonal and is cultivated during three seasons in a year (rainy, postrainy and summer) to supply raw material during 3–4 months a year for ethanol production. Grain and sugar yields are best in the rainy and summer seasons whereas in the postrainy season grain yield is high with a bearing on stalk sugar yields. A commercial ethanol distillery requires feedstock year-round (at least 6 months in a year) for continuous operation. ICRISAT and partners are working on a combination of developing genotypes with different maturity durations, use of improved crop management practices (different dates of planting and harvesting, fertilizer schedules, ratooning etc.), and establishing decentralized syrup production units to increase the window of sweet sorghum availability for ethanol production. A brief description of the currently used supply chain models follows.

Centralized model – Stalks supplied directly to distilleries: India currently has two sweet sorghum-based distilleries, namely Rusni Distilleries Pvt Ltd (based in Hyderabad, Andhra Pradesh) and Tata Chemicals Limited (based in Nanded, Maharashtra). The distilleries located in sugar factories can also use sweet sorghum feedstock with minor modifications in the crushing and fermentation stages.

1. **Rusni Distilleries Pvt Ltd:** This first sweet sorghum distillery located in Medak district of Andhra Pradesh and amenable to multiple feedstock

use was set up in 2007 for ethanol production. It has a capacity of 40 kilo litres per day (KLPD) and produces fuel ethanol (99.4% alcohol), Extra Neutral Alcohol (ENA) (96%) and pharma alcohol (99.8%) from agro-based raw materials such as sweet sorghum stalks (juice), molded grains, broken rice, cassava and rotten fruits.

2. **Tata Chemicals Limited**: This 30 KLPD sweet sorghum distillery in Nanded, Maharastra, started operations in 2009 (Fig. 33) solely based on sweet sorghum. It uses commecially grown sweet sorghum in the 25 km radius of the plant to produce transport grade ethanol and ENA. The sweet sorghum cultivars used are CSH 22SS, ICSV 93046, sugargraze, JK Recova and RSSV 9. The productivity levels in farmers' fields is satisfactory. In 2010, the distillery produced 90 KL of ethanol compared to 25 KL in 2009.

CF biotech Limited, a multi-feedstock 200 KLPD centralised distillery is being established at Gadag, Karnataka. The results of the sweet sorghum field trials in the region were promising.

Decentralized model – Village crushing and syrup-making unit: To trim the cost of transporting bulky raw material, decentralized crushing units (DCU) can be set up locally, and based on the prevailing laws of the nation, either syrup or alcohol can be produced following the Seed-to-Tank approach (Fig. 34).

Under the ICRISAT and National Agricultural Innovation Project (NAIP) value chain development sub-project, ICRISAT and partners work with farmers in Ibrahimbad cluster comprising 12 villages in Medak district,

Figure 33. *The Tata Chemicals Limited 30 KLPD plant in Nanded, Maharashtra, India.*

Andhra Pradesh (Fig. 35). Farmers are provided improved seeds, fertilizers and agrochemicals and technical expertise to obtain the best productivity under rainfed conditions. The crop is harvested at physiological maturity (grains harvested by farmers for food) and the stalks are crushed at the decentralized unit set up in the village under the ICRISAT-NAIP-Indian Council of Agricultural Research (ICAR) project. The juice obtained is boiled (in pans) to produce concentrated syrup (>70% Brix) that is supplied

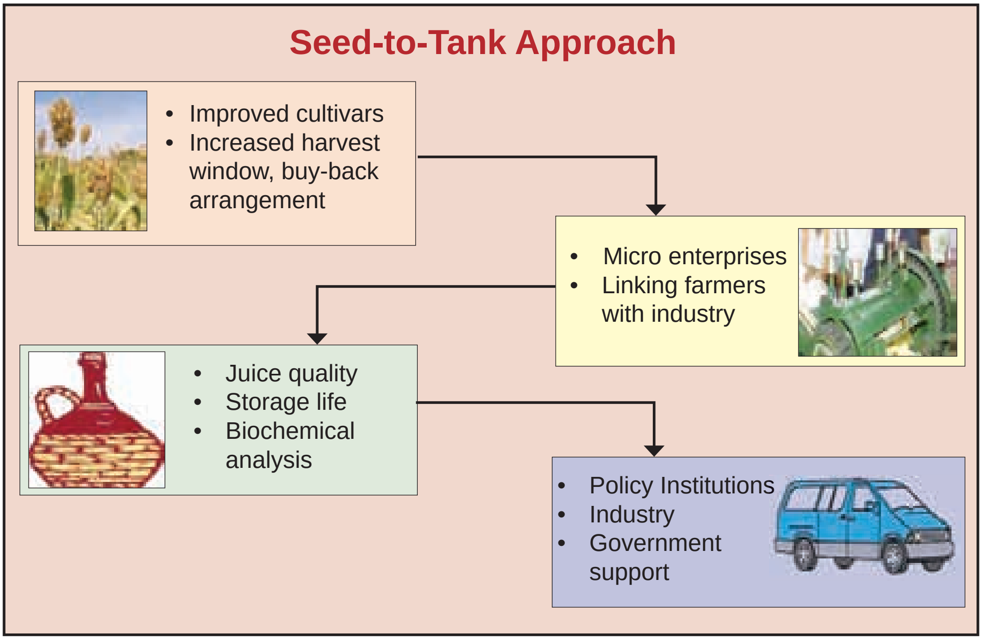

Figure 34. *The seed-to-tank approach that reduces transportation costs.*

Figure 35. *The decentralized crushing and syrup making unit in Ibrahimbad village, Medak district, Andhra Pradesh.*

to a distillery for further processing to produce ethanol. In the 2009 rainy season, 102 farmers cultivated sweet sorghum on 44 ha and 600 t of stalks were crushed to realize 29 t of syrup that was supplied to Rusni Distilleries Pvt Ltd for ethanol production. The efficiency of the DCU needs to be improved to make it commercially viable, besides ensuring a remunerative price for syrup. A pilot scale DCU was set up in Nandkheda village under Marathwada Agricultural University (MAU), Parbhani, Maharastra, under the ICRISAT-Common Fund for Commodities (CFC) sweet sorghum project in 2010 and was operational during the 2010 rainy season.

2. China

The Sorghum Research Institute (SRI) is a premier national center for sorghum improvement that began sweet sorghum research in the early 1980s. A total of 15 sweet sorghum hybrids and 20 hybrid parents have been registered and released so far by different organizations in China. Among these 15 hybrids, 13 were bred by SRI. Liantian No. 1, 4, 5, 6 and 9 have been found very promising for sugar yield (Fig. 36). Work on the development of RIL populations to map stalk sugar qualitative trait loci (QTLs) is in progress.

In the past, sweet sorghum was used mainly as livestock fodder, juice and to process into sugar and liquor. Recent years have seen greater use of the crop's stalk to produce ethanol. China is the second largest consumer

Figure 36. *(a) The sweet sorghum hybrid Liantian No. 6 in China and (b) the ZTE Agribusiness Company Limited distillery in Inner Mongolia.*

of gasoline after USA. About 40% of the oil consumed is imported. Its oil resources are insufficient to meet the country's rapidly growing energy demand.

According to a survey, China consumes more than 40 million t of gasoline every year, and at present, the proportion of ethanol to gasoline is 1:9. So, if the mixed gasoline is widely used in China, 10 million t of gasoline can be saved. Sugarcane, sweet sorghum and sugar beet are all good materials for ethanol processing in China. Though sugarcane and sugar beet production are restricted by climate and regional conditions, sweet sorghum is more suitable for ethanol production since it can be grown in most of the regions in China.

The last five years have seen biomass processing enterprises showing interest in sweet sorghum. With SRI support, a few of them – Liaoning Guofu Bioenergy Development Company Limited, Binzhou Guanghua Biology Energy Company Ltd, Jiangxi Qishengyuan Agri-Biology Science and Technology Company Ltd, Xinjiang Santai Distillery, Jilin Fuel Alcohol Company Limited, Heilongjiang Huachuan Siyi Bio-fuel Ethanol Company Ltd, ZTE Agribusiness Company Limited and Fuxin Green BioEnergy Corporation – have conducted large-scale sweet sorghum trials. A few problems were identified in the processing of sweet sorghum stalks. In 2010, ZTE Agribusiness Company Limited, Wuyuan County, Inner Mongolia and Fuxin Green BioEnergy Corporation, Heishan County, Shenyang province used sweet sorghum as material to produce ethanol.

The Chinese government is encouraging sweet sorghum processing industries by offering a subsidy of ¥180 mu^{-1} to farmers or companies cultivating sweet sorghum and ¥1300 t^{-1} for ethanol produced to the industry. Given these sops, the area under sweet sorghum is likely to increase substantially.

3. Other Countries

The area under sweet sorghum in countries other than China, India and Philippines is insignificant given the lack of awareness and policy support. ICRISAT is promoting sweet sorghum as a fodder crop in Jordan, Israel, Syria, Yemen, Palestine and Oman in partnership with NARS and the International Centre for Biosaline Agriculture (ICBA), Dubai, UAE.

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Annexure I. Sweet sorghum lines/hybrids supplied to partners in the Philippines during 2005-10.

Recipient partner	Total	SSPHT	SSGR	A-lines	B-Lines	ISSHET	ISSVET	MSSBT	MSSHT	MSSVT	SSP	R- lines	SS F_3	SSA lines	SSB lines	SSHT	SSR lines	SSV
DA	42			12	12							7	11					
PEQS	44				7							12					5	13
MMSU	4																	4
MMSU	49												49					
MMSU	55															44		11
MMSU	55															44		11
MMSU	10																	10
MMSU	1																	1
UPLB	75					53	20				2							
MMSU	195					53	20											122
UPLB	47													18	18			11
ATI	3																	3
UPLB	30													10	10		10	
UPLB	11													4	4			3
MMSU	377	181	20					10	20	20			100	3	3	12		8
MMSU	16								8	8								
Total	1014	181	20	12	19	106	40	10	28	28	2	19	160	35	35	100	15	197

SSPHT = Sweet Sorghum Preliminary Hybrid Trial; SSGR = Sweet Sorghum Germplasm Resources; A-lines = Male sterile line; B-line = Maintainer line; ISSHET = International Sweet Sorghum Hybrids Evaluation Trial; ISSVET = International Sweet Sorghum Varieties Evaluation Trial; MSSBT = Multilocation Sweet Sorghum B-line Trial; MSSHT = Multilocation Sweet Sorghum Hybrids Trial; MSSVT = Multilocation Sweet Sorghum Varieties Trial; SSP = Sweet Sorghum Progenies; R-lines = Restorer lines; SSHT = Sweet Sorghum Hybrid Trial and SSV = Sweet Sorghum Variety.

Annexure II. Undergraduate and graduate theses, bulletins and articles published by Philippine R&D organizations involved in sweet sorghum research, 2006-10.

Title	Author(s)	Name of book/journal	Year
Production of ethanol from sweet sorghum Juice	Richard G Reantillo	Undergraduate thesis	2006
Optimization of ethanol production from sweet sorghum (ICSR 93034 and NTJ2) stalk *Zymomonas mobilis* by fermentation	Carlo Jay Camalig	Undergraduate thesis	2006
Production of ethanol from sweet sorghum molasses	Ruth A Valiente	Undergraduate thesis	2006
Fermentation of sweet sorghum (*Sorghum bicolor* (L) Moench) juice using different strains of *Saccharomyces cerevisiae*	Maingelline R Bacarisa	Undergraduate thesis	2007
Production of bio-ethanol from sweet sorghum (*Sorghum bicolor* (L) Moench) juice using different strains of *Zymomonas mobilis*	Venus Michelle Duropan	Undergraduate thesis	2007
Determination of total sugar and starch from the extracted sweet sorghum juice planted at MMSU, 2006	Rose Marie T Pacris	Undergraduate thesis	2007
Evaluation of *Zymomonas mobilis* for ethanol production from sweet sorghum (*Sorghum bicolor*) jaggery	Kristine M Aquino	Undergraduate thesis	2007
Evaluation of *Saccharomyces cerevisiae* strains for bio-ethanol production from sweet sorghum (*Sorghum bicolor* (L) Moench) jagerry/molasses	Laarni Doroneo	Undergraduate thesis	2007
Evaluation of bacterial strains from Cornick waste for the degradation of sweet sorghum (*Sorghum bicolor* (L) Moench) bagasse	Desiree Dagdagan	Undergraduate thesis	2007
Evaluation of bacterial strains from cow cud for the degradation of sweet sorghum (*Sorghum bicolor* (L) Moench) bagasse	Cecile A Gaoat	Undergraduate thesis	2007
Isolation and characterization of *Saccharomyces* strains obtained from the juice of three different varieties of sweet sorghum (*Sorghum bicolor* (L) Moench)	Mary Grace Balintag	Undergraduate thesis	2008

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Title	Author(s)	Name of book/journal	Year
Screening of *Saccharomyces cerevisiae* strains for fermenting sweet sorghum (*Sorghum bicolor* (L) Moench) jaggery for bio-ethanol production	Elena M Castillo	Graduate thesis	2008
Preliminary study on the fermentation of sweet sorghum juice using *Zymomonas mobilis* and design of fermenter and distillation set-up	Marcial S Alega Jr, Kristina M Asuncion, Reynaldeth P Echanique and Jakilou B Pudiquet	Undergraduate thesis	2008
Isolation and characterization of native *Saccharomyces* strains from jaggery obtained from the different varieties of sweet sorghum (*Sorghum bicolor* (L) Moench)	Rowena Leah Acosta	Undergraduate thesis	2008
Isolation and characterization of putative biotechnologically important bacteria from compost soil	Leo Vincent Garvida	Undergraduate thesis	2008
Hypocholesterolemic property of jaggery obtained from the two varieties (ICSV 700 and SPV 422)	Jethrew E Daduyo,Myrel R Domingcil,Joemar C Ilaban,Armynne Mae, Gianellee A Pajas and Mae I Valencia	Undergraduate thesis	2008
Isolation, characterization and screening of potential industrially important bacteria from goat saliva	Vicka Marija C Coloma	Undergraduate thesis	2009
Isolation, characterization and screening of industrially important bacteria from cow saliva	Ivy Florence B Calamaan	Undergraduate thesis	2009
Wound-healing potential of sweet sorghum (*Sorghum bicolor* (L) Moench) SPV 422 juice on white mice (*Mus musculus*)	Ria Aiza A Corpuz	Undergraduate thesis	2009

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Title	Author(s)	Name of book/journal	Year
Effects of sweet sorghum (*Sorghum bicolor* (L) Moench) SPV 422 grain and flour on the blood glucose level of white mice (*Mus musculus*)	Lea Z Flor	Undergraduate thesis	2009
Diuretic effect of sweet sorghum (*Sorghum bicolor* (L) Moench) grain extract on rabbit (*Oryctolagus cuniculus*)	Lea Riza P Salisipan	Undergraduate thesis	2009
Microbial and glycemic effect of the jaggery obtained from the three sweet sorghum (*Sorghum bicolor* (L) Moench) varieties	Mae Ann Batuyong	Graduate thesis	2009
Sweet Sorghum Food Products: A Compendium	Estrella C Zaballa, Zosimo Battad and Norman De Jesus	PAC-DA-BAR publication	2009
The effect of planting density and fertilizer rate on the grain and juice yield of sweet sorghum during the wet and dry season	Heraldo L Layaoen, Samuel S Franco, Sixto Pascua and Mario Remolacio	Philippine Society of Soil Science and Technology	2010
Screening of *Zymomonas mobilis* strains for fermentation of sweet sorghum (*Sorghum bicolor* (L) Moench) jaggery for bio-ethanol production	Danilo Vidad	Graduate thesis	2010
Isolation, characterization and utilization of indigenous bacteria from sweet sorghum (*Sorghum bicolor* (L) Moench) grains	Remelyn Soliman	Undergraduate thesis	2010
A field guide in identifying insect pests infesting sweet sorghum	Thelma Layaoen, Odilon Caraan and Heraldo Layaoen	Information Bulletin No. 330/2010 (First Edition)	2010
A field guide in identifying diseases infecting sweet sorghum	Thelma Layaoen, Odilon Caraan and Heraldo Layaoen	Information Bulletin No. 329/2010 (First Edition)	2010

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Title	Author(s)	Name of book/journal	Year
Isolation, characterization and utilization of bacteria from the gut of katydid (*Phanoreptera furcifera*) infecting sweet sorghum	Joan Zaragosa	Undergraduate thesis	2010
Isolation, characterization and utilization of bacteria from the gut of armyworm (*Spodoptera* spp.) infecting sweet sorghum	Vanessa Mae Dumlao	Undergraduate thesis	2010
Isolation, characterization and utilization of bacteria from the gut of earworm infecting sweet sorghum	Sheryl Timbreza	Undergraduate thesis	2010
Isolation, characterization and utilization of bacteria from the gut of semi looper (*Chrysodeixis chalcites*) infecting sweet sorghum	Vanessa Pasugnod	Undergraduate thesis	2010
Effects of sweet sorghum grain and flour in the blood cholesterol level of white mice (*Mus musculus*)	Ella Mar Agpuldo	Undergraduate thesis	2010

About ICRISAT

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) is a non-profit, non-political organization that conducts agricultural research for development in Asia and sub-Saharan Africa with a wide array of partners throughout the world. Covering 6.5 million square kilometers of land in 55 countries, the semi-arid tropics have over 2 billion people, and 644 million of these are the poorest of the poor. ICRISAT and its partners help empower these poor people to overcome poverty, hunger, malnutrition and a degraded environment through better and more resilient agriculture.

ICRISAT is headquartered in Hyderabad, Andhra Pradesh, India, with two regional hubs and four country offices in sub-Saharan Africa. It belongs to the Consortium of Centers supported by the Consultative Group on International Agricultural Research (CGIAR).

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