Development of Hybrid Rice in India: A transformation towards improved grain quality with enhanced yield gain

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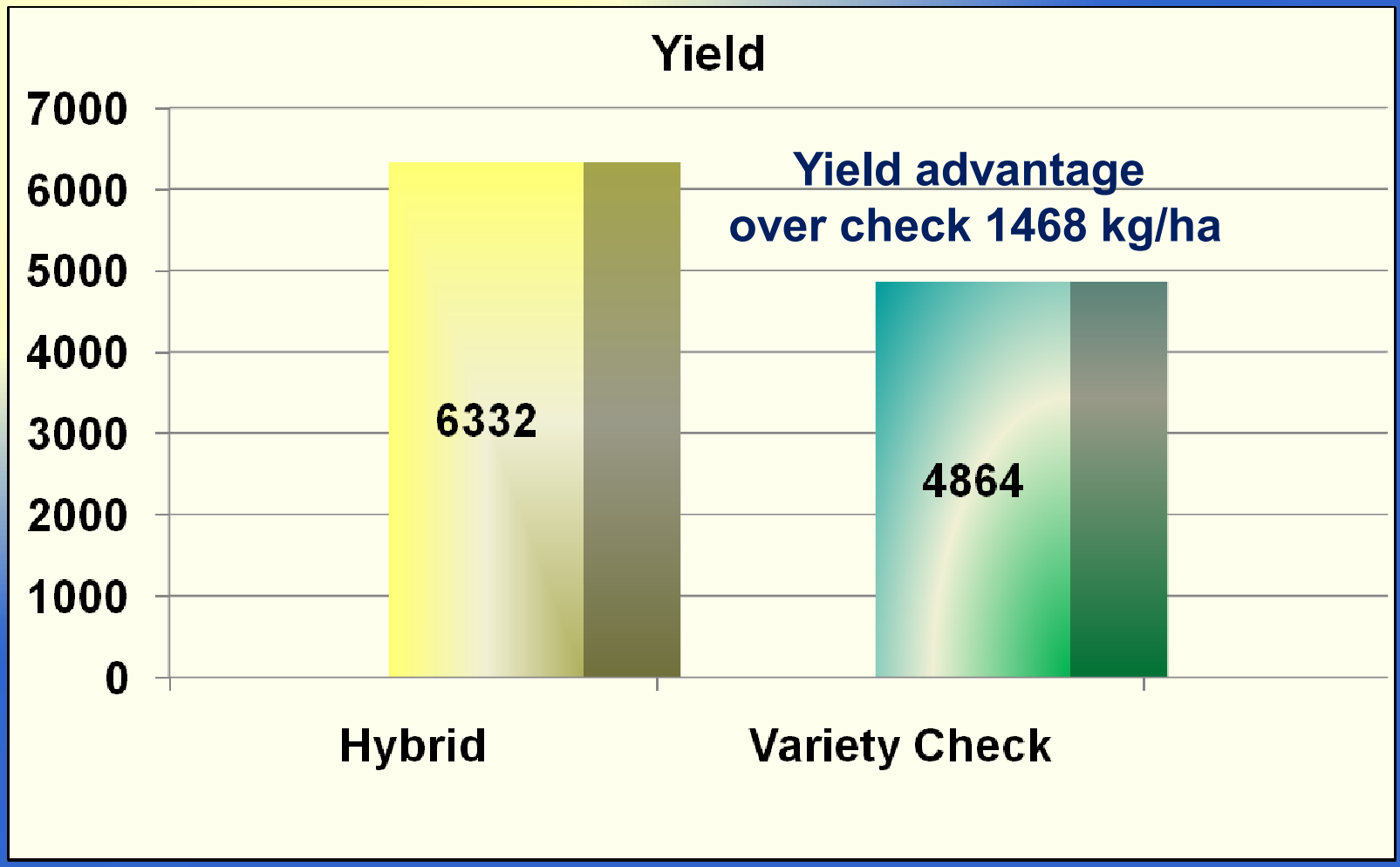
Advances in Hybrid Rice Technology

- To sustain the self sufficiency attained in rice production and to break the current yield barrier, hybrid rice technology has been successfully demonstrated as one of the most powerful tools in China and intensified efforts were made by the Indian scientists to replicate the Chinese miracle in India since last 22 years.
- Impressive progress was made in hybrid rice research and (31 public & 28 private bred) 59 hybrids have been released in the country.
- These hybrids are promising not only in irrigated areas, but some are good for abiotic situations and to aerobic conditions as well.
- Consumer acceptance is one of the important factors that determine the extent of spread of rice hybrids.

Extent of yield advantage of released Hybrids VS Varietal checks 2005 - 2010



Test sites (approximately): 450 from 2005 - 2010

Grain Quality of Hybrid Rice

- Despite yield advantage

  +

  biotic/abiotic tolerance
- Acceptance of rice hybrids depends upon

  Visual appearance, Milling

  &

  Cooking quality
- which are determined by the physical and chemical properties of rice grain

Grain Quality in Hybrids

- Grain harvested from commercial rice hybrids denote F_2 generation produce and differs in grain characteristics.
- Hence, developing hybrids with acceptable grain quality to meet the consumer preferences is a challenging objective, which has a direct impact on the adoption of this technology.

Structure of the Rice Grain

- Hull is the outer covering of the caryopsis (Brown rice)
- Pericarp, Seed Coat (Tegmen), Nucellus and Aleurone along with embryo comprise the bran portion of the rice grain
- Sub-Aleurone and Starchy Endosperm: Milling of rice caryopsis removes the sub aleurone and small parts of the starchy endosperm layer. The sub aleurone layer (Brown rice) is rich in protein and lipid bodies while the starchy endosperm contains starch granules and some protein bodies.

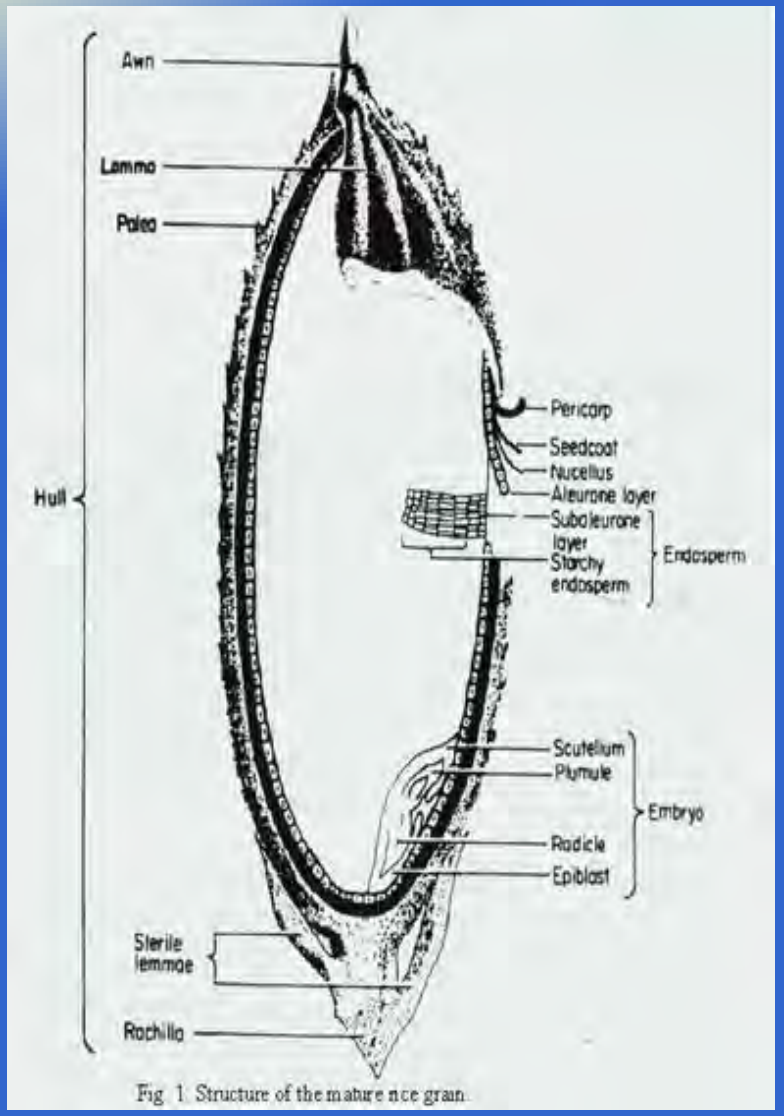


Fig. 1. Structure of the mature rice grain

Initial glitches with Hybrid rice

- **Hybrid rice developed in China, when first introduced into India in early 90s were not preferred because of the bigger grain size and shape, excessive chalkiness, low milling yield, many with soft and sticky cooked texture and aroma.**

- **Millers and consumer acceptance are very important to exploit the higher yield advantage of hybrid technology.**

- **Further, hybrids should also give higher economic returns to the farmers in terms of price advantage compared to varietal checks.**

Rice Grain Quality Characteristics

Milling Characteristics	:	Hulling (%), Milling (%), Head Rice Recovery,
Grain Characteristics	:	Kernel length, Kernel breadth, L/B ratio, Grain type, Grain chalkiness,
Cooking Quality	:	Gelatinization Temperature through Alkali Spreading Value, Amylose content, Gel consistency, Kernel length after cooking, Elongation ratio, Water uptake, Volume expansion ratio,
Eating Quality through Panel Test	:	Appearance, Cohesiveness, Touching, Chewing, Taste, Aroma,

Problems of converging quality traits with yield due to complex inheritance

Aroma	Monogenic recessive, Monogenic recessive with an inhibitor, Monogenic dominant, Digenic or trigenic dominant, Two dominant complimentary genes, Digenic recessive, Four complimentary genes, Polygenic
Kernel elongation	Polygenic, predominant, non-additive
Kernel length	Monogenic, Digenic, Trigenic, Polygenic, Triallelic, Polygenic additive and dominant
Amylose content	Monogenic with modifiers (incompletely dominant), Two complimentary genes, Digenic with partial dominance of high over low Dosage effect of genes
Gelatinization temperature	Two pairs of major genes (with duplicate action cumulative effect), Monogenic recessive, Dominant and additive effect, Additive gene effect, Trigenic, Polygenic, additive and non-additive
Gel consistency	Monogenic, hard gel consistency dominant, Cytoplasmic effect, Monogenic with several minor genes and / or modifiers

Milling Quality

- **Milling recovery is one of the most important criteria especially from marketing angle**
- **A variety should possess a high turn out of whole grain (head) rice and total milled rice**
- **Milling recovery of rough rice is an estimation of the quantity of head rice and total milled rice that can be produced from a unit of rough rice**

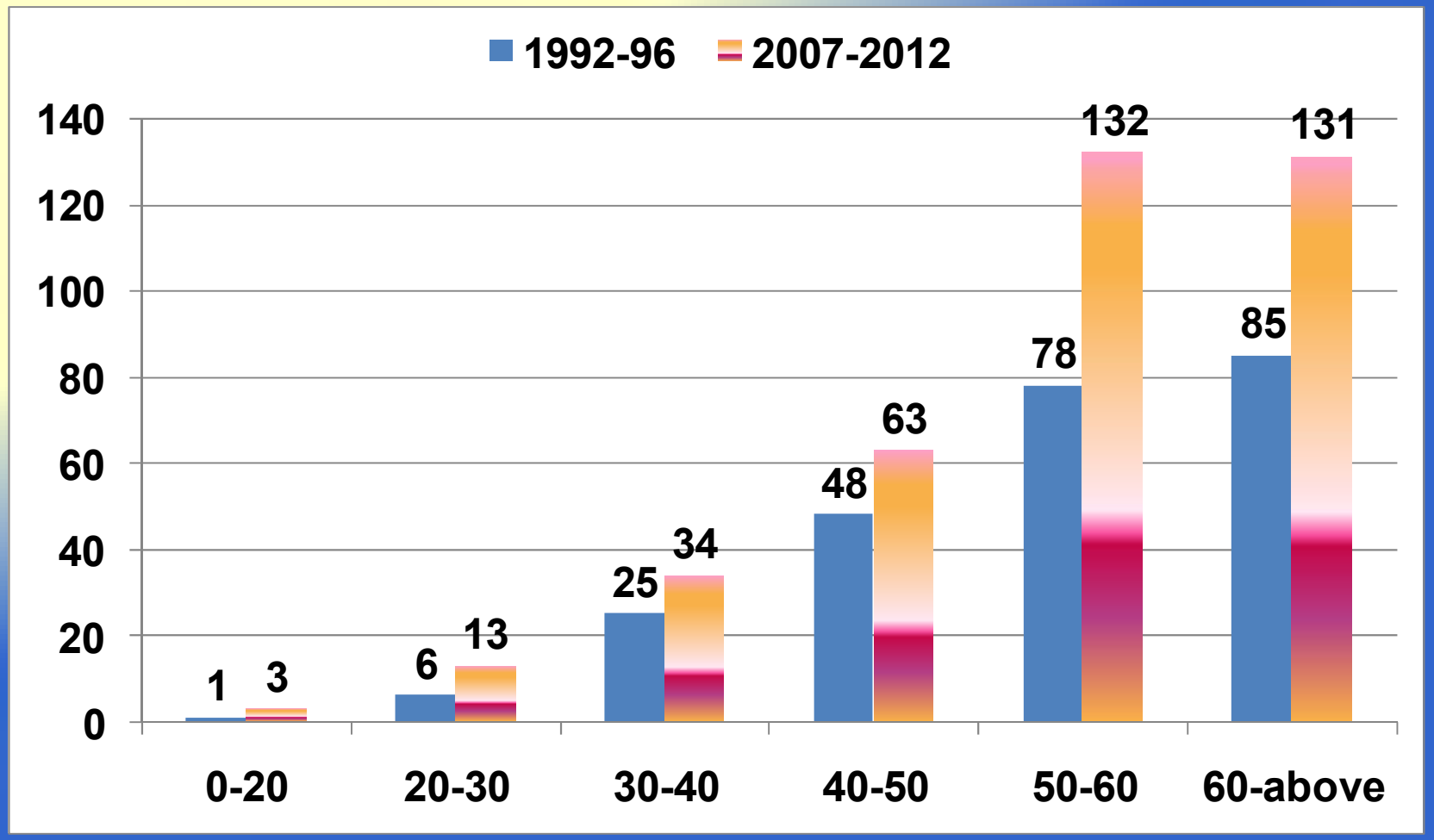
Factors influencing Head Rice Recovery (HRR)

- Heritable trait
- Grain dimensions and hardness
- Abdominal white presence/absence
- Immature and fissured grains
- Moisture content
- Presence of infestation
- Mill type

Factors affecting HRR in hybrids

- **Low milling recovery was one of the significant deficiencies in rice hybrids.**
- **The problem is attributed to the narrow genetic base of the CMS lines involving mainly two lines *viz.*, IR 58025A and IR 62829 A which have low HRR.**
- **Studies have shown that hybrids with higher head rice recovery can be obtained when the parents are selected carefully.**
- **It is essential to choose parents with high head rice especially restorers and this should not pose a problem given the wide choice of restorers and new CMS lines now available in the hybrid rice breeding programme.**

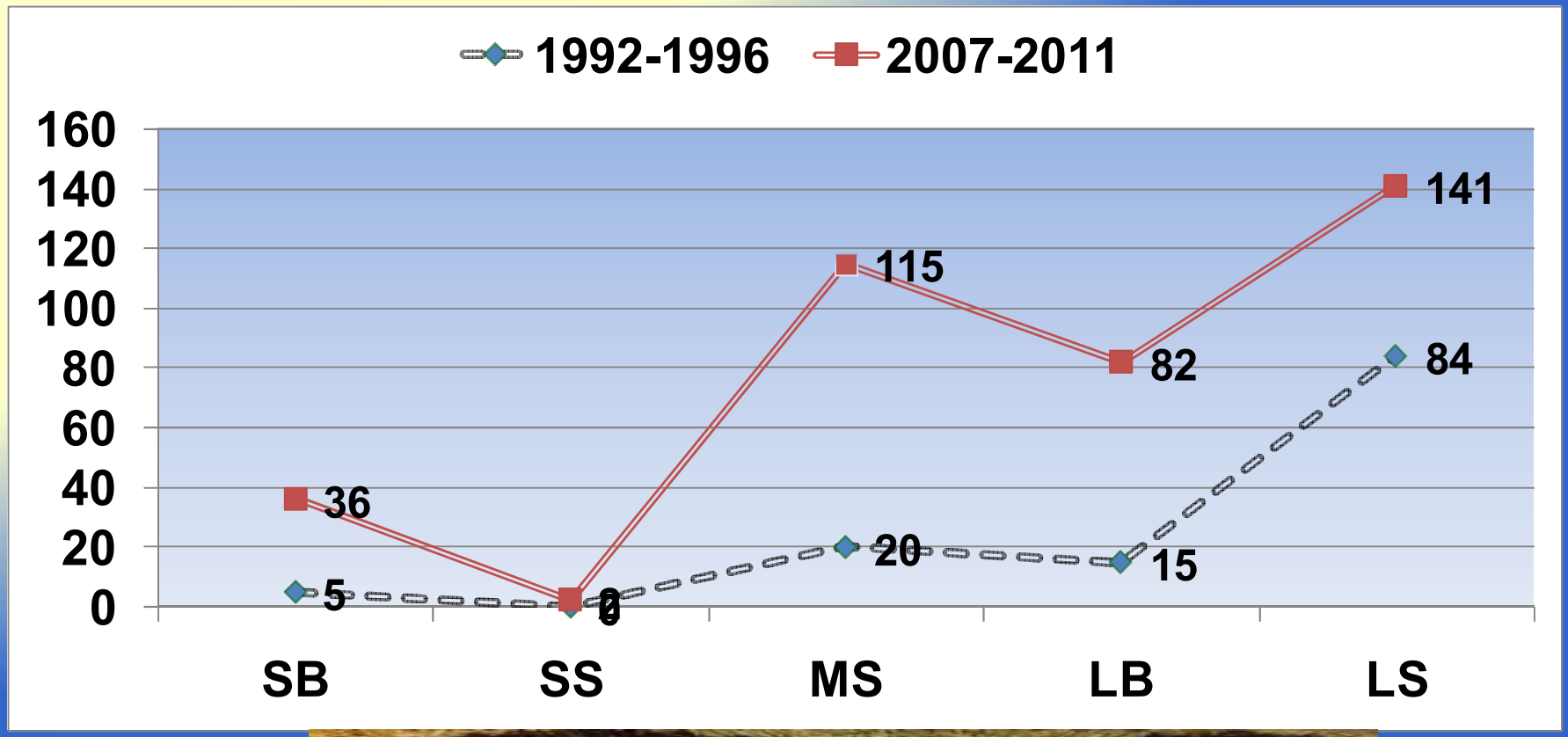
Improvement in HRR (%) in Hybrid Rice



Grain Size, shape and appearance

- Preference for grain size and shape vary
- Length of the grain is more variable than width, thickness or shape.
- Medium and short grains break less than long slender.
- The lemma and palea of the rice hull are maternal tissues. Seed size and shape are determined by the shape and size of hulls.
- Genetic segregation for shape and size of hulls for spikelets borne on F1 plants does not occur, as all F2 seeds have similar dimensions.
- Grains borne of F1 plants never exceed the long slender parent either in length or shape. Hence, to develop medium grained hybrids, parents possessing long and short grain can be used.
- But to develop long grain hybrids the parents must have long slender grains.

Grain Type variation in hybrids tested



Grain Appearance

- Consumer preference is for white, translucent grains and endosperm opacity is determined by the amount of chalkiness.
- Endosperm is classified as Waxy or non waxy.
- Waxy – devoid of Amylose and are opaque.
- Non-waxy – contain Amylose ranging from (2.1~32%) are dull, hazy or translucent.

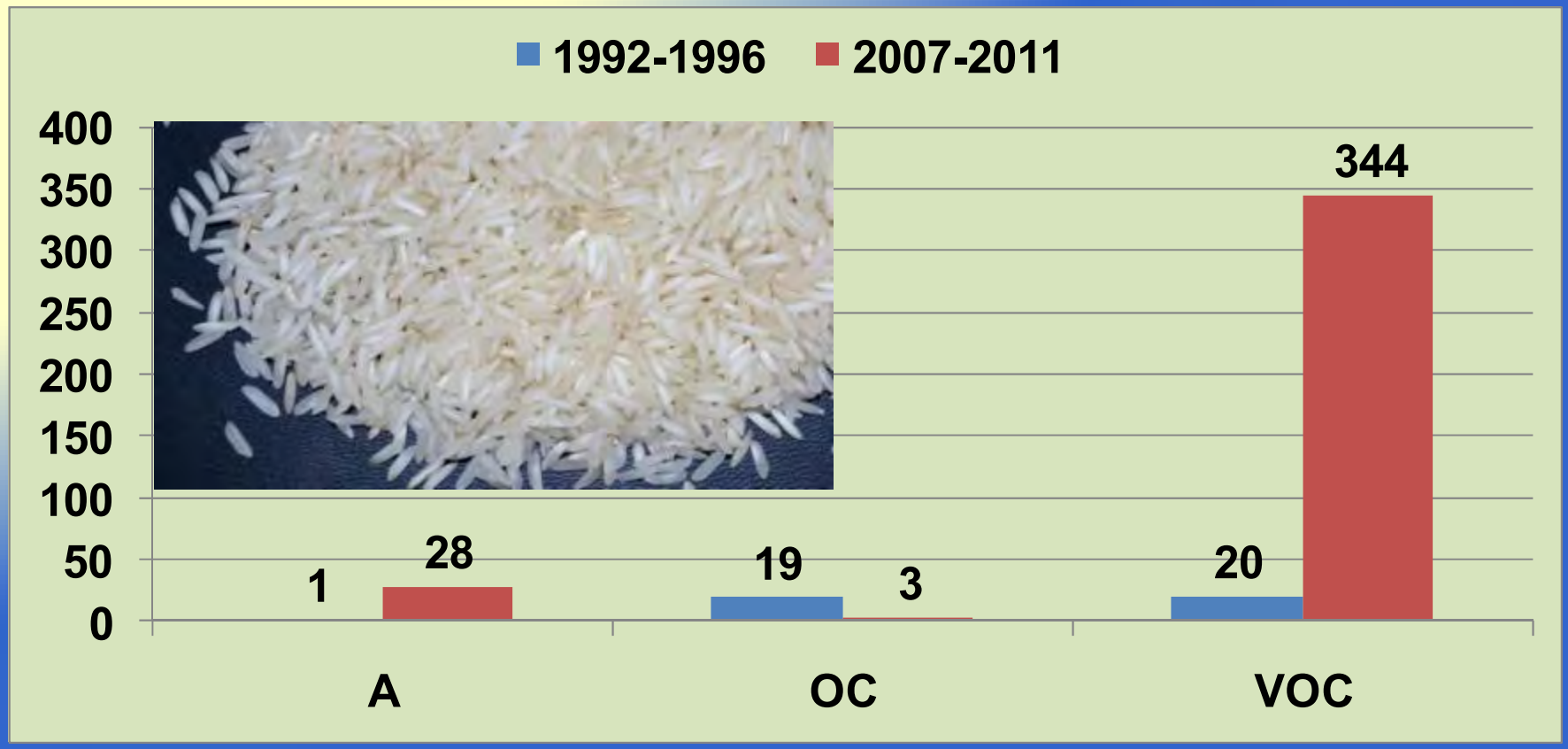
Grain Appearance

- **Endosperm is a triploid tissue formed by fusion of 1 male nucleus 2 female nuclei (polar bodies). If the parents vary in endosperm appearance the F_2 grains show clear segregation and may pose a problem in hybrids.**
- **As Waxy rices are not preferred in India and as all parental lines have varying levels of whiteness to translucency in appearance, this should not be an impediment in developing hybrids.**

Grain chalkiness

- Chalky white spots often appear in the starchy endosperm which lower the market value of the variety.
- **White belly (Abdominal white)** Soft textured, white spots occurring in the middle part on the ventral side (side on which the embryo lies)
- **White core** A white chalky region extending to the edge of the ventral side and towards the centre of the endosperm
- **White back** A long white streak on the dorsal side
- Chalky areas are not as hard as the translucent and grains with chalkiness are more prone to breakage
- Of the 130 parental lines tested, 34% were fully chalky, 50% occassionally chalky and 14% devoid of it
- By selecting suitable parents, hybrids without any chalky spots can be developed

Grain Chalkiness



Cooking & Eating Characteristics

- **Gelatinization temperature**
- **Amylose content**
- **Gel consistency**

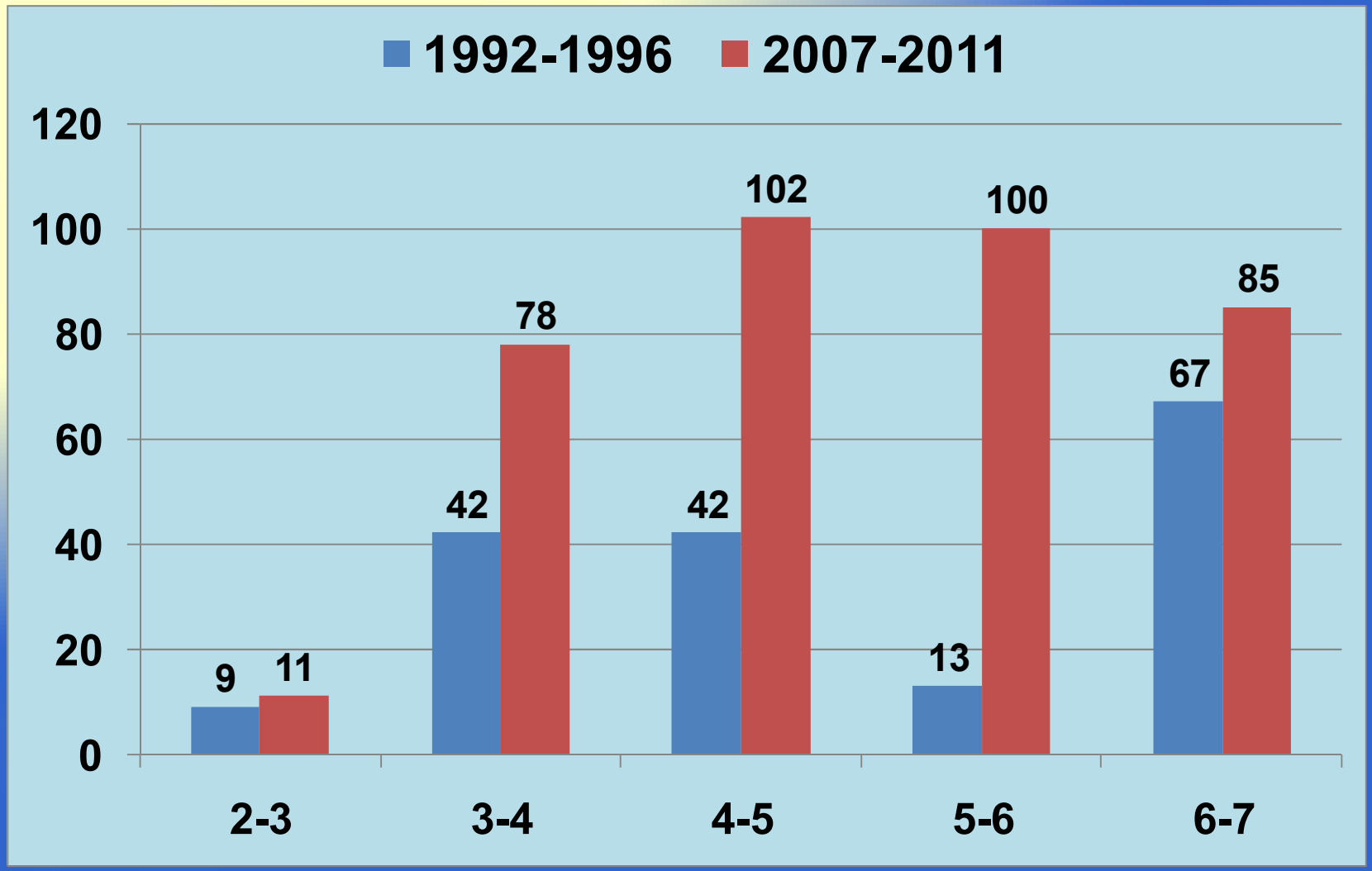
Gelatinization Temperature through Alkali Spreading Value

- Unmodified starch granules are generally insoluble in water below 50°C. Over a critical temperature range, the starch granules undergo irreversible process known as gelatinization Temperature (GT).
- The gelatinization temperature (GT) of rice varieties may be classified as low (55 to 69°C), intermediate (70 to 74°C) and high (>74°C).
- Estimate of the GT is indexed by the alkali digestability test and measured by alkali spreading value (ASV).

ASV Score & its relation Hybrid Quality

- In hybrid programme, hybrids with low GT were attained when both parents had low GT, while intermediate GT were derived when intermediate x intermediate and intermediate x high types used.
- As the grain size and shape does not normally differ in hybrids, when bulk sample of low and intermediate GT grains are cooked, low GT (high ASV) grains cook first and release heat and water which affects the cohesiveness of cooked rice. **Segregation thus is not desirable as high GT (low ASV) types remain under cooked.**
- To isolate hybrids with intermediate GT, it is important to select especially **male parent with intermediate GT** as the two widely used CMS lines IR 62829A and IR 58025A have high and low GT values.

Alkali Spreading Value



Amylose Content

- Amylose content (AC) is the single most important character predicting rice cooking and eating quality features

- Amylose is the linear fraction of starch while amylopectin is the branched fraction

AC Classification	Content (%)
Waxy or glutinous	1-2%
Very low amylose	3-9%
Low	10-19%
Intermediate	20-25%
High	>25%

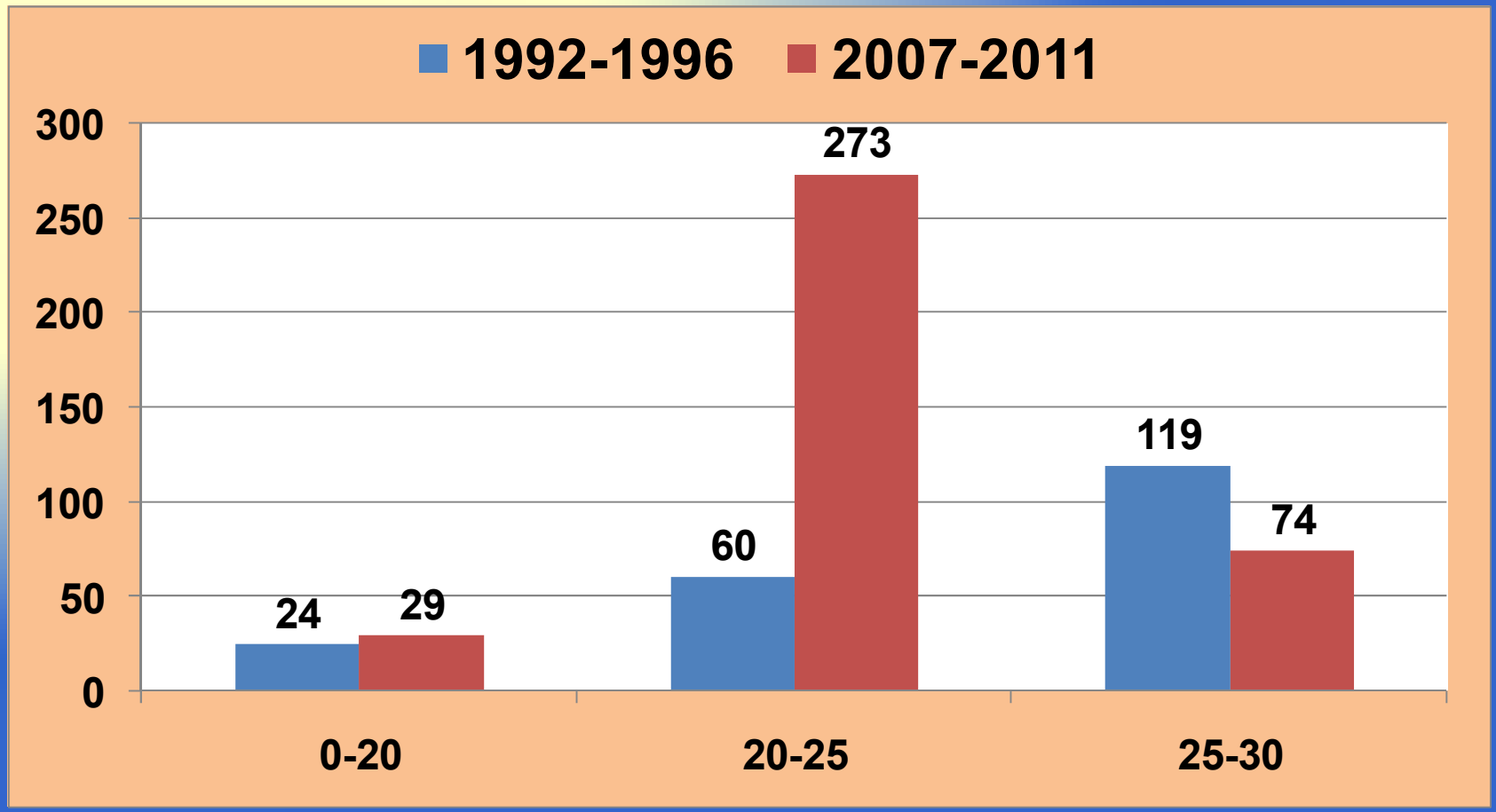
Amylose Content

- **Non-glutinous or non-waxy varieties, make up the bulk of the world's rices.**
- **Low amylose varieties are moist, sticky and glossy; when cooked readily split and disintegrate when over cooked.**
- **Rices with high amylose cook dry and fluffy but become hard on cooking.**
- **Intermediate types are fluffy but retain soft texture when on cooling.**

Amylose Content

- **In hybrid breeding it has been reported that the mean AC of F2 bulk seed samples was between that of the parents in many crosses and the more the parents differ the more is the differences in the F_2 seeds.**
- **Reports exist low x high AC parents produced intermediate hybrids; likewise medium x low AC parents transgressed to high AC indicating that the inheritance pattern differs based on the cross.**
- **For developing hybrids with appropriate AC depending on regional preferences, suitable parents should be selected so that uniformly cooked rice with desirable flakiness, tenderness and cohesiveness is achieved.**

Amylose Content (%)

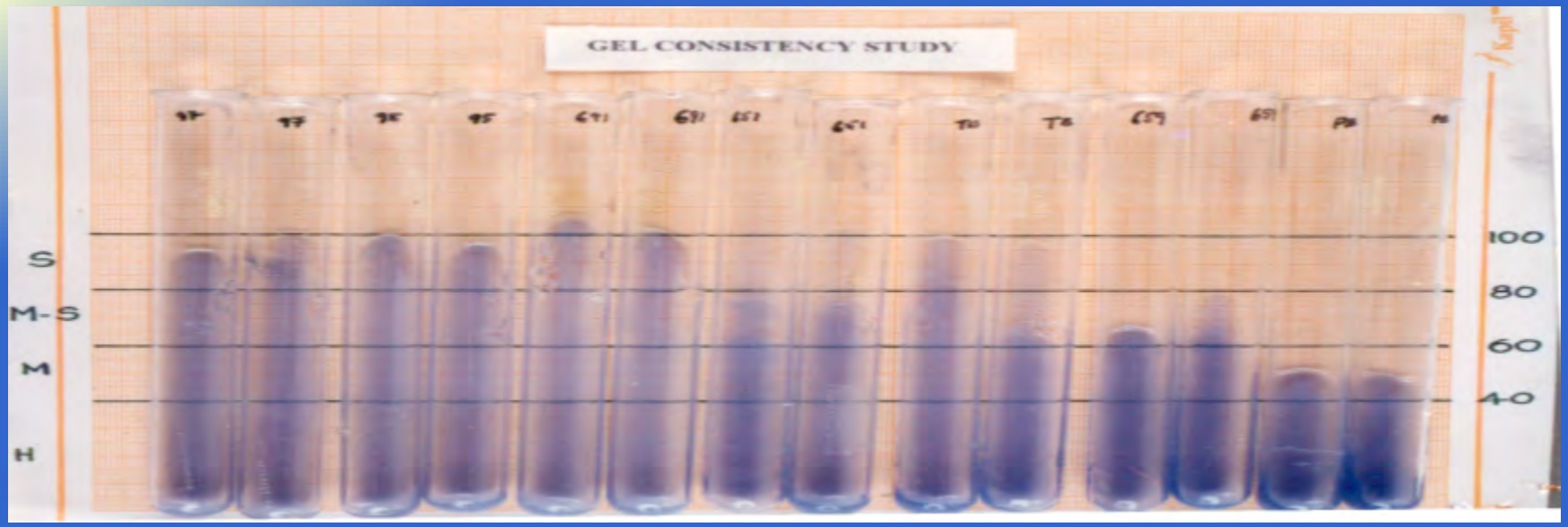


Gel Consistency

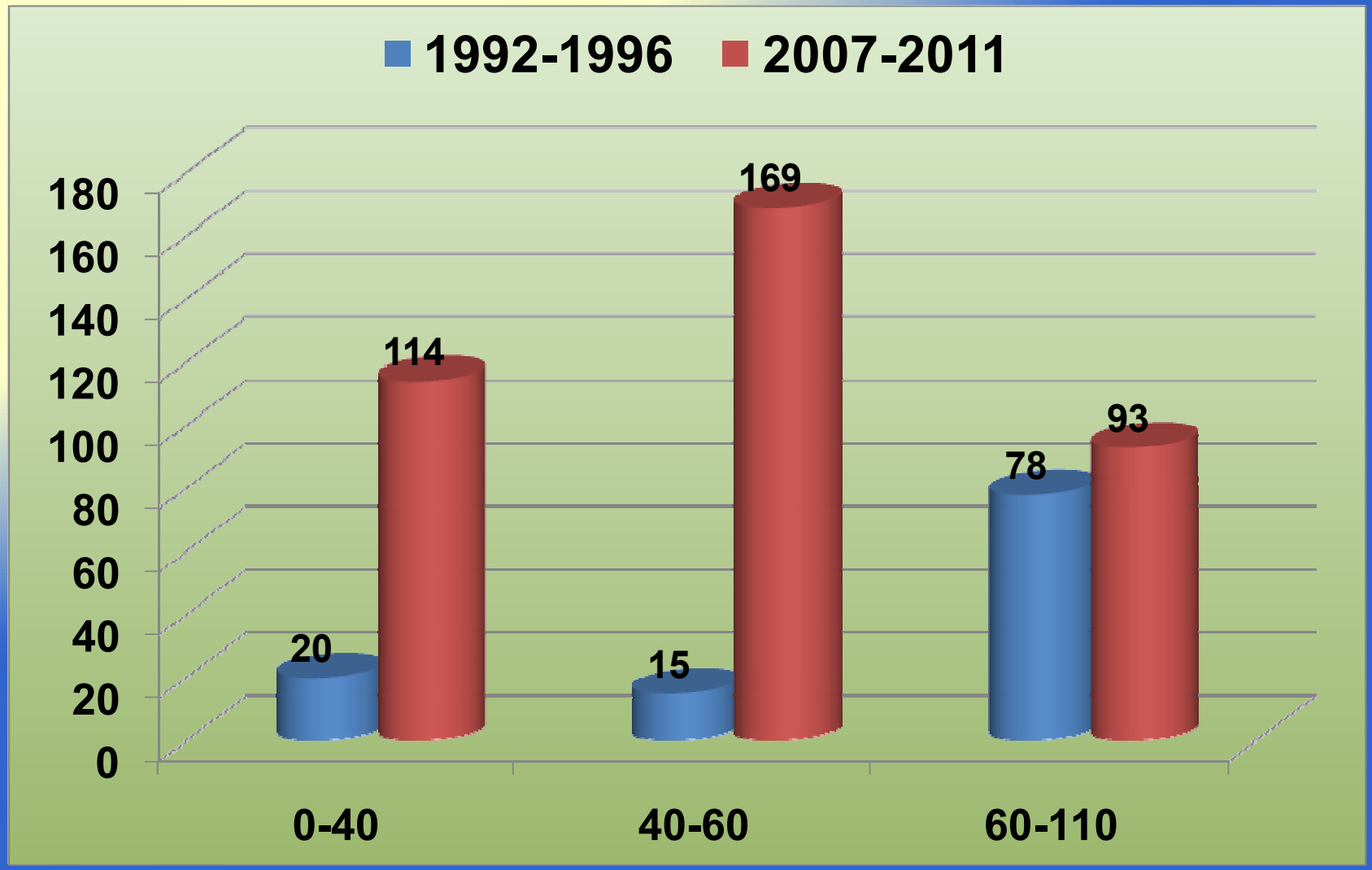
- **Gel consistency (GC) determines the cohesiveness, tenderness and gloss of cooked rice when the amylose content is high.**
- **Varietal differences in gel consistency exist among varieties of similar AC (>25%).**
- **The GC test is based on the consistency of the rice paste and differentiates among the varieties with high AC.**

Gel Consistency

- The test separates high AC rices into 3 categories:
  - Very flaky rices with hard gel (gel length < 40mm)
  - Flaky rices with medium gel (41-60mm)
  - Soft rices with soft gel (61-100 mm)
- Varieties with soft gel are preferred as the rice cooked would be tender. GC is normally soft when the AC is less than 25%.



Gel Consistency (mm)



Aroma & Fragrance

- The aroma of rice plays a dominant role in consumer acceptability and it draws premium price in certain speciality markets. Basmati rices of India and Pakistan, Bahra of Afghanistan, Domsiah of Iran, Azucena & Malagkit Sung Song of Philippines, Khao Dawk Mali of Thailand and short grain indigenous aromatic rices like Dubraj etc., of India are know for this trait.
- More than 100 compounds contribute to aroma. The popcorn like smell of aromatic rice stems primarily from **2 acetyl-1 pyrroline conent.**

Aroma & Grain Elongation

- In crosses between aromatic male sterile line IR 54758A and non aromatic varieties such as IR 46 and IR 64, the bulk grain sample had moderately weak to slightly strong aroma.
- If aromatic rice hybrids are preferred at least one of the parent must be aromatic
- The most widely used CMS lines IR 58025A and IR 62829A are aromatic and many hybrids thus developed possess aroma.

Good Texture and Cooking Quality in Rice Hybrids

Good Texture and Cooking Quality in Rice Hybrids

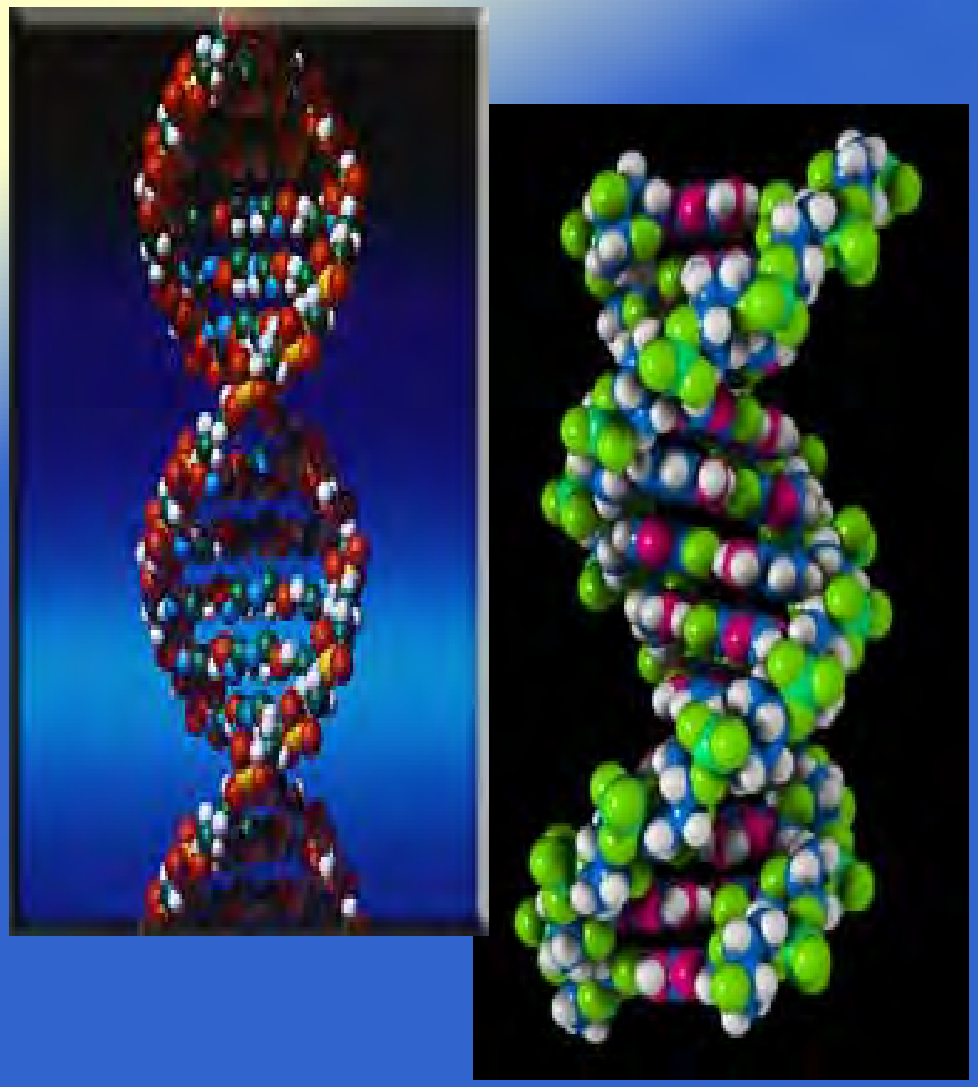
Poor cooking quality in some rice Hybrids

Correlations among quality characteristics

Significant positive correlations were recorded among important quality traits such as:

- Milling and Head Rice Recovery (HRR)
- Kernel Length and L/B ratio, Water Uptake, Kernel Length After Cooking (KLAC)
- KLAC with Elongation Ratio (ER)
- ER and Amylose Content (AC)(%)
- The high correlation between Kernel Length and L/B ratio indicates that desired grain shape and size can be selected.
- Significant negative correlation existed between AC and Gel Consistency (GC) but with high AC, soft GC can be selected for achieving acceptable cooking quality.

Achievements of Use of Marker tools in quality rice breeding



Innovative studies underway

Aroma	● 8 base pair deletion and 3 SNPs in exon 7 of *badh2,* likely cause of fragrance in Jasmine and Basmati ● Using, this polymorphism, a multiplex marker and simple functional marker developed. Presence of other QTLs also reported
Amylose content	❖ Controlled by major locus *Wx* encoding granule bound starch synthase (GBSS) and multi minor loci ■ The SSR marker and two SNPs in the exons of *Wx* gene reported to show association in japonica genotypes
Gelatinization Temperature	● Mainly controlled either by alkali degeneration gene (*alk*) which codes for starch synthase IIa (*SSIIa*) ● CAPS markers developed targeting SNPs of *SSIIa* and GC/TT polymorphism explored for developing markers for its association
Gel Consistency	QTLs identified, no perfect markers have been reported
Kernel elongation on Cooking	■ A simple marker (DRR GL-1) targeting the functional nucleotide polymorphism at *GS3* showed effective genotyping of kernel elongation in Basmati and non Basmati genotypes ■ *Os*SPL16 for grain size & shape
Chalkiness	● QTLs identified on Chrs.2, 4, 5 and 10 ● such chromosomal regions could be targets for MAS, fine mapping and map based cloning for low chalkiness breeding

Milling Characteristics of Released Hybrids, 1990 - 2000

Hybrid	Hulling (%)	Milling (%)	HRR (%)	KL (mm)	KB (mm)	L/B ratio	Grain type
DRRH-1	77.5	67.8	54	6.8	2.1	3.3	LS
KRH-2	77.6	67.3	57.3	6.1	2.2	2.8	LS
ADTRH-1	79.1	70.9	48.8	6.6	2.1	3.2	LS
PHB-71	79.7	71.3	58.6	6.5	2.1	3.1	LS
NSD-2	78.3	70.5	46.2	6.6	2.2	3.0	LS
PA 6201	77.2	70.1	59.6	6.0	2.1	2.8	LB
APHR-2	76.6	67.8	55.9	6.2	2.1	2.9	LB
CNRH-3	77.6	70.3	51.7	5.8	2.3	2.6	MS
CORH-2	79.0	70.9	48.0	5.9	2.3	2.6	MS
DRRH 2	-	72.9	63.0	6.66	1.96	3.39	LS
CRHR 5	75.9	70.2	59.2	6.78	1.98	3.42	LS
CRHR 7	80.0	72.3	62.0	6.80	1.99	3.42	LS
NDRH 2	81.40	72.30	53.30	6.99	2.06	3.39	LS
NDURH-3	-	70.50	52.50	5.95	2.16	2.75	MS
PSD-3	-	70.7	63.8	6.91	2.09	3.31	LS
Jaya	78.7	71.5	68.5	5.9	2.6	2.3	SB
Samba Mahsuri	78.3	70.2	64.0	4.9	1.8	2.8	MS

HRR: Head rice recovery; KL : Kernel length; KB : Kernel breadth; L/B ratio: Length/ breadth ratio

Cooking Characteristics of Released Hybrids, 1990 - 2000

Hybrid	ASV (%)	AC (%)	WU (ml)	VER	KLAC (mm)	ER (mm)
DRRH-1	5.2	22.4	208	5.3	11.3	1.7
KRH-2	5.0	20.9	203	4.7	12.3	2.0
ADTRH-1	5.1	24.5	240	5.0	11.4	1.7
PHB-71	6.0	22.8	223	4.7	12.4	1.9
NSD-2	6.1	21.2	238	5.0	11.7	1.8
PA 6201	4.5	21.3	110	5.2	10.9	1.8
APHR-2	2.5	27.8	260	3.8	10.2	1.6
CNRH-3	3.5	27.5	220	4.5	10.9	1.9
CORH-2	4.1	25.9	355	4.7	11.3	1.9
DRRH 2	7.0	26.04	220	5.1	9.2	1.42
CRHR-5	5.0	23.8	218	4.0	11.1	1.64
CRHR-7	4.5	24.9	222	4.08	11.0	1.62
NDRH-2	-	25.70	305	3.78	11.06	1.66
NDURH-3	5.5	-	-	-	-	-
PSD-3	7.0	20.0	245	3.9	11.9	1.72
Jaya	7.0	27.9	293	4.0	11.7	2.0
Samba Mahsuri	4.9	22.6	220	4.2	9.4	1.9

ASV: Alkali spreading value; AC: Amylose content; WU: water uptake; ER: Elongation ratio; VER: Volume expansion ration

Popular Hybrids grown in the Country

Public Sector	Private Sector
KRH-2	PHB-71
Pusa RH 10	PA-6201
DRRH-2	PA-6129
Sahydri-4	PA- 6444
CORH-3	JKRH-401

In addition to these released hybrids 30-40 truthfully labeled hybrids from private sector are being cultivated in the country.

KRH-2 Quality Characters & Crop Stand

Kernel length (mm)	6.1
Kernel breadth (mm)	2.2
L/B ratio	2.8
Grain Type	LB
Kernel appearance	White, VOC
Hulling recovery	77.6
Milling recovery	73.0
Head rice recovery	57.3
Alkali value	5.5
Amylose content	22.61
Aroma	Present

KRH-2

DRRH-2 Quality Characters & Crop Stand

Quality character	Parameters
Kernel length (mm)	6.50
Kernel breadth (mm)	1.96
L/B ratio	3.39
Grain Type	LS
Kernel appearance	White, VOC
Milling recovery (%)	71
Head rice recovery (%)	59
Alkali value	6.5
Amylose content (%)	25.6
Gel consistency (mm)	70.0

Sahydri-4 Quality Characters & Crop Stand

Quality character	Parameters
Kernel length (mm)	6.5
Kernel breadth (mm)	1.8
L/B ratio	3.6
Grain Type	LS, White
Milling recovery (%)	69.6
Head rice recovery (%)	40.3
Alkali value	7.0
Amylose content (%)	22.6
Gel consistency (mm)	63.5
Aroma	Present

CORH-3 Quality Characters & Crop Stand

Quality character	Parameters
Kernel length (mm)	6.50
Kernel breadth (mm)	2.2
L/B ratio	2.95
Grain Type	LB, White
Milling recovery (%)	68.2
Head rice recovery (%)	60.3
Alkali value	4.0
Amylose content (%)	21.7
Gel consistency (mm)	70

CORH-3

DRRH-3 Quality Characters & Crop Stand

DRRH 3 (IET 19453) is the first hybrid with Samba Mahsuri type grain quality. It recorded 31% higher yield than Samba Mahsuri and is R - NBL and MR - BS, RTV and LBL.

Quality Parameter	DRRH 3	BPT 5204
Head Rice Recovery (%)	56.7	61.4
Kernel Length (mm)	5.36	4.93
L/B Ratio	2.60	2.68
Alkali Spreading Value	4.6	5.0
Amylose Content (%)	24.90	24.14

Pusa RH-10 : The World's First Superfine Grain Aromatic Rice Hybrid

Quality character	Parameters
Kernel length (mm)	7.16
Kernel breadth (mm)	1.79
L/B ratio	4.0
Grain Type	LS, White
Kernel appearance	VOC
Milling recovery (%)	71.1
Head rice recovery (%)	46.2
Kernel Length After Cooking (mm)	11.2
Alkali value	7.0
Amylose content (%)	22.05
Aroma	Present

Quality Characters of PHB 71 & PA 6201

PA 6201	
Quality characters	**Para-meters**
Kernel length (mm)	6.0
L / B ratio	2.8
Head Rice (%)	61.0
Amylose Content (%)	24.0
Alkali value	4.8

PHB 71	
Quality characters	**Para-meters**
Kernel length (mm)	6.5
L / B ratio	3.1
Head Rice (%)	58.6
Amylose Content (%)	22.8
Alkali value	2.4

Quality Characters of PA 6444 & VNR 204

PA 6444

PA 6444	
Quality characters	**Values**
Kernel length	6.4
L / B ratio	3.0
Head Rice	64.0
Amylose Content	24.5
Alkali value	4.5

VNR 204	
Quality characters	**Values**
Kernel length	6.6
L / B ratio	3.3
Head Rice	67.2
Amylose Content	24.1
Alkali value	4.0

VNR 204

Quality Characters of PA 6129 & JKRH 401

PA 6129

PA 6129	
Quality characters	Value
Kernel length (mm)	6.3
L / B ratio	2.7
Head Rice (%)	70.7
Amylose Content (%)	23.1
Alkali value	7.0

JKRH 401	
Quality characters	Value
Kernel length (mm)	6.3
L / B ratio	2.9
Head Rice (%)	61.5
Amylose Content (%)	23.5
Alkali value	5.2

Promising Hybrids with Medium Slender Grain Quality

Hybrid	Grain yield		Grain quality traits					
	t/ha	Adv (%)	Mill (%)	HRR (%)	WU (ml)	ASV	AC (%)	GC (mm)
DRRH-3	6.1	33	72	67	205	5.0	23.8	63
27911	5.8	26	74	70	255	5.0	22.9	26
HRI 159	5.4	17	69	65	245	5.0	22	24
BPT 5204	4.6	--	72	68	200	5.0	23.4	23

Commercialization of DRR Hybrids

DRR has made 16 MoAs (DRRH-2 [8], DRRH-3 [7], Improved Samba Mahsuri [1]) with private companies following the ICAR Guidelines on non-exclusive basis for commercialization, production and marketing of DRR varieties/hybrids with the use of DRR & ICAR logo and on certain payment criteria.

MoA with JK Agri Genetics Ltd for DRRH 3

MoA with Chareon Pokphand Seeds Pvt. Ltd for DRRH 2

Prospects for Quality Improvement Rice Hybrids

- It is very important to choose those parental lines which have an excellent array grain quality traits and consumer acceptability for developing rice hybrids.
- Parental lines having diverse endosperm properties should not be chosen.
- Hybrids with enhanced head rice is possible when both parents have high HRR likewise to produce MS grain type crossing among the long, medium and short grain parents can be attempted.
- It is essential that the important quality features of typical basmati varieties have to be retained.
- For Genes/QTLs reported tightly linked markers and their validation needs to be done before attempting marker assisted breeding for improving quality traits in varieties/hybrids.
- The key to success lies in selection of suitable parental lines.

Prospects for Quality Improvement Rice Hybrids

One state of art National Facility for Quality, Processing and Nutrition laboratory needs to be established in XII plan with suitable adequate staff at DRR.

Thank You