Effect of Temperature During Grain Development on Stability of Cooking Quality Components in Rice

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Thirty one rice varieties representing five amylose categories were grown under four different controlled temperature conditions in the IRRI Phytotron to study the effect of temperature during grain development on the amylose content, gelatinization temperature, and gel consistency. Stability analysis revealed predominance of linear component of variety-temperature interaction for all the three components. In general the amylose content decreased with increasing temperature. All the variety in the waxy group and majority of those in high amylose group showed absence of variety-temperature interaction for amylose content. Varieties in the very low, low and intermediate categories were either responsive or unstable. Similarly for gelatinization temperature and gel consistency also a number of varieties showed absence of interaction with temperature, some were responsive and others unstable. Waxy varieties IR29 and Malagkit Sungsong and high amylose variety IR42 were found to exhibit no interaction with the temperature for all the three quality components. Implications of the study on breeding strategy are discussed.

KEY WORDS: *Oryza sativa* L., amylose content, gelatinization temperature, gel consistency, stability, controlled temperatures.

Introduction

Rice is one of the most extensively cultivated crops in the world and is grown under wide range of environmental conditions extending from 53°N to 40° S and from sea level to an altitude as high as 2000 M or more. Such a great diversity in agro-climatic factors affect both yield and cooking quality characteristics of rice kernels. Preferred cooking quality may change from one ethnic group or geographic region to another (Juliano *et al.* 1964). Thus it becomes essential to breed varieties showing least changes in cooking quality characteristics when grown under such diverse agro-climatic regions. Since the cooking quality primarily depends on amylose content, gelatinization temperature and gel consistency of rice starch, the stability of performance of these attributes would be of interest to the breeders. The present investigation was thus undertaken to assess the effect of four ambient temperatures on the stability of cooking quality components of thirty one varieties representing all five categories of amylose content.

Materials and Methods

Thirty one rice varieties, seven each form very-low (2.1~10.0%) and high (<25%); six each from waxy (0~2%) and intermediate (20.1~25.0%); and five from low amylose content (10.1~20.0%) categories were chosen for the study. The varieties were selected from the yield trials of the Plant Breeding Department, IRRI, based on the amylose content for the last two seasons. All the varieties were seeded in the wooden boxes kept at 29°C/21°C

growth chamber of the Phytotron at the International Rice Research Institute, Los Banos, Philippines. Thirty day old seedlings of each variety were transplanted in eight pots with two plants in each pot. Two pots of each variety represented two replications for each of the four temperature treatments to be given from flowering to maturity. Pots were randomized within each replication and kept at 29/21°C until flowering. As soon as a variety flowered it was shifted to its respective day (8 hours)/night (16 hours) temperature treatment chamber i.e. 25/21°C, 29/21°C, 33/25°C, and 37/29°C in the Phytotron till maturity. The pots within each replication were kept at random.

Individual plants were harvested at maturity, air dried and stabilized for moisture content in the air conditioned grain quality laboratory of the Plant Breeding Department at IRRI. The rough rice was dehulled in Satake dehuller and polished in test tube miller. Samples were analyzed for amylose content (JUJIANO, 1971), gelatinization temperature (LITTLE et al. 1958) and gel consistency (CAGAMPANG et al. 1973). The data were analyzed following EBERHART and RUSSEL (1966) and PERKINS and JINKS (1968) stability models.

Results and Discussion

The joint regresion analysis of the data are presented in Table 1. The results indicate that differences between the varieties, the temperatures and variety-temperature interactions were significant. Heterogeneity between regressions (linear) and remainder (non-linear) components of variety-temperature interaction were highly significant. However, the linear component was predominant compared to the non-linear component in all the cases suggesting the differences among the varieties for their response to changing temperature and stability over temperatures.

Estimates of the stability parameters viz. mean, b_i and S^2_{di}; and individual regression analysis for all the varieties are presented in Table 2 for the three cooking quality characteristics.

Amylose content

Based on individual regression analysis the 31 varieties could be grouped into three categories. The first category shows absence of g × t interaction; as observed in the six varieties of waxy group and four varieties (IR42, IR68, SPR 7419-92-2 and Kartiksail) of high amylose content group. Stability parameters also indicated these varieties to be highly stable ($S^2_{di} \sim 0$). These varieties are expected not to show any significant change in their amylose content irrespective of temperature fluctuations and are hence the most stable varieties. The second category shows significant regression and non-significant remainder ms; as observed in 12 varieties. All these varieties though stable differ in their linear response to temperatures. Nine of them viz. IR2071-137, IR42235-4 in very low amylose group; IR24 and CP231 in low amylose; Basmaṭi 370, IR36 and Punjab Basmati in the intermediate; and IR8 and RD19 in high amylose group were average responsive to temperatures. Remaining three varieties IR37307-8, Nagadhan and IR480-5 were above average responsive. Their behaviour is predicable in the sense that when such varieties as IR37307-8 is grown at a location where ambient temperature during grain development is in the range of 25/21°C it is expected to produce around 17-18% amylose content but at another location with temperatures

Table 1. Joint regresson analysis in respect of amylose content, gelatinization temperature, and gel consistency in rice

Source of Variation	Amylose content		Gelatinization temperature		Gel Consistency	
	d.f.	MS	d.f.	MS	d.f.	MS
Varieties	30	320.09**	28	8.84**	25	2046.87**
Temperatures (Joint regresseion)	3	148.96**	3	1.44**	3	85.26**
Varieties × Temperatures (G × T int.)	90	5.30**	84	0.24**	75	50.76**
Heterogeneity between regressions	30	11.86**+	28	0.49**+	25	86.61**+
Remainder	60	2.02*	56	0.12**	50	32.84**
Pooled error	111	0.69	103	0.05	94	11.65

*, **: Significant at 5% and 1% levels, respectively.
**+: Heterogeneity between regression significant against error m.s. as well as against significant remainders m.s.

Table 2. Estimates of stability parameters and individual regression analysis for different quality components in rice

Varieties	Amylose content			Gel. Temperature			Gel. Consistency		
	X	bi	S²di	X	bi	S²di	X	bi	S²di
Waxy									
IR29	0.04	-0.01	-0.683	7.0	0.00	-0.049	99.9	0.11	-11.612
IR65	0.07	-0.05	-0.681	6.7	1.71*	0.147*	100.0	0.00	-11.647
Malagkit Sungsong	0.03	-0.01	-0.648	6.6	0.70	-0.016	89.2	1.53	-11.621
UBN6721-11-1-6 (3)	0.12	-0.01	-0.648	—	—	—	100.0	0.00	-11.647
Niaw San Pah Tawng	0.15	0.04	-0.686	6.9	0.17	0.013	—	—	—
Kap Nhay	0.0	0.00	-0.691	5.6	3.06**+	0.056	82.8	3.19*	42.540*
Very low amylose									
IR2071-137-5-5-1	6.82	1.24*	-0.624	2.6	2.08*	0.020	80.9	-0.14	5.869
IR37815-20-2-2-2	6.15	1.28*	3.120*	7.0	0.00	-0.049	86.7	1.89	8.206
IR37307-8	10.36	2.62*+	0.900	6.5	1.58*	-0.028	68.2	-1.95	2.381
Nagadhan	11.62	2.23*+	-0.398	6.6	0.68	0.064	—	—	—
IR42235-3-3-3	8.19	1.58*	4.515*	3.0	-0.74	-0.015	83.5	1.08	46.586*
IR42235-4-1-2	6.40	0.58*	0.049	3.0	0.57	-0.007	79.2	1.45	31.913*
Adan Buda	10.33	1.91**+	2.343*	3.1	-2.54*+	0.907*	70.1	0.22	1.821

Varieties	Amylose content			Gel. Temperature			Gel. Consistency		
	X	bi	S^2_{di}	X	bi	S^2_{di}	X	bi	S^2_{di}
Low amylose									
Pusa 167-120-3-2	12.74	1.61*	2.898*	6.8	1.41*	0.046	70.8	4.05*	2.382
ARC 11554	18.27	1.24*	4.258*	4.4	-0.60	0.237*	38.9	-1.46	-2.550
IR24	11.17	1.24*	0.346	6.7	1.75*	0.193*	71.1	0.03	5.786
IRAT 13	9.51	2.17*+	4.213*	3.4	2.36*	0.091	82.5	1.17	15.374
Century Patna 231	12.82	1.47*	-0.006	2.4	1.69*	0.145*	88.8	-0.88	90.297*
Intermediate amylose									
Basmati 370	20.38	1.50*	0.460	4.8	0.20	-0.016	—	—	—
IR36	20.59	0.52*	1.128	5.6	4.82*+	0.021	32.6	-0.19	-11.539
IR480-5-9-3	19.10	1.91*+	0.728	6.8	2.25*	0.352*	51.2	7.41*+	154.319*
IR24632-34	17.42	2.93*+	9.518*	—	—	—	—	—	—
BPI 121-407	18.65	1.91*+	4.993*	6.9	0.31	-0.042	43.9	4.70*	266.727*
Punjab Basmati	20.69	0.94*	-0.508	4.9	-0.03	0.193*	41.7	0.69	26.998*
High amylose									
IR8	23.87	0.86*	1.161	6.9	0.19	-0.047	31.1	0.02	-11.483
IR42	25.87	-0.18	0.285	7.0	0.06	-0.049	30.8	0.36	-11.017
IR68	26.80	0.36	0.195	7.0	0.00	-0.049	—	—	—
Pusa 150-9-4-1	23.85	0.45*	1.728*	6.9	-0.03	-0.021	31.0	-0.50	-11.354
SPR7419-92-2-1	26.38	-0.13	-0.504	7.0	0.00	-0.049	56.5	7.37*+	-4.838
Kartiksail	27.37	-0.03	-0.137	5.6	2.25*+	0.072	75.8	-5.03*+	45.292*
RD19	24.54	0.73*	-0.605	5.1	6.09*+	0.819*	44.9	3.95*	69.258*
SE ±	0.82	0.33		0.2	0.93		3.3	2.05	
CD 5%	1.64			0.4			6.6		

* Significant regression m.s. in case of b_1 and significant remainder m.s. in case of S^2_{di} at 5% level.

** Regression m.s. significant against error m.s. and its significant remainder m.s.

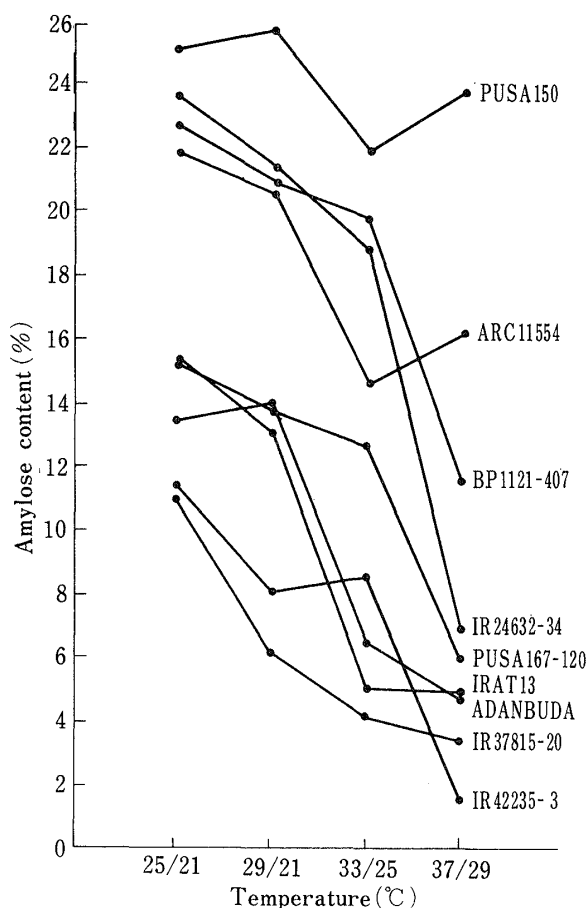+ b_1 significantly different from 1.0

Fig. 1. Effect of temperature from flowering to maturity on amylose content of unstable genotypes in different amylose categories.
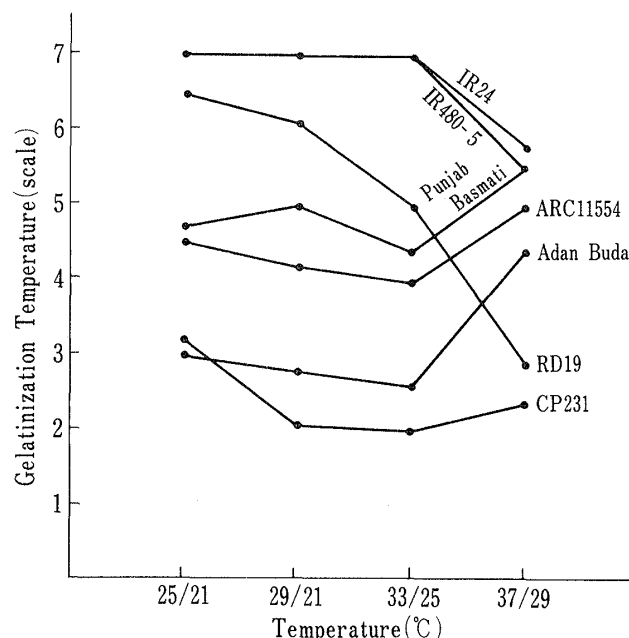

Fig. 2. Effect of temperature from flowering to maturity on the geletinization temperature of unstable genotypes.

around 37/29°C its amylose may be as low as 4%. The third category shows significant regression and remainder ms, as observed in varieties IR37815-20, IR42235-3, Pusa 167-120, ARC 11554, IRAT 13, IR24632-34, BPI 121-407, Pusa 150-9 and Adan Buda. Both the linear and non-linear components were of almost equal magnitude in all the varieties except Adan Buda where linear component was predominant. All these varieties were highly unstable ($S^2_{di} \neq 0$). Drastic fluctuations in the amylose content of these varieties at different temperatures are presented in Fig. 1. In variety IR24632-34 the amylose content dropped from 23.5% (at 25/21°C) to as low as 6.9% (at 37/29°C), a reduction of about 16%. So a variety which may be intermediate amylose at a sub-temperate location can be very low amylose at a tropical location.

Gelatinization temperature (GT)

Based on individual regresson analysis and stability parameters, eleven varieties of low GT group (Alkali Digestion value <5.0); Basmati 370 of intermediate GT (ADV = 4 to 5); and two varieties viz IR42235-3 and IR42235-4 of high/intermediate GT (ADV = 3) showed absence of variety-temperature interaction and were thus the most stable varieties. Their
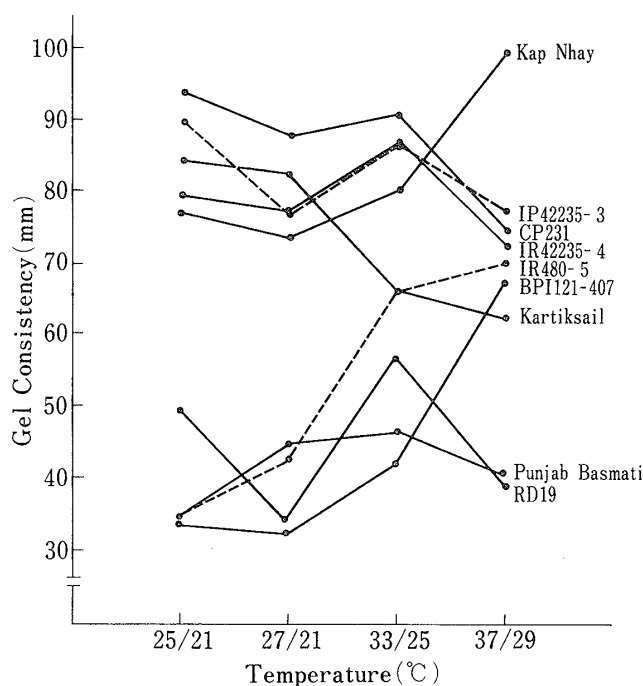
Fig. 3. Effect of temperature from flowering to maturity on gel consistency of unstable genotypes.
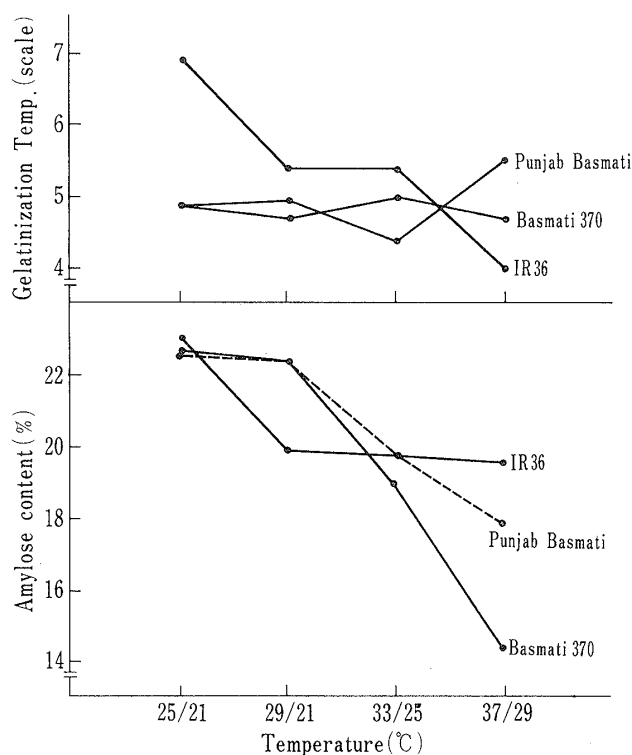

Fig. 4. Effect of temperature from flowering to maturity on the amylose content and gelatinization temperature of some high quality rices.

gelatinization temperature is expected to remain unchanged under most temperature situations. Varieties Kap Nhay, IR37307-8, Pusa 167-120, IR36 and Kartiksail of low GT; IRAT 13 of high/intermediate GT; and IR2071-137 of high GT group had only significant linear component. These varieties though stable, differed in their linear response to temperatures and all above varieties except IR36 and Kap Nhay were average responsive. Varieties IR65, IR24, IR480-5 and RD19 of low; ARC 11554 and Punjab Basmati of intermediate and Adan Buda and CP231 of high GT group were highly unstable as S^2_{di}, the non-linear component of g × t, was highly significant in all these cases. Variation in the ADV of these varieties at different temperatures are presented in Fig. 2. ADV score of RD19 dropped from 6.4 at 25/21°C temperature to as low as 2.8 at 37/29°C and that of Adan Buda increased abruptly from 2.6 at 33/25°C to 4.4 at 37/29°C.

Gel Consistency

The gel consistency of different varieties varied differently at different temperatures. Ten varieties with soft gel consistency (51 to 100 mm gel length) and all the five varieties with hard (30 to 40 mm) or medium GC (ARC 11554, IR36, IR8, IR42 and Pusa 150-9) showed no variety-temperature interaction i.e. their GC remained stable over all the temperatures. Pusa 167-120 and SPR7419-92 with soft GC had only significant linear component and were thus stable with average and above average responsiveness, respectively. Khap Nhay, IR42235-3, IR42235-4, CP 231 and Kartiksail with soft GC and IR480-5, BPI 121-407, RD19 and Punjab Basmati with medium GC were highly unstable varieties as non-linear component (S^2_{di}) was highly significant in all

these cases. The gel consistency of these unstable varieties at various temperatures are presented in Fig. 3. Gel consistency of Kartikasail decreased from 84.5 at 25/21°C to 62.5 at 37/29°C, whereas that of BPI 121-407 increased from 32.5 at 29/21°C to 67.0 at 37/29°C to 67.0 at 37/29°C.

IR29 and Malagkit Sungsong among the waxy group and IR42 among the high amylose group turned out to be the most stable varieties for all three cooking quality components. Fig. 4 shows fluctuations in amylose content and gelatinization temperatures of Basmati 370, Punjab Basmati and IR36. Basmati rices which are specifically adapted to sub-tropical areas where temperatures during ripening remain cooler, show a deterioration of quality characteristics when grown in tropical areas. As revealed from the graphs the amylose content of Basmati 370 remains in the intermediate category when grown at temperatures below 30°C. At higher temperatures the amylose decreases to low, thus resulting in less flakiness and slight stickiness of the cooked rice.

Implications in breeding program

The variability of any variety with respect to environment can be subdivided into predictable part corresponding to regression and an unpredictable part corresponding to deviation from regression. A variety is considered stable if it shows least deviation from regression. Unlike grain yield where the breeders want rice varieties with linear response to environments like fertilizer etc., the scientists working on cooking quality aspects are interested in varieties which do not show any change in the quality traits. The term stability in true sense, in such cases, is referred to relative absence of variety $\times$ temperature interaction. Varieties with average responsiveness (b $=$ 1 and S^2_{di} $=$ 0) is the second choice of the breeder, whereas, varieties with b$>$/1 or b$<$1 and S^2_{di}# 0 would be undesirable from cooking quality point of view.

The results of present studies show high stability for amylose content in waxy and high amylose content varieties. The selection for these amylose content levels can thus be done in relatively broad category of environments. For very-low, low and intermediate amylose content varieties, which are more vulnerable to changes in temperature, the selection may be done in the region where they have to be grown. Otherwise, a variety bred in temperate region may show different amylose content and thus change cooking characteristics when grown in tropical areas or vice versa. Same will hold true for other quality characteristics. Effect of temperature on starch properties has also been recorded in japonica rices (OKUNO et al. 1985; TAKEDA and SASAKI, 1988). ASAOKA et al. (1984) reported that the amylose concentration in the endosperm starch of rice is determined by the environment temperature from 5 to 15 days after anthesis and that higher temperatures increase the amount of long chains and decrease that of short chains of amylopectin.

Although, very-low, low and intermediate amylose content is known to be controlled by a single major gene (KUMAR and KHUSH, 1986, 1987, 1988; KUMAR et al. 1987; YANO et al. 1988), the segregating material for the above amylose levels should be tested in different environments to select for suitable amylose level or other quality components lest the success to breed for the widely adaptable variety with desirable quality components may be delayed.

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米の食味諸要素に及ぼす登熟気温の効果

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米のアミロース含量, 糊北温度およびゲルコンシステンシーに及ぼす登熟気温の効果を明らかにするために, 5段階のアミロース含量 (糯, 極低, 低, 中および高) を代表する 31 品種を, IRRI のファイトトロン内 4 つの温度条件 (21／25, 29／21, 33／25 および 37／29℃) 下で生育させた. 食味に関するこれら 3 要素の登熟気温に対する安定性について分散分析した結果, 品種効果, 温度効果および品種と温度との交互作用はいずれも有意であった. また交互作用項では, 回帰の品種間差 (線型成分) および残差 (非線型成分) が共に高い有意性を示したが, 線型成分は誤差に対してだけでなく非線型成分に対しても有意であった. これは, 登熟気温に対する各要素の反応が, 品種によって大きな差のあることを示唆している. 一般に, 登熟気温の上昇に伴って, アミロース含量は低下した. 全ての糯品種およびほとんどの高アミロース品種では, アミロース含量に対する品種と温度との交互作用が認められなかった. 一方, アミロース含量極低, 低および中の品種は, 登熟気温に感応性 (回帰係数のみ有意) あるいは不安定 (回帰係数と残差共に有意) であった. 糊化温度およびゲルコンシステンシーについても, 多くの品種では温度との交互作用が認められなかった. 糯品種の IR 29 および Malagkit Sungsong ならびに高アミロース品種 IR 42 は, 3 要素全てについて最も安定していた. 本研究の結果から食味および広域適応性の両形質に関する育種戦略を考えると, アミロース含量極低～中レベルの品種育成については, 環境効果による食味諸要素の変動が認められるので, 選抜の場が重要な意味を持つことになろう.