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Genetics of gel consistency in rice (*Oryza sativa* L.)

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Abstract. Inheritance of gel consistency in rice was studied in crosses involving high-amylose, low-gelatinization temperature parents with hard, medium, and soft gel consistency. The results of single-grain analysis of parents, F_1, F_2, B_1F_1, B_2F_1, and their reciprocal crosses from a single-season harvest showed that the differences between hard and soft, hard and medium, and medium and soft gel consistency are under monogenic control and that modifiers affect the expression of the trait. Multiple alleles at the same locus, hereby designated as *gec*^{a} for medium gel consistency and *gec*^{b} for soft gel consistency, were recessive to the wild type allele for hard gel consistency and *gec*^{a} was dominant over *gec*^{b}. The results indicate that selection for desired gel consistency can effectively be done in early segregating generations.

Keywords. Rice; gel consistency; inheritance; cooking quality.

1. Introduction

Gel consistency, which is a measure of cold paste-viscosity of cooked milled rice flour, is a good index of cooked rice texture, especially among rices of high amylose content. Rices differ in gel consistency from–soft to hard (Cagampang *et al.* 1973; Juliano 1979). Cooked rices with hard gel consistency harden faster than those with a soft one. Rices with soft gel consistency cook tender, and remain soft even upon cooling (Juliano 1979). Rices with soft gel consistency are preferred by most rice consumers. Breeders are therefore trying to develop high-yielding varieties with soft gel consistency (Khush *et al.* 1979). Information on the inheritance of the trait is useful for adopting appropriate selection procedures. This study was therefore undertaken to investigate the inheritance of gel consistency in rice.

2. Materials and methods

Three true breeding lines–IR33043–46 (soft gel consistency), IR28224-3 (medium gel consistency), and IR37865-29 (hard gel consistency)–were used in the study. These lines have a high amylose content, low gelatinization temperature, and are similar in other agronomic characteristics. They were crossed with each other in a diallel manner including reciprocals in the 1987 dry season. The parents and F_1s were grown in the 1987 wet season at the International Rice Research Institute (IRRI), Los Baños, Philippines, to obtain F_2 seeds. F_1s were also crossed with both parents to produce B_1F_1 and B_2F_1 seeds. Additional F_1 seeds of the crosses were again produced during the 1987 wet season. Thus, F_1, F_2, and backcross seeds produced in the same season, were used for genetic analysis to minimize environmental effects.

The dehulled grains of the above populations were milled in a test tube miller. The embryo remnants were carefully removed from each grain with a blade. The methods of Cagampang *et al.* (1973) and Zaman *et al.* (1985) were modified to carry

out single grain analysis for gel consistency. All grains were stored in an airconditioned room for 5 days to stabilize the moisture content at about 12%. The individual grains were ground in a Wig-L-Bug amalgamator using a plastic tube for 15 s to a fine powder of about 100 mesh.

A ten milligramme sample of ground powder of each grain was weighed and put into a 7-x 75-mm test tube. Three small drops (0·026 ml) of 95% ethanol containing 0·025% thymol blue were added to each tube. The tubes were shaken well by stirring in a Vortex Genie, 0·26 ml of 0·2 N KOH was then added, and the tubes stirred again. The test tubes were covered with glass marbles, placed over a boiling water bath for 6 min, removed and kept at room temperature for 5 min, and finally transferred to an ice-water bath for 15 min. After this treatment, the tubes were placed horizontally on a table for 30 min before measuring the gel length from the bottom of the tube to the end of the gel in millimetres. The single grain analysis for gel consistency was carried out with 30 seeds from each parent and each F_1, 360 seeds from each F_2, and about 40–80 seeds from each backcross population.

3. Results

3.1 *Cross IR37865-29/IR33043-46 (hard/soft gel consistency)*

The cold gels of parent IR37865-29 were shorter, with a mean length of only 19·2 mm (hard gel consistency), while those of parent IR33043-46 were longer, with an average length of 54·5 mm (soft gel consistency) (figure 1). The two parents showed a difference of about 35·3 mm in gel length. The F_1 seeds of their cross had the mean gel length of 20·4 mm, being almost the same as that of the hard gel consistency parent. The mean gel length of the reciprocal F_1 seeds was 22·1 mm (figure 2). These results indicate that soft gel consistency is a recessive trait.

The segregation for gel consistency of F_2, B_1F_1, and F_2F_1 seeds is shown in figure 1. The F_2 seeds show a bimodal distribution with 275 seeds in category 1 (16–34 mm) and 85 seeds in category 2 (35–60 mm). These data show a satisfactory fit to the 3:1 ratio ($X^2=0·30$, $P=0·50$–$0·75$). The B_1F_1 seeds show a unimodal curve (17–30 mm). The B_2F_1 seeds clearly segregate into two classes with 36 seeds in category 1 (17–30 mm) and 32 seeds in category 2 (34–60 mm). These data fit a 1:1 ratio ($P>0·50$). The results show that soft gel consistency is a monogenic recessive trait.

The segregation of F_2, B_1F_1, and B_2F_1 seeds from the reciprocal cross show a similar pattern (figure 2). In the F_2 population, there were 269 seeds in category 1 (16–34 mm) and 91 seeds in category 2 (36–60 mm). These data fit a 3:1 ratio ($P>0·99$). The B_1F_1 seeds also show a unimodal curve (17–30 mm). The B_2F_1 seeds, as expected, segregate into two distinct classes with 34 seeds in the category of hard gel and 34 seeds in the category of soft gel, agreeing with a 1:1 ratio ($P>0·99$). The results confirm that soft gel consistency is under monogenic recessive gene control.

In the analysis of F_2 seeds, a variation in the gel consistency of each category of bimodal curve was observed. For instance, in category 1 of F_2 seeds of the cross IR37865-29/IR33043-46, the gel length varied from 16 to 34 mm, and in category 2, from 35 to 60 mm. The variation in gel consistency was also observed in the two backcross populations. These data suggest that, in addition to the single major

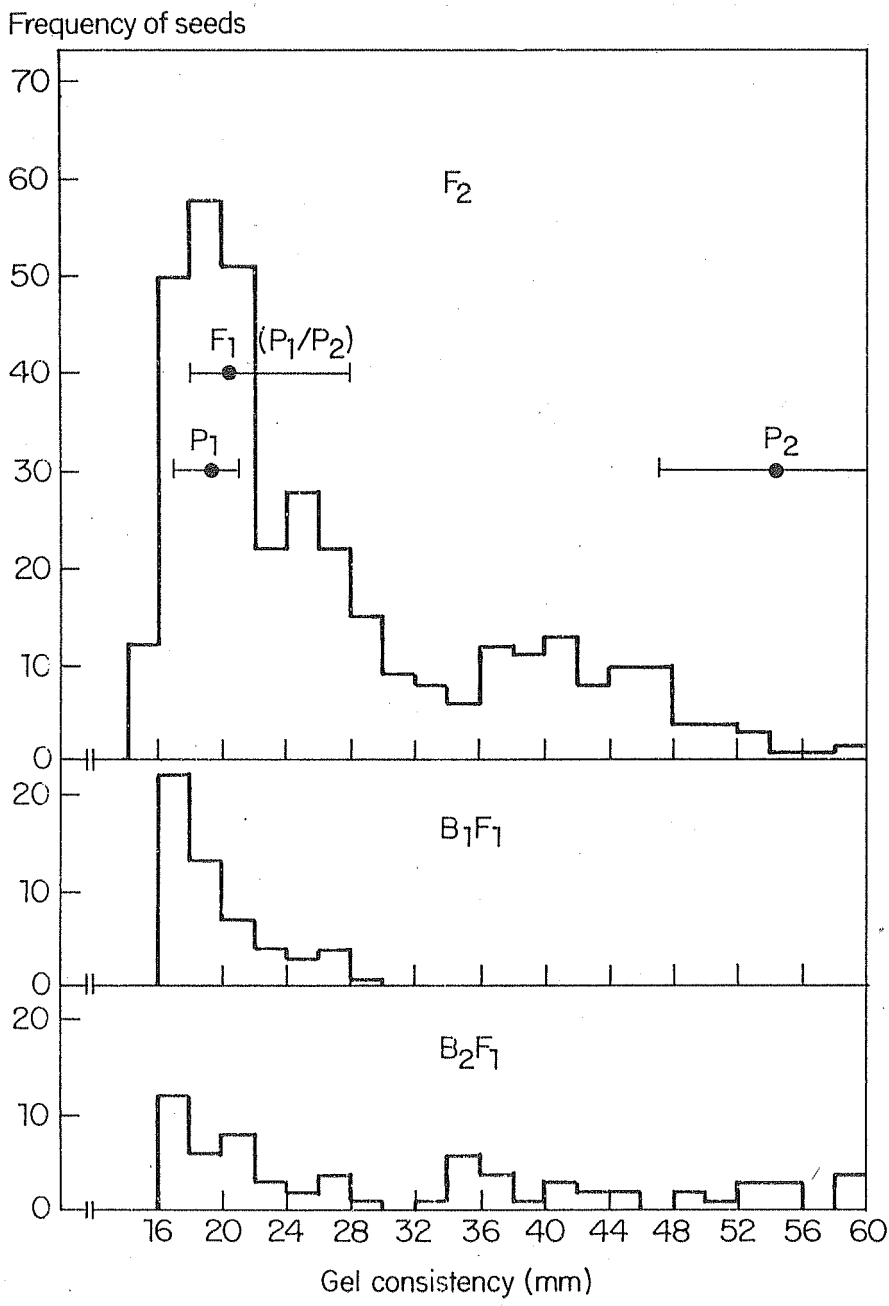

Figure 1. Frequency distribution of seeds with different gel consistency from the cross IR37865-29 (P_1)/IR33043-46 (P_2).

gene, several minor genes or modifiers influencing gel consistency segregate in this cross.

3.2 *Cross IR37865-29/IR28224-3 (hard/medium gel consistency)*

The average gel length of IR37865-29 was 19·2 mm and that of IR28224-3 was

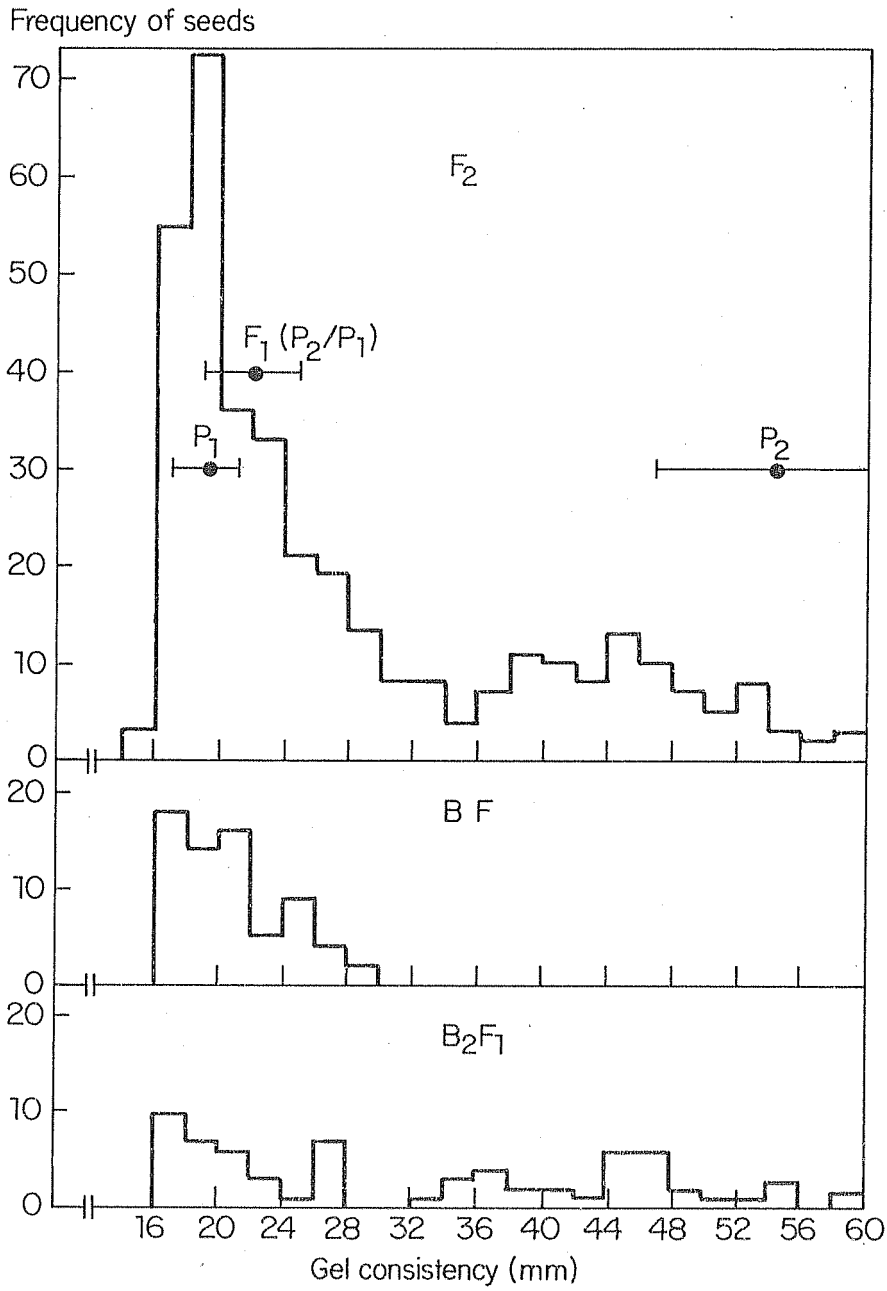

Figure 2. Frequency distribution of seeds with different gel consistency from the cross IR33043-46 (P_2)/IR37865-29 (P_1).

24·9 mm, showing only a small difference in gel length (figure 3). The gel consistency of the F_1 seeds of this cross was hard (20·8 mm). The reciprocal F_1 seeds had an average gel length of 21·9 mm (figure 4).

The gel length of F_2 seeds varied from 16 to 35 mm, indicating some transgressive segregation in the F_2 population (figure 3). However, the F_2 seeds could be

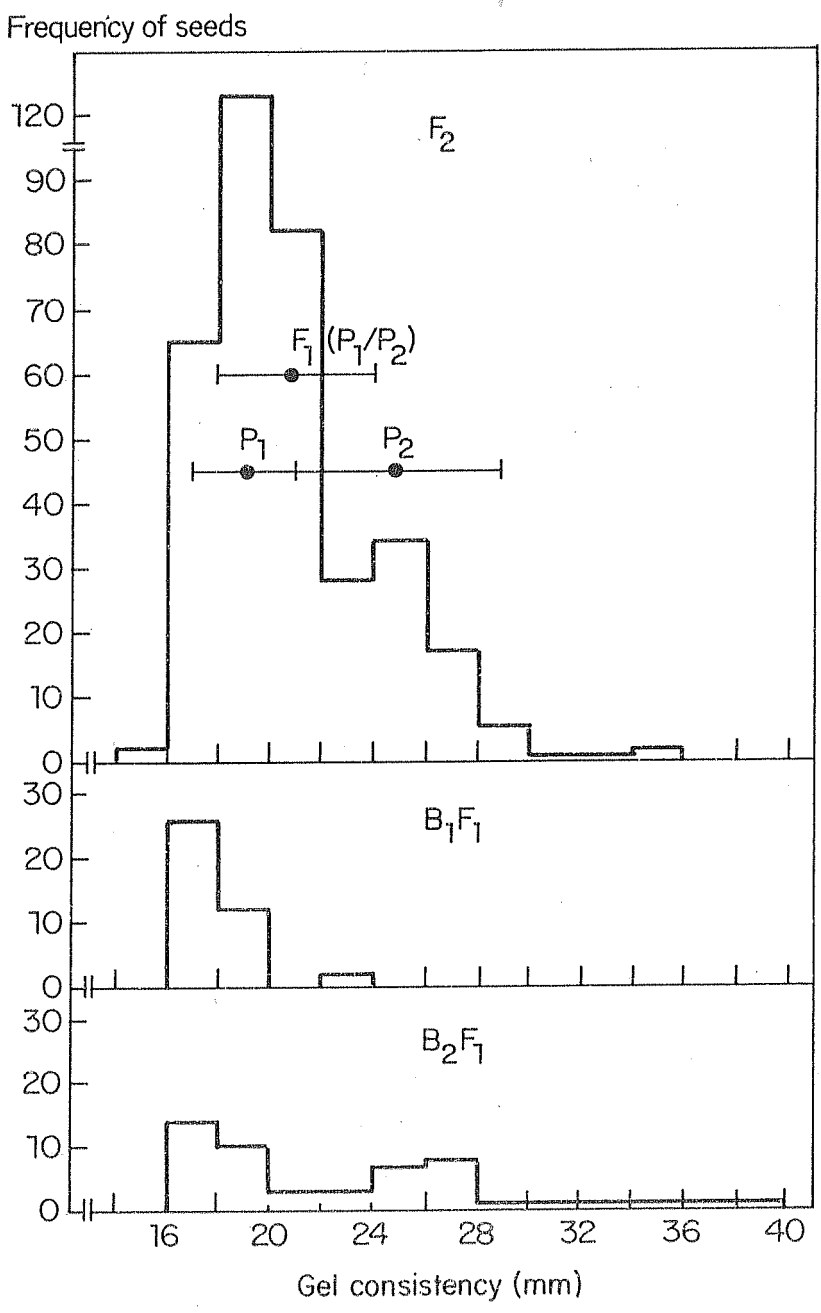

Figure 3. Frequency distribution of seeds with different gel consistency from the cross IR37865-29 (P_1)/IR28224-3 (P_2).

classified into two distinct categories, i.e., 16–22 mm and 23–35 mm. The distribution of the F_2 seeds into these classes was bimodal with 272 seeds in the first category and 88 seeds in the second category. These data agree with a 3:1 ratio ($P > 0{\cdot}75$). The B_1F_1 seeds show a unimodal distribution. The B_2F_1 seeds could be

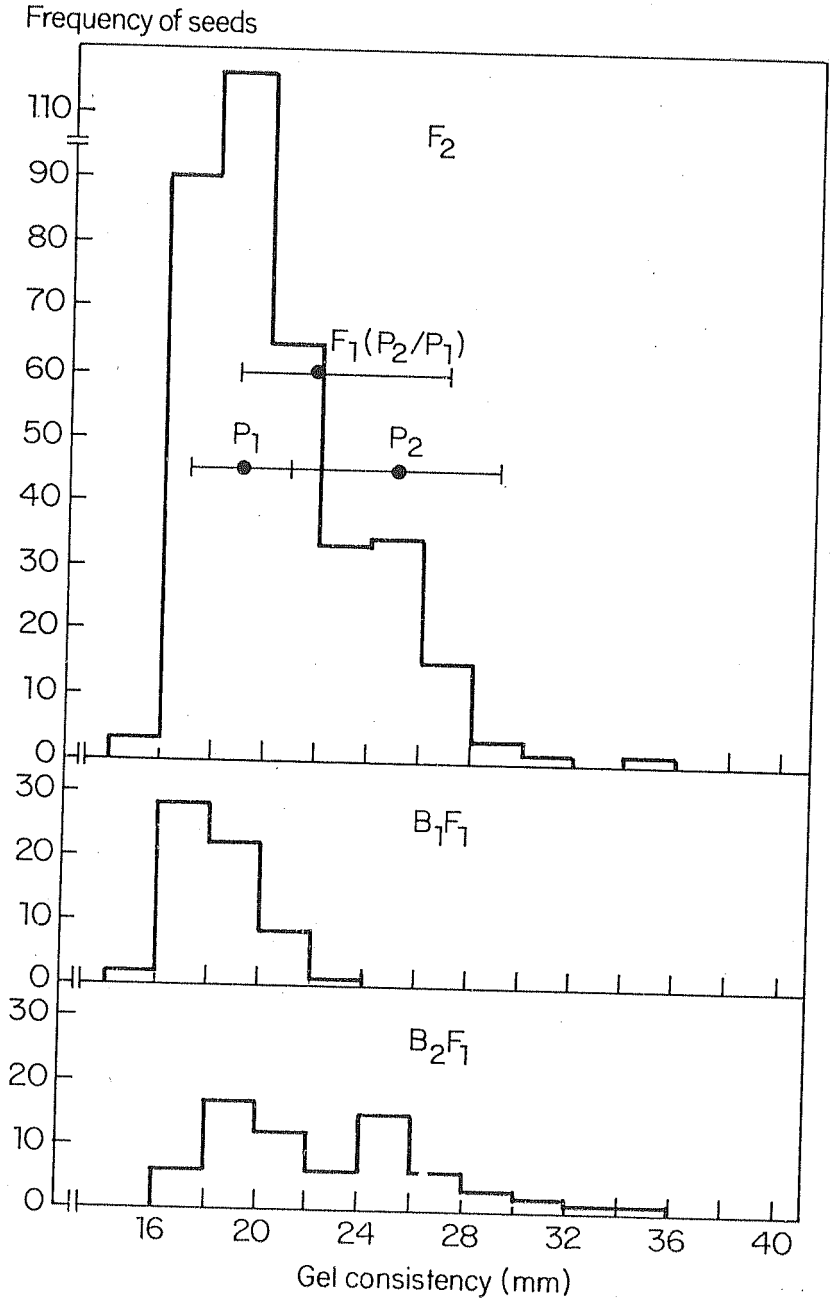

Figure 4. Frequency distribution of seeds with different gel consistency from the cross IR28224-3 (P_2)/IR37865-29 (P_1).

classified into two categories with 27 seeds in category 1 (17–22 mm) and 27 seeds in category 2 (24–40 mm). These data agree with a 1:1 monogenic ratio ($P > 0{\cdot}75$). The results of analysis of F_2, B_1F_1, and B_2F_1 populations show that medium gel consistency is monogenic and recessive to hard gel consistency.

The results of analyses of F_2, B_1F_1 and B_2F_1 populations of the reciprocal cross (figure 4) confirm the results obtained above. In the F_2 population, 273 out of 360 seeds had hard gel consistency (16–22 mm) and 87 seeds had medium gel consistency (23–35 mm). These data agreed with a 3:1 ratio ($P > 0{\cdot}75$). The B_1F_1 population showed unimodal distribution and B_2F_1 segregated in a ratio of 1:1. Some transgressive segregants were observed in the F_2 and the backcross populations. These data confirm that a single major gene and some modifiers govern the difference between hard and medium gel consistency and that medium gel consistency is a recessive trait to hard gel consistency.

3.3 *Cross of IR28224-3/IR33043-46 (medium/soft gel consistency)*

The average gel consistency of IR28224-3 was 24·9 mm and that of IR33043–46 was 54·5 mm, showing a difference of about 29·6 mm in gel length (figure 5). The F_1 seeds of their cross showed an average gel length of 29·2 mm, which is nearer to that of the medium gel consistency parent (IR28224-3). The reciprocal F_1 seeds had an average gel length of 31·8 mm (figure 6).

The F_2 seeds show a variation in gel consistency from 19 to 57 mm, with two distinct peaks (figure 5) indicating a bimodal distribution. There were 273 seeds in category 1 (19–36 mm) and 87 in category 2 (37–57 mm). This segregation also agrees with a 3:1 ratio ($P > 0{\cdot}75$). All the B_1F_1 seeds were within the range of the medium gel consistency parent. In the B_2F_1 population, there were 43 and 34 seeds in the two categories, respectively. This segregation agrees with a 1:1 ratio ($P > 0{\cdot}25$).

The results of analysis of F_2, B_1F_1, and B_2F_1 populations of reciprocal (figure 6) cross confirm the results obtained above. In the F_2 population, 259 seeds were in category 1 (gel length of 19 to 36 mm) and 101 in category 2 (gel length of 37 to 60 mm), showing a good fit to a 3:1 ratio ($P = 0{\cdot}30$–$0{\cdot}25$). The B_1F_1 seeds show a unimodal distribution. The B_2F_1 seeds display a bimodal pattern of segregation, with the dividing line at 36 mm. Forty-two seeds were placed in category 1 (gel length 21–35 mm) and the gel length of 40 seeds ranged from 37 to 67 mm, showing a satisfactory fit to a 1:1 ratio ($P = 0{\cdot}90$). These results show that soft gel consistency is recessive to medium and the difference is under monogenic control.

4. Discussion

The results of genetic analysis involving parents with hard, medium, and soft gel consistency clearly show that differences among the three categories are under monogenic control. Hard gel consistency is dominant over medium and soft gel consistency, and medium gel consistency is dominant over soft gel consistency. Thus, at least three multiple alleles at the same locus control this important grain quality characteristic. Plants with a wild type allele have hard gel consistency. Recessive alleles, herewith designated *gec*^{a} and *gec*^{b}, condition medium and soft gel consistency, respectively; *gec*^{a} is dominant over *gec*^{b}. The segregation data also show that in addition to the major genes, minor genes or modifiers also influence the expression of this trait and account for the occurrence of transgressive segregants in some crosses. Similar conclusions were drawn when the segregation

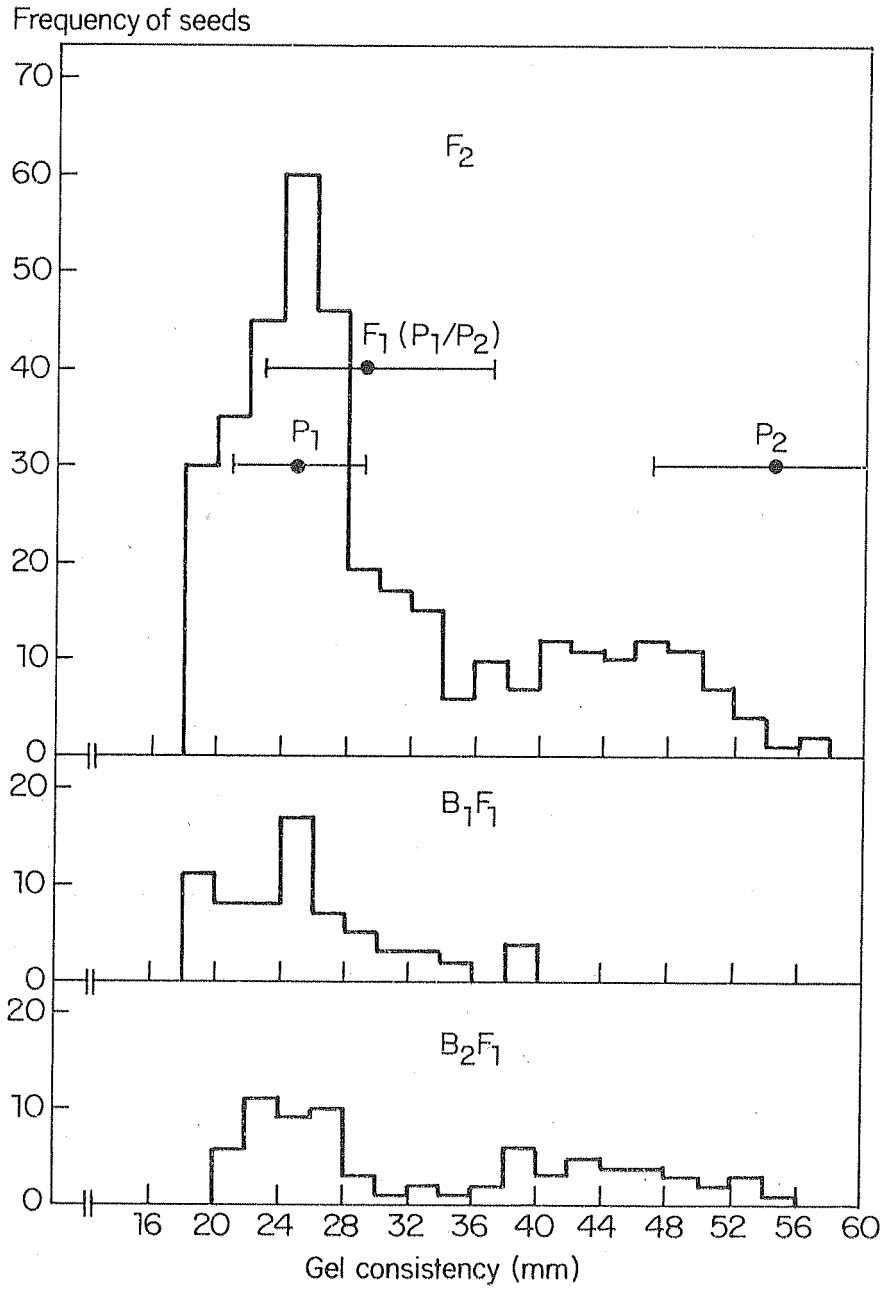

Figure 5. Frequency distribution of seeds with different gel consistency from the cross IR28224-3 (P_1)/IR33043-46 (P_2).

data was subjected to diallel analysis (Tang *et al.* 1989). It should be noted that multiple alleles at the same locus also condition amylose content in rice (Kumar and Khush 1987) which is another important determinant of grain quality.

Since the grains borne on an F_2 plant are genetically different from one another,

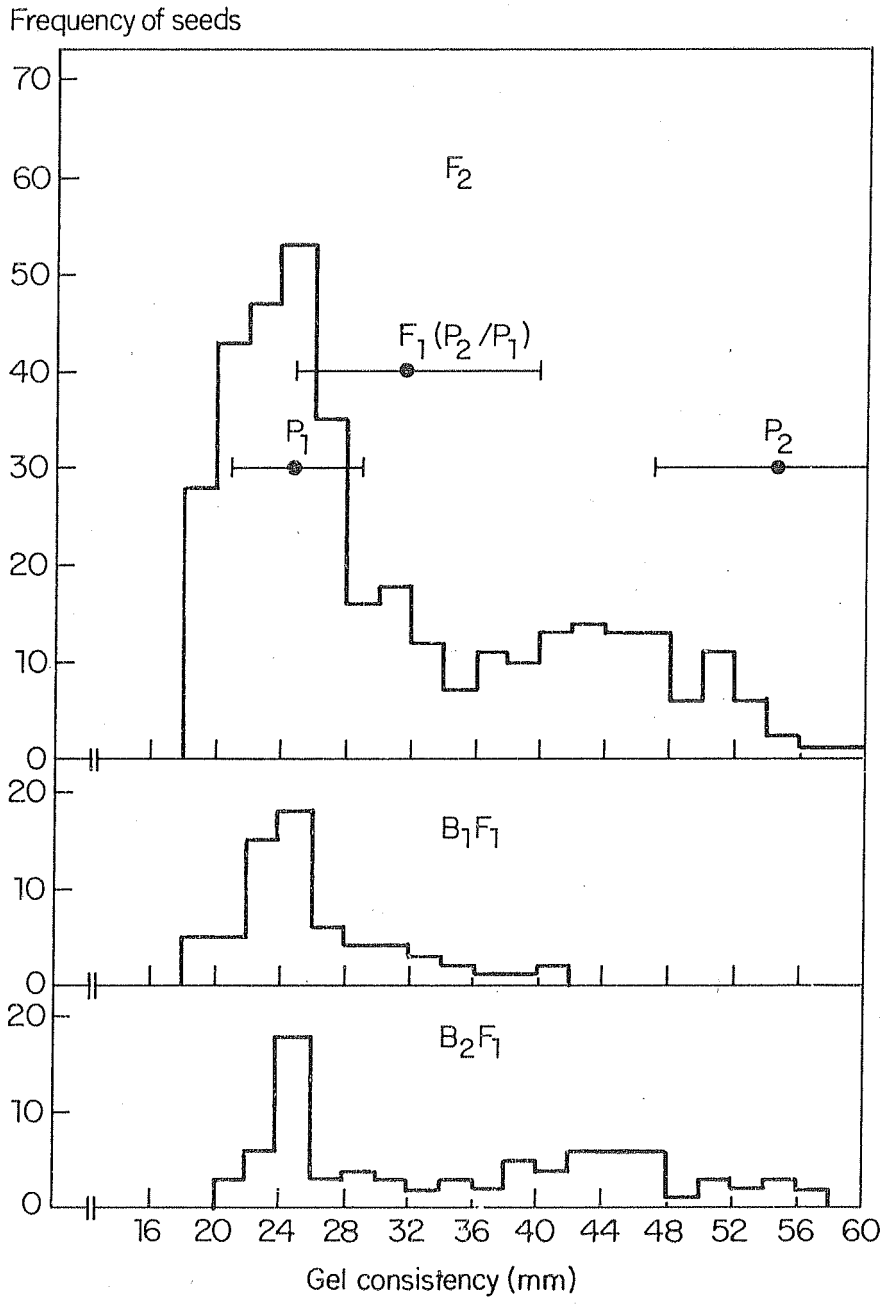

Figure 6. Frequency distribution of seeds with different gel consistency from the cross IR33043-46 (P_2)/IR28224-3 (P_1).

characteristics of quality must be determined on individual grains as in this study. In earlier studies on inheritance of gel consistency (Chang and Li 1981; Hsieh and Kuo 1982; Zaman *et al.* 1985), F_2 and F_3 seeds were bulked for genetic analysis and the results cannot be considered critical.

The results of this study show that rices with appropriate gel consistency can be easily selected (provided one of the parents has the desired gel consistency) and that selection in the early generations would be highly effective.

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