TORTILLA PRODUCTION: STUDY OF VARIABLES AFFECTING THE PROCESSING OF RAW CORN INTO TORTILLAS

by

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INTRODUCTION

The corn (Zea mays) tortilla is the "daily bread" throughout much of Latin America, Mexico, and parts of the United States (1 & 2). The popularity of Mexican foods, largely based on the tortilla is steadily increasing throughout most of the U. S. This rise in popularity has extended the demands for large-scale commercial production of tortillas.

The basics of processing corn into tortillas were developed many centuries ago by Indian cultures in Latin and South America. There the corn was cooked with water and alkali, allowed to steep (the hydrated form is commonly termed nixtamal), washed, ground between stones to form a dough known as masa, moulded into a flat round cake (normally 6 inches in diameter and 1 - 2 mm thick) and baked on hot stones to form the tortilla. Most commercial tortilla plants today, though using modern equipment, still follow this basic procedure.

Control of the entire production process remains an art in most commercial tortilla plants in the U. S. today. The intermediate products of nixtamal and masa are visually observed, touched, smelled, and tasted to determine whether they are acceptable or not. Few plants appear to know accurately the temperatures, moisture contents, pressures, pH's, or other physical parameters of the process; or if known, are not used to help control processing. Most plants try to obtain a consistent supply of corn, then vary processing according to previous experience until an acceptable product is made.

In our study of tortilla production, the first need was to define desirable tortilla qualities, to determine which processing parameters were most important, and what their critical ranges were. The initial cooking (consisting of heating to 75 - 100°C and subsequent cooling) of the raw

corn is the first critical processing step. Therefore this study was designed to evaluate the cooking parameters and their effects on tortilla production. Though figures were obtained for temperatures, times, and ingredient weights from the literature and commercial plants, there was wide variation and little justification. Using an analysis method termed "response surface methodology" (abbreviated RSM), we were able to study several variables simultaneously and determine their relative importance and interrelationships as they affected processing parameters and product characteristics. Concurrently, many product properties and control tests were evaluated to determine their value in indicating processing changes. Optimistically we hoped to establish acceptable ranges for the most critical parameters for production of an "optimum" tortilla.

LITERATURE REVIEW

The traditional process of making tortillas can be broken down into four major steps: (1) heating the corn in alkali-water and steeping; (2) draining the steep liquor and rinsing of the nixtamal; (3) grinding the nixtamal into masa; and (4) forming and baking the masa to form tortillas (see Figure 1).

Commercial processors of tortillas normally use the traditional process, going directly from raw corn to the final product. (Some plants, however, are processing tortilla flours that can be hydrated to produce masa). The process in most plants is yet an art. Herrera (3) estimated that 80% of the industry controls the operation "by feel." A practiced eye, experienced fingers, and a sensitive nose are used to: (1) determine how long the corn should cook, (2) how much water should be added to the nixtamal while it is being ground, (3) how good the masa is, and (4) what temperatures and time should be used in baking the tortilla. An instructional sheet published by Curry Manufacturing (4) noted that proper water addition while grinding "can only be accomplished with practice," and that if the masa did not feel fine enough, the pressure (between stones) should be increased "until the fineness needed is reached." Such vague guidelines may be sufficient for a small plant with a single corn supply and small output. However they are insufficient for large plants that must buy several different types or grades of corn, and have a large daily output that must conform to desired product specifications. Such large plants have need of a quality control procedure that will ensure products possessing the desired quality.

This problem is further complicated by the different functions that a tortilla may serve. The two basic types of tortillas are the table (or hand) tortilla and the taco tortilla (3). The table tortilla is a round, flat,

TORTILLA PROCESSING STEPS AND EQUIPMENT

Major Processing Steps	Basic Process Flow	Processing Equipment and Methods: Primitive	Commercial
Cooking-Steeping	Corn + Water + Lime Mixture heated (75 - 100°C) Steeping (cooling) (8 - 20 hours)	Bucket over fire	Large Heated Vat or Continuous Cooker
Draining-Rinsing	Nixtamal Steep Liquor Decanted Nixtamal Washed and Decanted	Handwashing	Spray Vats
Grinding	Nixtamal Ground Masa	Metate (stone hand grinding)	Large-capacity (powered stone grinder)
Forming-Baking	Sheeting-Cutting Baking Tortilla	Hand Formed Baked on hot stone or griddle	Sheeting-Cutting on rolls Large Capacity triple-pass oven

Figure 1

baked tortilla, soft and flexible, that is usually eaten warm, either plain or filled. A taco tortilla is a baked tortilla that has subsequently been formed into a U or V shape and fried in oil. The "taco" commonly sold in restaurants and hamburger stands consists of the fried shell filled with meat, cheese, and vegetables. Masa for table tortillas is ground to a smaller particle size than that for taco tortillas. It holds together more easily and has a higher moisture content than that of taco masa (3). They are also normally slightly thicker than taco tortillas. The taco tortilla contains less moisture and is of a coarser grind. The lower moisture and coarseness allow for the moisture to be more easily lost, enable the tortilla to be fried faster, and prevent puffing of the tortilla. Tamales are also made from masa (they are composed of a meat filling coated with masa, wrapped with corn husks, and steamed), but a very coarsely ground masa is used, and they are not baked before a filling is added.

The first step of tortilla processing, alkali-water treatment of the corn, is the key to forming a dough with the unique properties that allow it to be formed into a tortilla. Inglett wrote that alkali treatment "gives a characteristic flavor and a physical texture that cannot be imitated by ordinary dry-milled products" (5). This attractive texture and flavor of fried tortillas (ie, tacos) has also greatly influenced the corn snack-chip market.

Fried pieces of tortillas have long been used as appetizers and snack chips. Recent years have shown many innovations in corn snack chips, many of them originating from the fried tortilla chip concept (6,7,8,9,10,11,12).

Inglett also mentioned that tortillas cannot be processed from "ordinary dry-milled products". Most of those who have desired to make a dry flour that can be used to make a tortilla or tortilla chip have first heat-alkali

treated raw corn in water and produced a nixtamal. The nixtamal was then ground, dried, sized, and reground if necessary (11,13,14,15). There have been several attempts in recent years to produce a "masa flour" directly from corn grits or corn flour; two have been published recently. The first, a patent by Mendoza of Mexico, utilizes a mixture of flour and lime. The mixture is propelled upward through a heating chamber, then collected in a cyclone and cooled (16). In the second (17), corn flour is hydrated, passed through a drum drier, cooled, ground to desired fineness.

The following literature review discusses some of the main divisions of tortilla processing. They are: (1) ingredients, (2) heating-steeping, (3) draining-rinsing of nixtamal, (4) grinding into masa, (5) forming and baking tortillas, and (6) quality control. Traditional processing is reviewed for three different geographical areas: Guatemala, Mexico, and the U. S. Masa flour production is reviewed separately, as is production of snack chips.

Raw Ingredients

Guatemala: There are only three basic ingredients in tortillas: corn, alkali (usually calcium hydroxide), and water. A food composition table prepared in Guatemala for use in Latin America compared average types of white and yellow corn. The corn compositions were exactly the same on all analyses listed except for vitamin A. Yellow corn possessed 4 to 14 times as much vitamin A (19). In 1958 Bressani (19) reported that white corn showed greater losses in ether extract, crude fiber, iron, riboflavin, and niacin than yellow corn when processed into tortillas; the main loss occurred in cooking raw corn into nixtamal. In this particular study, one part corn was used to 1.04 parts water, and 0.38 - 0.47% lime (all lime percentages listed will refer to percent by weight of raw corn used). A recent study by

Bressani reported a corn to water ratio of 1:1.2, with 0.5% lime being commonly used (20).

Mexico: A 1943 study by Illescas in Mexico found that the corn-water ratio was 1:2, with 1.0% lime used (21). A 1972 patent review gave a corn to water ratio of 1:0.5 - 0.8, with limewater at pH - 12.0 (requiring 0.5 - 1.5% lime) (22). A recent study (23) listed a corn to water ratio of 1:2 with 1.5% lime. 1.4 to 1.5% lime was used by del Valle in processing tortillas from a corn-soybean mixture (24).

U. S.: A review of a commercial plant in the U. S. listed white corn being used with 0.75% lime. The lime was added to the steep water and was kept continuously circulating around the kernels (25). Instructional material by the Curry Company (4) suggested clean white corn, enough water to cover the corn with 1.5 inches of water, and 1.3% lime in summer or 1.8% in winter (In winter it is more difficult to peel the kernels with heat and alkaline water, therefore a higher concentration of lime is used to reduce this difficulty.). Other instructions by the J.C. Ford Company noted that with over 1,000 varieties of corn and environmental variations possible, their instructions should serve merely as a starting point. They listed 1 part yellow corn (cleaned and dry) to 2 parts water, using 1.0% lime (26). Mr. Herrera (3) stated that mostly white corn was used in tortilla production. Water was added until it was 2 inches above the corn. He mentioned that lime concentration was variable; the more lime the greater the preservative effect, and the less lime the more "natural" the taste in the tortilla.

Tortilla Flour: The first patent, by Lloyd and Sotres in 1952, did not specify type of corn preferred. They proposed that the corn-water ratio "may suitably be" 1:1.8, and listed a lime concentration of 0.9 - 1.25% (13). According to a 1955 patent, enough alkali was needed to reach a pH of 13 (14).

Eytinge (27) used a cleaned corn mixture with 2/3 white and 1/3 yellow kernels, and a steep liquor pH of 11 - 12.4. Mendoza, using a corn flour plus lime mixture, added up to 0.04% lime to achieve his desired product (16). Inglett attributed a stronger flavor to yellow corn meal than white corn meal (5).

Snack Chips: Cunningham and co-workers used a white to yellow corn mixture of 1:3, but used no lime in their process (6). A 2:3 proportion of white to yellow was given in a patent by Anderson and Brown (7), with a nixtamal pH of 8.5 or higher preferred. To achieve this a high lime concentration of 1.5 to 2.0% was used. Berg listed a proportion of 2:1 white to yellow corn and 1.3% lime. Water was added to completely cover the corn (12).

Steeping Parameters

Guatemala: Bressani, in a study of processing in Guatemalan homes, noted that the corn-water-lime mixture was heated to 94°C (boiling point at that particular altitude) for 45 to 60 minutes, and steeped overnight (about 14 hours) (19). In a recent paper he reiterated these conditions; cooking at 94°C for 50 minutes, and steeping 14 hours (20).

Mexico: Cravioto, in a 1975 study, reported that the mixture was heated to 80°C for 20 - 45 minutes, and steeped overnight. Boiling produced sticky masa, and was to be avoided (21). Rubio, in a patent literature review, explained that corn was added to a boiling alkali solution and cooled gradually (22). Cortez and co-workers used a peak temperature of 80°C, holding this temperature until the "seed coat" (pericarp) was easily detachable (requiring 30 minutes or longer). A steep time of 12 hours was used (23). In processing tortillas from corn-soybean mixtures, a peak temperature of 100°C was held for 50 minutes; steep time was 10 hours (24).

U. S.: A review of a large commercial batch (2,000 lb corn per batch) was made by Havighorst. Corn and water was added to the cooker; a hot spray

and steam injection was used to agitate the kernels and raise the temperature to 49°C; where it was held for the desired time. Temperature was increased to 74°C by additional steam, and held for a period of time. The temperature was gradually allowed to drop to 60°C, and then the mixture was allowed to steep overnight (25). The Curry Company suggested heating the mixture to a boil (or until the pericarp peels off) and then soaking overnight (at least 6 hours, and normally 10), with occasional stirring (4). According to the Ford instructions (26), the mixture should be soaked for 30 minutes, the temperature raised to boiling (99°C) (with an elapsed time of no more than one hour of heat application), and the heat then shut off (assuming gas-fired cookers). A steep time of 6 to 24 hours is then needed for "moisture absorption." If the corn has been properly cooked; (1) the kernel "center" should still be hard and "chalky," (2) the pericarp should peel with slight pressure, and (3) the masa formed should be uniformly smooth but not sticky, and be sheetable to a thickness of 1.6 mm (0.062 inch). Mr. Herrera reported that most plants producing tortillas use 200 to 1000 pound batches; however, some cook batches up to 2500 pounds. Heat produced by gas is common for smaller plants; the larger ones tend to use steam for corn cooking. The mixture is heated to an average temperature of 77°C, the heat turned off, and the mixture steeped 8 or more hours. Steeping conditions varied greatly among manufacturers. Steam jacketed kettles utilize higher peak temperatures and require shorter steep times, however, the yield is usually less (3).

Tortilla Flour: Lloyd and Sotres added corn to a boiling lime solution, which dropped the mixture temperature to 90°C. This temperature was held for the remainder of the steep. Small batches (up to 600 pounds) required only 1 - 2 hours. Time was not critical as long as the corn was steeped to give 34 - 45% moisture. The lime (measured as calcium oxide) concentration

in their product was 0.25 to 0.30% (13). Sollano and Berriozaba used sufficient alkali to reach a pH between 11.5 and 13. Below pH = 11.5 the cellulose was not hydrolyzed regardless of steep time. Peak temperatures and steep times were variable and listed as follows: 68°C - 2 hours, 78°C - 1.2 hours, 82°C - 0.5 hour. If 82°C was held over one-half hour, the grain became partly gelatinized. They reported that gelatinized starch possessed acceptable elasticity and plasticity, but was too sticky for commercial operations. When the nixtamal was properly hydrolyzed, the hull could be removed and wadded into a gummy ball which retained its shape. A 20% loss of crude fiber (dry basis) occurred in going from raw corn to the final tortilla. Properly cooked dent corn possessed a moisture content of 45 - 46%, however for very thick kernels optimum was 40% or less (14). Another process utilized a steep liquor pH of 13 and a steep time sufficient for the corn to reach a minimum of 42 - 43% moisture. Less moisture caused excessive cracking in the tortilla (15). Eytinge preferred a peak temperature of 80°C. He employed a continuously circulating steep liquor of pH 11 - 12.4. A pH of 10 or less required too long a steep time. Masa pH could be 7 or less. Using this process, a 5 hour steep time was required to produce nixtamal at the desired 50 - 52% moisture content, versus 10 hours for the traditional method. However, hard kernels (example - Texas) required a 7 hour steep to reach optimum (27).

Snack Chips: Cunningham and co-workers produced chips without lime. Corn was boiled 30 minutes (until the whiteness disappeared), drained, and immediately cooled. Cooking times of greater than 30 minutes (1) caused deterioration of fibers, (2) caused hydrolyzation of starch, and (3) resulted in a loss of minerals and proteins (6). Anderson and Brown (7 & 8) used pressure to cook the corn; an average time was 20 minutes at 15 psig, although

time and pressure could be interchanged between pressures of 5 - 25 psig. The corn was cooled rapidly to 77°C and steeped 60 minutes (time and temperature both being variable). The kernels were agitated every 10 minutes. This effected better lime penetration without excessive wearing away of the pericarp. They believed that presence of hydrolyzed pericarp helped in grinding and sheeting properties, besides increasing yield. Berg also used boiling to cook the corn; approximately 30 - 40 minutes was required to cause the corn to adsorb the desired 40 - 43% moisture after cooking for one hour (12).

Draining-Rinsing Parameters

Quatemala and Mexico: Bressani (19) observed that the steep liquor was decanted, and the corn washed four or five times with water. In the recent report (20) he listed decanting plus three separate washes with water. Cravioto's 1945 study in Mexico reported decanting of steep liquor followed by washing two or three times (21). The 1975 study by del Valle (24) cited draining of steep liquor plus washing the nixtamal twice with tap water.

U. S.: Havighorst's review of a large commercial operation stated that the steep liquor was drained, fresh water added to sluice the corn from the cooker, and nixtamal washed before grinding (25). Curry (4) suggested that the nixtamal (after draining) should be washed but not rubbed. They believed that some pericarp was needed for cohesion within the masa. The Ford instructions listed draining of steep liquor, plus rinsing with an equal amount of water (26). Mr. Herrera commented that the more pericarp left on the kernel, the more "body" given to the tortilla (3).

Tortilla Flour: Lloyd and Sotres (13) followed conventional techniques and utilized draining of the steep liquor, and washing with an equal amount of cold water. Sollano and Berriozaba preferred dipping of kernels into a container to conventional washing. They believed dipping decreased rubbing

and subsequent pericarp loss, and stated that washing of the nixtamal produced undesirable tortilla flour (14).

Snack Chips: Anderson and Brown eliminated washing of the nixtamal, citing better yields and no need of water addition during grinding as reasons (7 & 8).

Grinding Parameters

Mexico: Cravioto's early study (21) noted that in the homes nixtamal was ground into masa on a stone "metate." In towns the nixtamal was taken into a central stone grinder to be ground to masa. A recent study in Mexico involving processing of different corn types into masa listed moisture contents of masa ranging from 52 - 69%, with an average of 57.9% (23).

U. S.: Havighorst stated that conventional 16 inch diameter (4 inch thick) stone grinders were used. These stones are powered by a 30 hp motor and have a capacity of 3000 lb corn per hour (25). Curry (4) suggested that water needed to be added to the masa while grinding. Mr. Herrera commented that most tortilla plants use the conventional 16 inch stone grinder as described above (3). The heat produced in the masa while grinding was quite critical, he noted, but varied greatly among plants.

Tortilla Flour: Lloyd and Sotres utilized a micro-pulverizer and flash drier to grind the nixtamal to produce a dry flour (13). Sollano and Berriozaba (14) reported that a "grinding mill" could be used, preferably of the hammermill type. They also used flash drying.

Snack Chips: Cunningham and co-workers used conventional stone grinders (6). Anderson and Brown (7) proposed that a meat-type grinder was suitable for corn chip production. However in a later patent (8) they observed that although such a grinder would reduce the corn, high friction of the corn caused the dough to become too sticky, causing the grinder to become clogged.

Consequently they developed a specialized worm and plate-type grinder that solved friction problems (8). Several other patents covered snack chip production starting from corn grits or flour (8,9, & 27).

Forming-Baking

Guatemala: In a study of home preparation Bressani reported that 45 g of masa was flattened and baked 3 minutes per side on a hot comal (212°C in the middle and 170°C on the sides) (19). A later paper (20) stated that tortillas were baked 5 minutes at a temperature of 180° to 250°C.

Mexico: Cravioto found that normally 50 g masa was used per tortilla. Flattened diameter was 15 - 20 cm, and thickness 2.0 mm. Baking was accomplished with a hot plate, the first side being baked 30 seconds. The tortilla was then flipped and the second side baked 75 - 100 seconds, then again flipped and the first side baked 30 more seconds (21). Tortillas were baked on a 143 - 210° hotplate according to Rubio. The first side was baked twice, at 15 - 20 seconds per time, and the second side baked 15 - 20 seconds more (22). Cortez and Wild-Altamirano formed 2 mm thick tortillas that were baked 15 seconds on the first side, 30 seconds on the second, and another 15 seconds on the first (23).

U. S.: The Curry Company noted that water should be mixed with the masa prior to baking, but also stated that this required previous experience. One commercial process (25) used a screw-type extruder that fed a ribbon of masa into the cutting head of a conventional tortilla oven. It was then sheeted, cut to shape, and passed through a single-pass gas-fired/infra-red oven with a retention time of 30 - 32 seconds and a temperature of 315°C. Mr. Herrera in 1976 stated that the largest segment of the industry still uses conventional triple-pass ovens (baking twice on the first side and once on the second). The most common is the four-row oven, with a 20 - 25 second retention time,

425°C ambient remperature, and a capacity of about 2000 dozen per hour (3). Snack chip processing was not reviewed as the baking is normally done much differently than in tortilla processing.

Quality Control

As previously explained, very few plants are known to have quality control testing other than sensory tests of touch, vision, smell, or taste. Some are known to run moisture tests on the masa.

Quality control, per se, assumes that a consistent product is to be produced with specific desired qualities. This itself assumes that such desired, qualities are known. However no literature was found that well described the desirable tortilla qualities. At best, the study in Mexico by Cortez and Wild-Altimirano noted many tests used for evaluating different corn types, tortillas, and tortilla production. The tests run on tortillas were: (1) fluffiness (increase in volume), (2) plasticity (degree of cohesion), (3) softness, (4) smoothness, (5) folding capability, (6) puff test (presence of puffing in the baked tortilla), and (7) flavor and odor. A fluffy, flexible tortilla that puffs when baked was indicated desirable. The masa was tested for "stretching capacity," actually the ability of the masa to flow laterally under pressure. The yields of masa produced and masa moisture contents were also compared among the different varieties tested. They evaluated tortilla flours produced from the different corn types with the mixograph, but the parameters measured and data were not well explained (23). Rubio, in another Mexican study, utilized a flexibility test in which a tortilla was wrapped around consecutively smaller diameter rods. The more flexible the tortilla, the smaller the final bar diameter. He also recorded that final moisture content in tortillas ranged from 40 - 58% (most around 45), and normal shelf life was 12 - 15 hours (22).

Wimmer concluded that, "the degree of starch gelztinization is the most critical factor in determining the proper working and handling characteristics" of masa produced from tortilla flours. His patent (10) outlined four tests used to determine degree of gelatinization in the product. They were: (1) Brookfield viscosity - cold paste, (2) Brookfield viscosity - hot paste, (3) percent of solubles adsorbed in cold water, and (4) adsorption of water as measured by sedimentation. Acceptable ranges for each test were established for his product. One study of hot-roll cooking and extrusion cooking of corn grits reported that water absorption increased, water solubility increased, and cooked viscosity decreased as the cooking temperature was increased (28). All three tests were indicative of greater gelatinization of grits. A later study by the same laboratory studied steam gelatinization of grits. Water absorption increased with: (1) increased moisture content in grits, (2) increased retention time in the autoclave, and (3) increased steam temperature. The amylograph peak at 95°C was 400 BU for 2.5 minutes retention time in the autoclave, but decreased to 75 BU at the peak when retention time was increased to 45 minutes (29). Skoch noted that several characteristics of corn starch were apparent from amylograph patterns: (1) moderate peak viscosity, (2) little breakdown during cooking, (3) low swelling power, and (4) good stability of the swollen granules. During subsequent cooling there was a high viscosity increase which he concluded was due to retrogradation of the linear starch fraction (30). Brockington (11) explained that in processing corn meals or flours, moisture content and temperature were critical in obtaining the desired degree of starch modification (either gelatinization or dextrinization). In recent presentation of processing tortilla flour by drum drying, the maximum amylograph value was stated to be a good index of tortilla flour quality (17).

MATERIALS AND METHODS

Raw Materials

Number one grade white dent corn was obtained from Texas for all tests. Two separate lots of the 1974 crop were obtained for the three different test series run. The kernels were large, flat, and included very few yellow kernels. Each sample was cleaned over a #5 wire to remove all small impurities and split on a Boerner divider into samples of the required size. Analytical grade calcium hydroxide, $Ca(OH)_2$, was used for the tests. Distilled water was also used for all testing.

Processing Equipment

Cooking (subsequent references to cooking refer to heating of the raw corn to 75 - 100°C in an alkaline-water steep liquor) of the corn was done in a 5500 cc stainless steel beaker fitted with a cover, over a 1600 watt Temco hotplate. A YSI model 42 telethermometer with steel probe coupled to a Houston Instrument Omniscribe recorder was used to monitor temperature changes of the corn-water-lime mixture during cooking and steeping. A separate glass thermometer was used to calibrate and occasionally check the accuracy of the telethermometer-recorder hookup. Styrofoam insulated chests were used for; (1) holding the beaker containing the cooked mixture for the desired time period at peak temperature, and (2) steeping the mixture for the required number of hours. After steeping the steep liquor was drained from the nixtamal by using a 1/4 inch mesh wire screen.

Grinding was performed with a modified 6-inch diameter, 1-HP stone grinder manufactured by the Curry Company of San Antonio, Texas. (Figure 2) Modifications included: (1) variable-speed screw system for feeding the nixtamal into the stones; (2) addition of a variable-speed water pump to

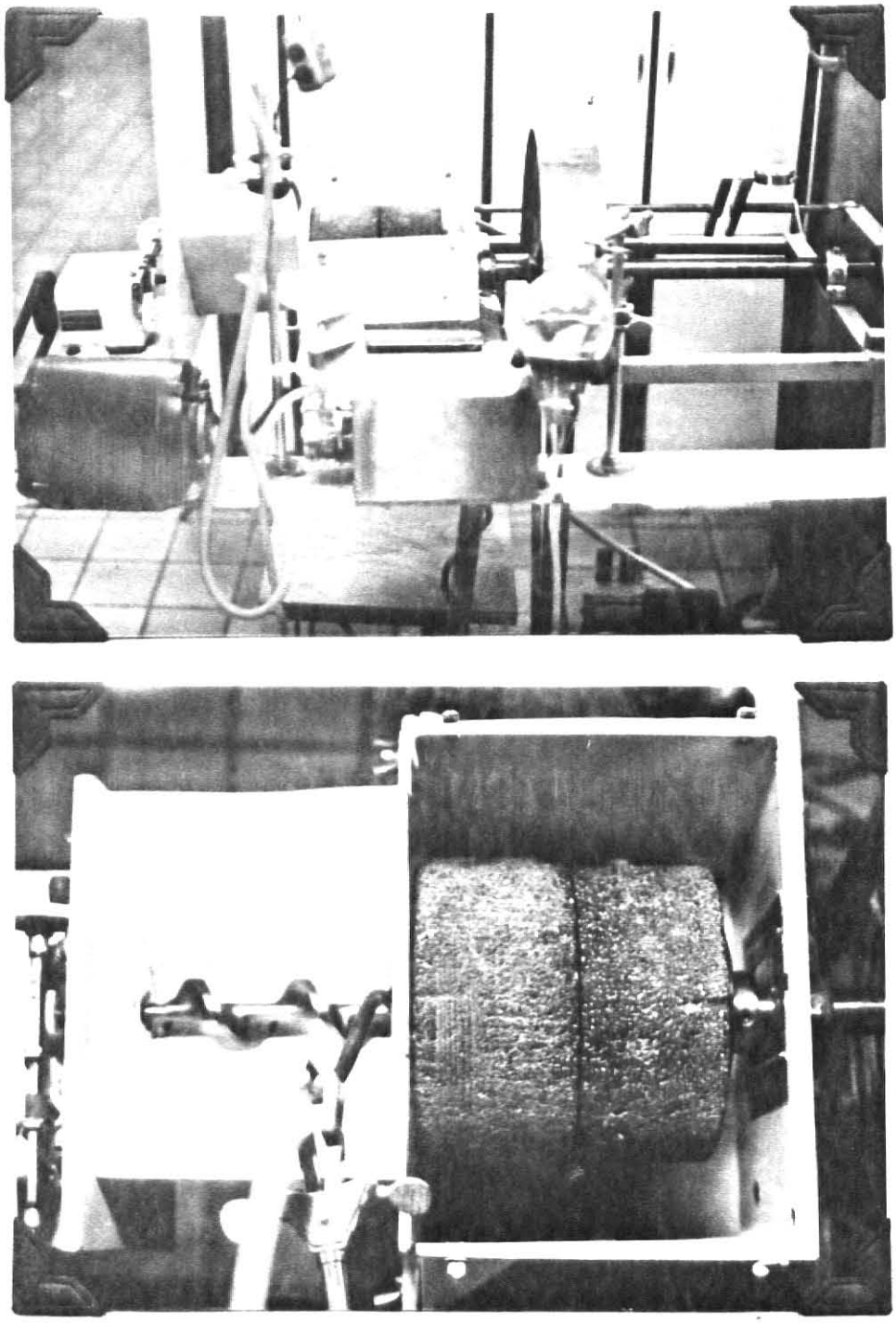


Figure 2 - Stone Grinding Apparatus

control addition of water to the nixtamal; and (3) installation of a dial that was directly proportional to the pressure forcing the stones together. For the second and third series, a Hobart (model A-200) mixer was used to mix masa samples to insure uniformity throughout the sample.

For the first series, the masa was passed through a manually-powered Casa Herrera forming head (the gap was set at approximately 1.14 mm) and the tortillas baked one-at-a-time on a gas-heated hotplate with a peripheral temperature of approximately 285°C. The first side was baked 15 seconds, the tortilla flipped and the second side baked 15 seconds, and the first side baked 15 additional seconds. The Herrera forming head was coupled to a model TC-5000 J.C. Ford triple-pass gas-fired oven for the second and third series. (Figures 3 and 4) A retention time of 40 seconds was maintained. Approximate temperatures of the three levels during processing were 250°C (top belt), 270°C (middle belt), and 225°C (bottom belt). These temperatures were recorded with a model 8395 Cole-Parmer pyrometer, with thermocouples that were located one inch above the surface of each belt.

Quality Control Equipment and Procedures

Two types of moisture content tests were run. The first was a two-stage moisture test. Weighed samples were oven-dried (at temperatures below 35°C) to approximately 10% moisture content then reweighed. Both nixtamal and masa samples were ground for one minute at high speed in a Waring blender; the nixtamal samples were further ground in a Wiley mill to pass a #40 mesh screen. Two-gram samples were weighed, dried one hour at 130°C in a forced draft oven, and reweighed. An infra-red moisture balance (O'haus model 6010, 10 g capacity) was also used to determine moisture content in the masa.

A specific volume test was utilized in the first test series. Two hundred gram (200 g) of nixtamal was added to 200 ml water in a graduated

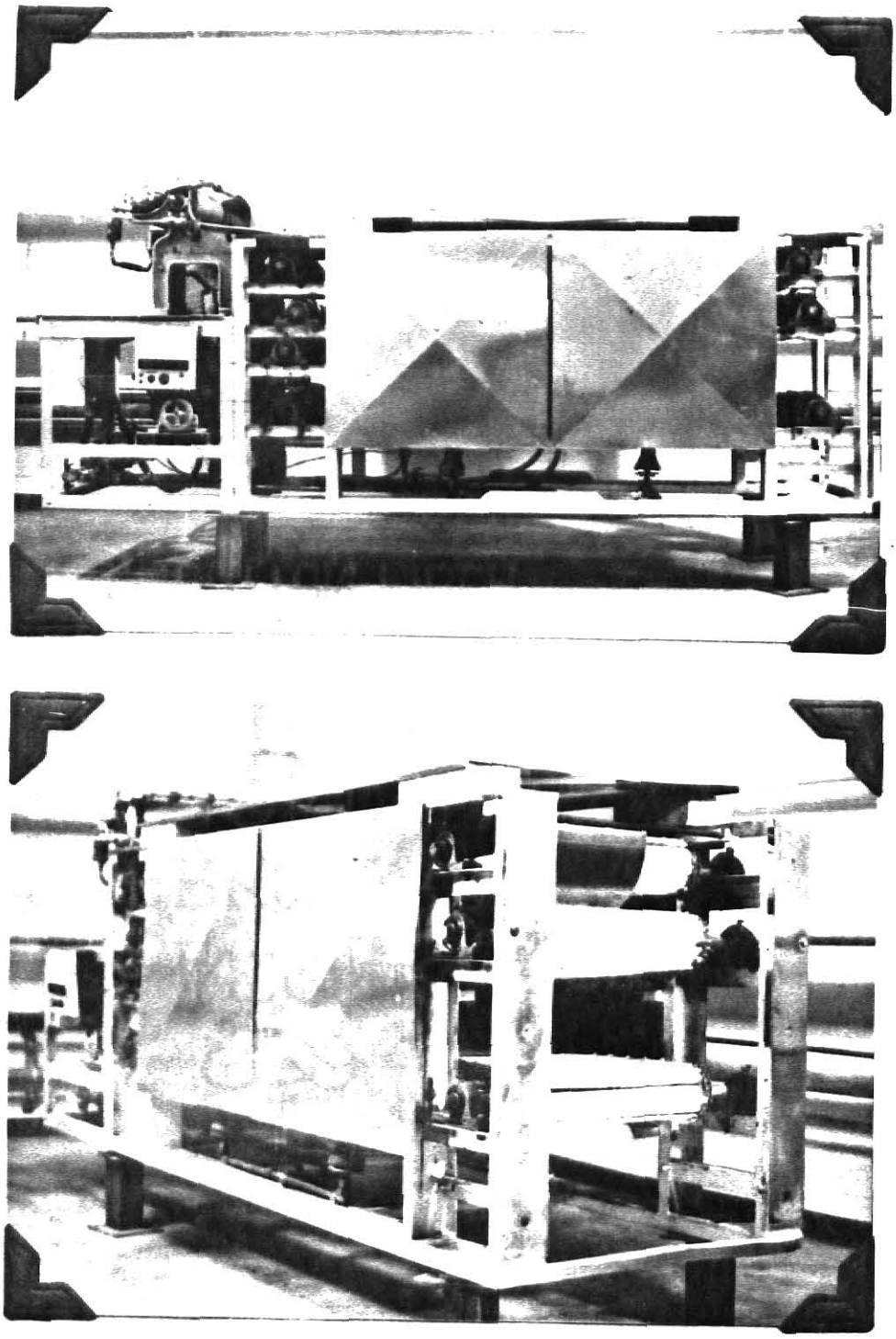
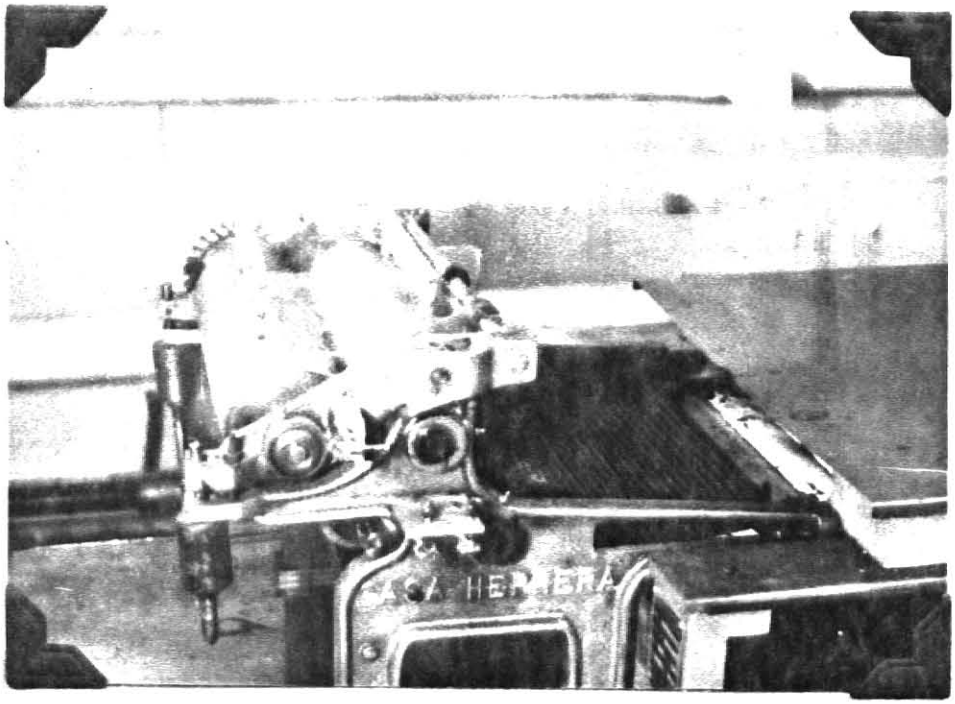
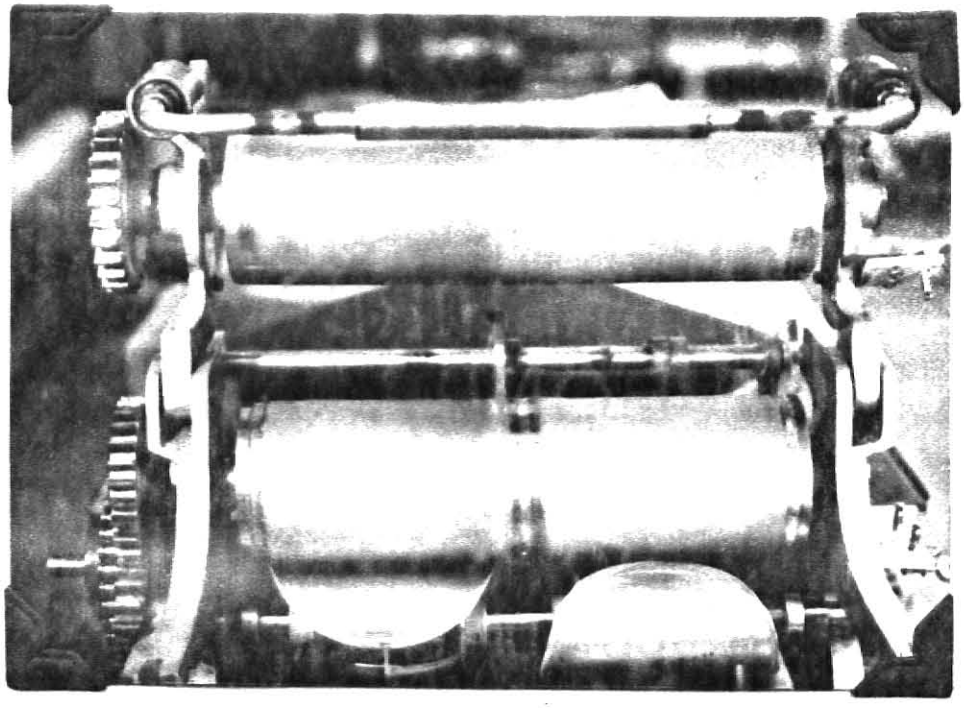


Figure 3 - Tortilla Oven



Normal Operating Position



Open for Cleaning

Figure 4 - Forming Head

cylinder and well-mixed. Specific volume was calculated in cubic centimeters per gram.

Measurements of pH were performed with two different meters using a Corning semi-micro combination electrode. During the first series a Corning model 10 was used, standardized with a pH 10 buffer. For the second and third series a Corning digital model 110 was obtained, and calibrated at pH 7 and 10. All samples were mixed with water, stirred till well-suspended, and the pH read.

An Agtron model M-500-A reflectance spectrophotometer was used to evaluate masa color in the second and third series. In preliminary testing the blue wavelength (436 mu) was found most responsive to changes in masa color, and Agtron standards of 12 and 44 were selected as the limits of the testing range. The masa was packed into a cell, and the reflectance read directly. Four readings were made per sample.

Particle size of the masa was performed using a series of standard screens of 833 (20 mesh), 417 (35 mesh), and 104 (150 mesh) microns. A 50 gram sample of known moisture content was suspended in water, placed on the top sieve, and any remaining lumps of masa broken up by hand. The sample was then sieved with the aid of a stream of water and by rotating-tapping the sieves. The overs of each sieve were first air-dried, and later dried one hour at 130°C and weighed. Overs of each sieve were calculated as percents of the dry matter in the original sample.

A mixograph and extrusion meter were both obtained to evaluate masa samples for the first testing series. A modified 10 g capacity mixograph was used (31). Twelve grams of masa were place in the bowl with the spring set at minimum resistance. Water increments of 0.5 ml were added 1.5 - 2.0 minute intervals, until sufficient water had been added to reduce the

mixograph curve to the 0 BU line. A curve of water added versus curve height (of a line drawn through the center of the curve) was plotted. The peak resistance (in BU's) and the actual moisture content of the sample at the peak were both calculated. Two tests were run per sample, and the results averaged.

The extrusion meter was a Simon "Research Water Absorption Meter" (abbreviated RWAM) that measured the time to extrude a dough through a given orifice. A 1.3 cm diameter orifice was used for the testing.

For the last two series a rapid amylograph curve was run on the masa using a Brabender Visco-Amylograph (Type VA-1) with a special paddle and bowl. (Figure 5) A temperature of 75°C was selected for the tests. A masa sample was weighed that contained 20 grams of dry material (normally 42 to 45 grams of masa was required), and enough distilled water added to yield a total sample weight of 132.1 grams. The sample was dispersed by manual cutting, and then stirring in a flask for five minutes. The suspended sample was placed in the amylograph and the test run for 18 minutes at 75 rpm. Amylograph parameters calculated were: (1) arrival time at the 100 BU line (in minutes), (2) time interval between the 100 and 400 BU lines (the reciprocal of this time gave a relative index of the amylograph slope), (3) the amylograph peak at 18 minutes, and (4) an amylograph index calculated by multiplying the peak by the slope index. Duplicates of each test were run.

The tortillas in all series were tested for thickness (in millimeters) and axis ratio (the ratio of the short axis, or diameter, to that of the long). The more circular the tortilla, the closer the ratio to one. (The axis ratio for the brass cutting form was 15.88 cm/19.43 cm, or .817.) In the first series, for each tortilla the thickness was measured with a micrometer at the center and at four other points, each one inch from the

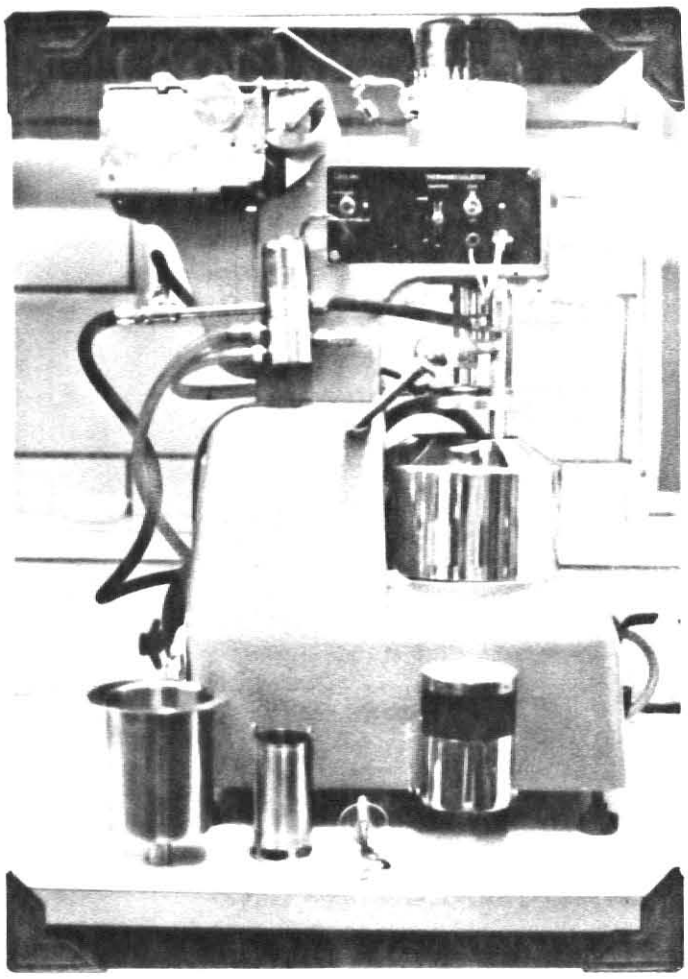


Figure 5 - Amylograph

circumference. The first series tortillas were also visually evaluated for texture and color using a relative scale from 1 (poor) to 5 (good). They were compared with tortillas from the RJR Foods San Antonio plant.

For the second and third series, tortilla thickness was measured at one-inch intervals along both axis', totalling nine points measured per tortilla. For each test six tortillas were measured and averaged. The average weight was also recorded. Axis ratio determination was performed the same as in the first series.

Softness was evaluated in series two and three by using a shear-force instrument. (Figure 6) The equipment consisted of a variable speed constant-force press that forced a circular punch of 0.945 cm diameter thru the tortilla. The force was transmitted to a strain guage directly below the die, and in turn was connected to a Brush amplifier and an Esterline-Angus recorder. The peak on the recorder plot occurred at the moment the tortilla was sheared. A standard 2 Kg weight was used to calibrate the instrument, and readings were translated into kilograms of force required to shear the tortilla. The nine points evaluated per tortilla for thickness were also evaluated for shear force, and six tortillas were evaluated per test. In order to correct for differences in shear force due to tortilla thickness, a calculation was made dividing the average force by the average thickness.

A trained 7-member organoleptic panel was established for the last two series to evaluate the tortillas. The seven members included two American whites, two Asian Indians, two South Americans, and one Mexican. Such a wide range of cultures were selected to help simulate the wide range found in the consuming public. Four parameters were evaluated; aroma, flexibility, mouthfeel, and taste. The control used to compare all samples were tortillas obtained from the midpoint design (88^{o}C peak temperature, 30 minutes hold

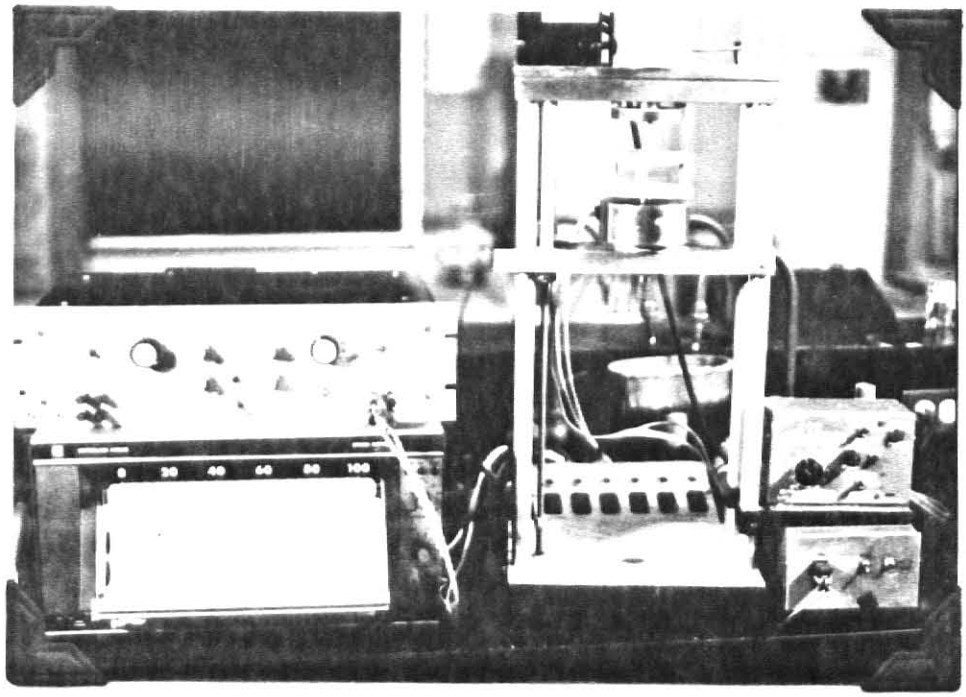


Figure 6 - Shear Force Tester

time, and 9 hours steep time) for the second series. The control was defined as the zero point for each parameter. A test tortilla that rated much better than the control would be rated +2, one much worse a -2, and if no difference could be detected, the test tortilla was rated 0. Desirable aroma was rated +2, ranging to -2 for an undesirable aroma. If the tortilla was hard and inflexible, a -2 flexibility was assigned versus a +2 for a soft and flexible one. Grittiness in a tortilla was given a mouthfeel rating of -2; if the mouthfeel was smooth a +2 was assigned. Taste was ranked from -2 for not acceptable to +2 for very acceptable. For each test, every panel member rated the test tortilla versus the control tortilla for all four parameters. All scores were then averaged for each test.

Experimental Design: Response Surface Methodology

Tortilla processing is concerned with many input parameters that interact and effect the outcome of the final product. (Figure 7) Response surface methodology (abbreviated RSM), an experimental design that allows the study of the interaction of multiple variables upon one dependent variable (or response) was used to help in analyzing tortilla processing in this study. Cox and Cochran have outlined the experimental design basis for RSM (32). To use this method the researcher must decide: (1) the desired number of independent variables, and (2) the range of each variable. A predetermined factorial design is used to plan the number of tests that have to be run, and the levels of each parameter for each test. A computer is used to help statistically analyze the data and to plot the data in the form of response surface curves. A three-variable model was chosen for both series. The Taylor expansion equation used to analyze and plot the data for three variables is as follows: $Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_1^2 + B_5X_2^2 + B_6X_3^2 + B_7X_1X_2 + B_8X_1X_3 + B_9X_2X_3$. For each response evaluated this basic equation was modified

VARIABLE FACTORS IN THE K.S.U. PILOT TORTILLA PROCESS

Variables: Material	Processing Equipment	Variables: Mechanical	Evalation Factors
RAW CORN Corn Water Lime	Stainless Steel Beaker over Hotplate Insulated Container	Rate of heating Peak temperature Time at peak temperature Steeping: Cooling rate Total time	Corn: Moisture content Test weight Thickness - size Endosperm: Type Hardness
NIXTAMAL Water (optional)	Steel Container	Rinsing Agitation Draining Time	pH Solid materials loss Drained nixtamal weight
NIXTAMAL (drained) Water (optional)	Stone Grinder	Nixtamal-feed rate Grinding Pressure Stone: RPM physical condition	Moisture content pH Density Starch changes (i.e., gelatinization)
MASA	Tortilla Former Tortilla Oven	Shape (length & width) Temperature (three levels) Retention time Cooling-Drying	Moisture content pH Particle size Rheological properties Color Starch changes
TORTILLAS			Moisture content Weight Thickness Axis ratio Resistance to shear Characteristics: Physical Organoleptic

Figure 7

to a form in which; (1) all B values were significantly different than 0 (using a significance level of 5%), and (2) the model contained the smallest mean-square residuals (33).

Testing Series

Series One - Response Surface Methodology: The variables of, (1) peak cooking temperature, (2) lime concentration, and (3) time at peak cooking temperature, were chosen for the first series (abbreviated RSM-S1). A three-level per variable RSM design was chosen that required 15 total tests. The ranges for the three variables were: (1) peak temperature, 80 - 90°C; (2) lime, 0.1 - 1.0%; and (3) time at peak temperature, 0 - 60 minutes.

The processing of the corn for the first series follows. Corn (2000 g), water (2800 g at 80°C), and lime (2 g, 11 g, or 20 g, corresponding to 0.1, 0.55, and 1.0%) were combined in the beaker, and heated to the desired peak temperature (80, 89 or 98°C, requiring times between 6 and 22 minutes to reach this peak). The cover was removed and the mixture stirred every four minutes during the heating phase. Once peak temperature was reached the beaker was placed in a closed styrafoam container for the desired holding time (0, 30, or 60 minutes), and then transferred to a semi-covered styrafoam container for 12 hours to steep. The nixtamal produced was drained of steep liquor for 10 minutes over a screen, then mixed well before grinding. A constant pressure of 34 lb of force was maintained throughout grinding. Each sample was ground for 2-1/2 minutes without addition of any water; the first minute of production was used to adjust the grinder and this masa discarded; the remainder of this masa was termed masa 1. Water was then added at the approximate rate of 75 g/min and the grinder readjusted. The first 1/2 minute production of this was also discarded; the remainder of this masa

was called masa 2. The masa was sheeted and baked on a griddle as previously noted.

The responses evaluated for RSM-S1 are listed below:

Steep Liquor;	pH
Nixtamal;	weight pH moisture content (two-stage) specific volume
Masa 1 & 2;	moisture content (two-stage) moisture content (infra-red) pH grinding temperature differential particle size (masa 1 only) RWAM values mixograph peak (average of two - masa 2 only) moisture content at the mixograph peak (average of two - masa 2 only)
Tortillas:	thickness (1 or 2 tortillas evaluated/test) axis (1 or 2 tortillas evaluated/test) texture (1 or 2 tortillas evaluated/test) color (1 or 2 tortillas evaluated/test)

The results of RSM-S1 did not establish the limits for the most important variables in tortilla production. Therefore the second series was planned using the results of the first series.

Series Two - Response Surface Methodology (abbreviated RSM-S2): The three variables chosen for the second series were: (1) peak cooking temperature, (2) time at peak cooking temperature, and (3) steep time. A five level per variable design was selected for this series that required 20 total tests. All tests were run in random order to avoid any time bias. Ranges of the variables were: (1) peak temperature, 78 - 98°C, (2) time at peak temperature, 0 - 60 minutes and (3) steep time, 3 - 15 hours.

Processing of each sample followed that described for RSM-S1 except for the following. A constant lime concentration of 1.0% (20 g) was used. Once the corn had been held at peak temperature for the desired time, it was

emptied into a second styrafoam container, which was completely covered for the steeping phase. Steeping times were varied between 2 and 15 hours. The nixtamal was cooled to less than 100°F before grinding. Grinding was again performed with a constant pressure of 34 lb of force between stones. Water was added at a constant rate of 92 (±2) grams per minute. The first minutes production of masa was used to adjust the grinder and was discarded. The remainder of the masa produced was blended for 3/4 minute with the Hobart mixer. Four hundred fifty grams (450 g) of this masa was set-aside for the quality control tests (300 g was immediately refrigerated and later used for the pH, color, and amylograph tests); the remainder of the masa was formed and baked in the tortilla oven as described previously. Once baked the tortillas were individually air-dried and cooled at ambient temperature (normally 23°C) for one minute. A representative sample of all tortillas produced per test was selected for each of the physical and organoleptic tests later tun. The tortillas that were selected for immediate physical tests and for photographing were left sealed at ambient temperatures for 4 - 8 hours. All other tortillas were frozen. The organoleptic tests were run after all 20 processing tests were completed.

The responses evaluated for each test are listed below:

Steep Liquor;	pH
Nixtamal;	weight moisture content (two-stage)
Masa;	rate of production temperature differential during grinding moisture content (two-stage) moisture content (infra-red) Agtron color (average of two) pH (average of two) particle size amylograph curve (average of two)

Tortillas; moisture content (average of two)
weight (6 tortillas evaluated/test)
axis ratio (6 tortillas evaluated/test)
thickness (9 points/tortilla, 6 tortillas/test)
shearing force (9 points/tortilla, 6 tortillas/test)
organoleptic tests;
- aroma
- flexibility
- mouthfeel
- taste

Series Three - Moisture Variation Series: The second series revealed the importance of moisture in tortilla production. Therefore the third series was run to help understand the effects of variable water addition at the grinding stage. Following the results of RSM-S2, a 90°C peak temperature, 40 minute holding time, and 11 hour steep time were selected as the conditions for running the moisture variation series. The samples were processed according to the procedure established for RSM-S2. During grinding three levels of water addition were used; 0, 70, and 150 g/min. The rest of each test followed the same procedure as that for RSM-S2. Duplicates of each test were run, totaling 6 tests for this series.

RESULTS AND DISCUSSION

Series 1 - Response Surface Methodology. Fifteen of the total 28 response parameters measured for RSM-S1 did not contain complete data (ie, data from some of the tests were missing), and were subsequently not analyzed by RSM. Thirteen other responses were analyzed by RSM. All response parameters measured are listed in Table 1; the simple linear correlations of the three independent variables with each response parameter are also listed. The "R^2" value listed is the coefficient of determination. It indicates how well the modified Taylor expansion equation for the response fits the data of the response. A value close to $R^2 = 1.0$ infers that most of the variation in the data can be explained by the equation. The three variables evaluated were: (1) peak temperature; (2) time at peak temperature (or holding time); and (3) calcium hydroxide concentration (lime concentration).

Nixtamal Weight. The determination coefficient, R^2, was 0.99, implying that the modified Taylor equation explained the data very well (Table 1). From the linear correlations, it can be concluded that all three parameters were positively correlated with nixtamal weight, peak temperature having the highest correlation ($r = 0.64$). At 30 minutes hold time, once lime concentration reached 0.55%, weight was largely proportional to increasing peak temperature (Figure 8). This pattern also occurred at the 0 and 60 minute hold times. Figure 9 exhibits the effect of peak temperature and holding time on nixtamal weight at 1.0% lime content. All the data results were expected since an increase in temperature, lime, or time should result in increased water penetration of the kernel, consequently increasing nixtamal weight.

Specific Volume. The determination coefficient was 0.98 with lime being most highly correlated at 0.49. However, because of the crude testing

TABLE 1

Response Parameters	Determination Coefficient (R^2)	Linear Correlation of Response With: Temperature	Lime	Hold Time
Weight - Nixtamal	0.99	0.64	0.46	0.43
Specific Volume - Nixtamal	0.97	0.24	0.49	0.30
Moisture Content (2-stage)				
Moisture - Nixtamal	0.99	0.58	0.56	0.46
Moisture - Masa 1	1.00	0.61	0.51	0.46
Moisture - Masa 2	1.00	0.68	0.45	0.46
pH - Steep Liquor	0.98	-0.12	0.89	-0.10
pH - Nixtamal	0.99	-0.10	0.92	-0.10
pH - Masa 1	0.99	0.18	0.96	0.01
pH - Masa 2	0.99	0.20	0.94	0.02
Production Rate - Masa 1	0.95	0.28	0.63	0.44
Production Rate - Masa 2	0.75	0.61	0.34	0.11
Mixograph - Masa 2				
Mixograph Peak Resistance	0.85	0.43	0.37	0.47
Moisture at Peak	0.99	0.62	0.44	0.55

Response Parameters Not Evaluated by RSM:

Grinding - Temperature Differential - Masa 1
Grinding - Temperature Differential - Masa 2
Particle Size - Masa 1
Moisture Content (infra-red) - Masa 1
Moisture Content (infra-red) - Masa 2
Research Water Absorption Meter Values - Masa 1
Research Water Absorption Meter Values - Masa 2
Axis Ratio - Tortilla 1
Axis Ratio - Tortilla 2
Thickness - Tortilla 1
Thickness - Tortilla 2
Texture - Tortilla 1
Texture - Tortilla 2
Color - Tortilla 1
Color - Tortilla 2

Fig. 8 Contour plot of nixtamal weight versus peak temperature and lime concentration at 30 min. hold time. Nixtamal weight code values are:

C = 3100 (grams)
D = 3200
E = 3300
F = 3400
G = 3500
H = 3600
J = 3700
K = 3800

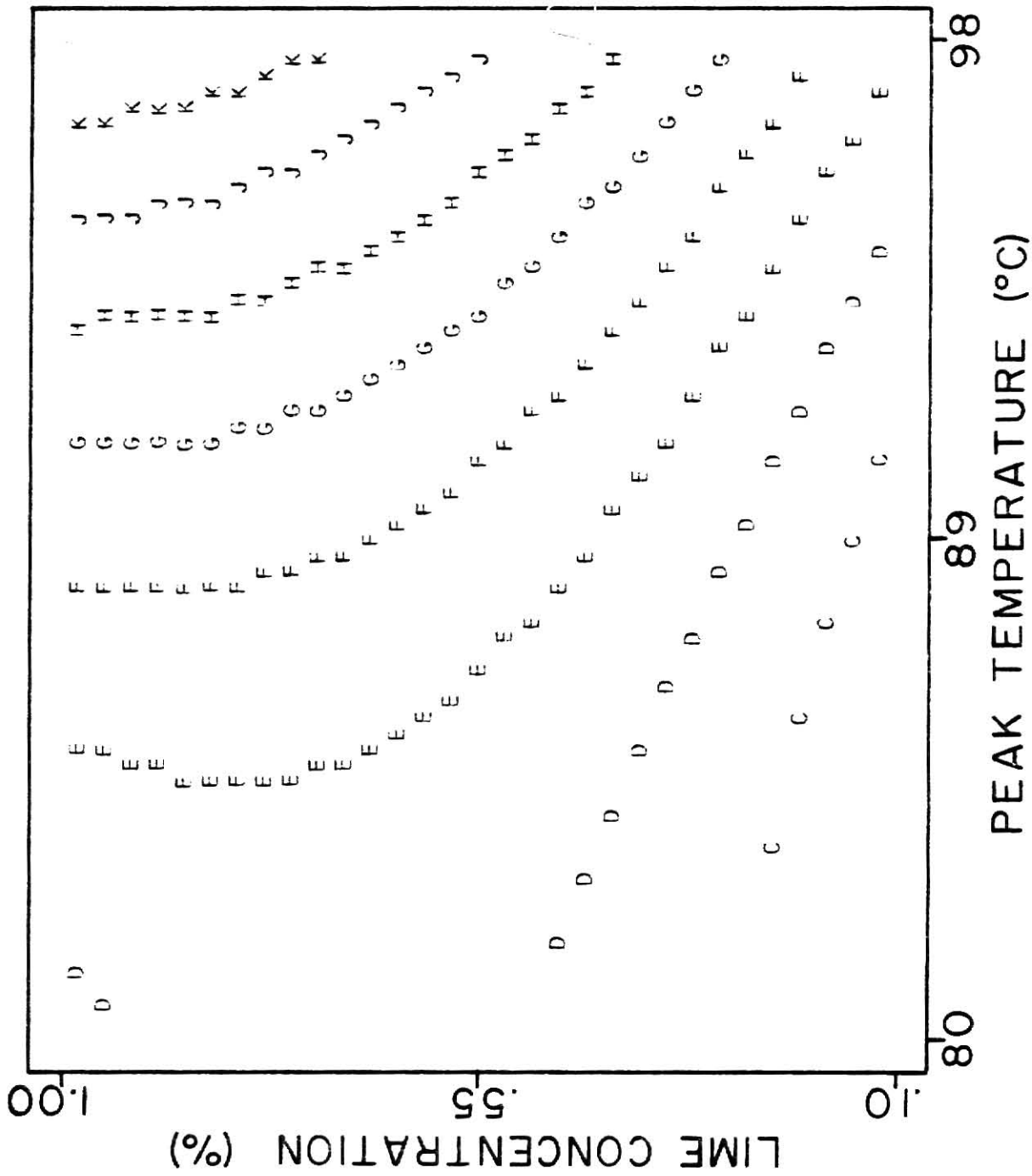
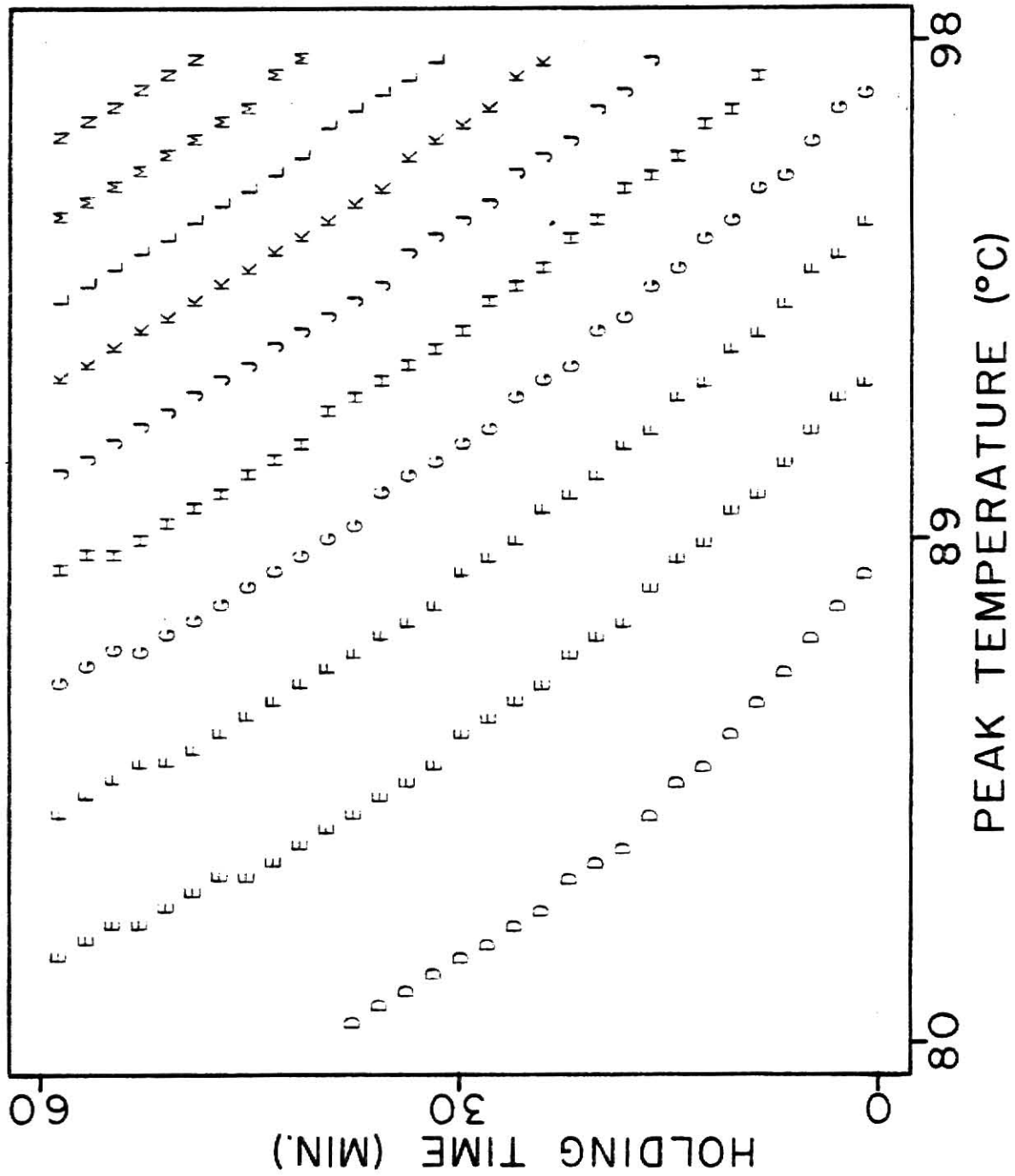

LIME CONCENTRATION (%)
1.00
.55
.10
80
89
98
PEAK TEMPERATURE (°C)

Fig. 9 Contour plot of nixtamal weight versus peak temperature and hold time at 1.0% lime concentration. Nixtamal weight code values are:

D = 3200 (grams)
E = 3300
F = 3400
G = 3500
H = 3600
J = 3700
K = 3800
L = 3900
M = 4000
N = 4100


HOLDING TIME (MIN.)
60
30
0
80
89
98
PEAK TEMPERATURE (°C)

method and small differences in specific volume among the tests, the data is not regarded as significant.

Moisture Content. A comparison of the nixtamal weight and nixtamal moisture content data (Table 1) and plots (Figures 8 & 10) are very similar. Figure 10 also establishes that moisture content increases up to a lime concentration of about 0.8. Beyond about 0.8% lime, further addition of lime has little effect. The optimum lime concentration for good moisture penetration therefore appears to be approximately 0.8 - 0.9%. The effect of holding time on moisture content can be seen in Figure 11 using a 1.0% lime level. Increasing temperature (R^2 = 0.58) from 80 - 98°C at 30 minute hold time increases moisture content by about 9.0%. Increasing holding time (R^2 = 0.46) from 0 - 60 minutes increases moisture content by only 6.0%.

The correlations of moisture content of masa 1 and masa 2 are more similar to that of the nixtamal weight than is nixtamal moisture content (Table 1). In actuality, nixtamal and masa 1 are the same except for the masa being the nixtamal in ground form. The plots of the nixtamal and masa moisture contents are essentially identical, therefore, a graph of the masa 1 moisture content is not shown. The only difference between masa 1 and masa 2 was that water (75 g/min) was added at the grinding stage for masa 2, thereby increasing the moisture content. Figure 12 is a plot of moisture content in masa 2 as effected by variations in peak temperature and lime at a 30 minute hold time. The general pattern of moisture changes parallels that of nixtamal moisture content in Figure 10. It is evident that lime content is limiting below a concentration of about 0.7 to 0.9%.

pH. Table 1 reveals that all pH data was consistent and well explained by the modified Taylor equations (R^2 values of 0.98 - 0.99). It indicated that lime was the only important variable affecting pH (r values between

Fig. 10 Contour plot of nixtamal moisture content versus peak temperature and lime concentration at 30 min. hold time. Moisture content code values are:

C = 42 (%)
D = 44
E = 46
F = 48
G = 50
H = 52

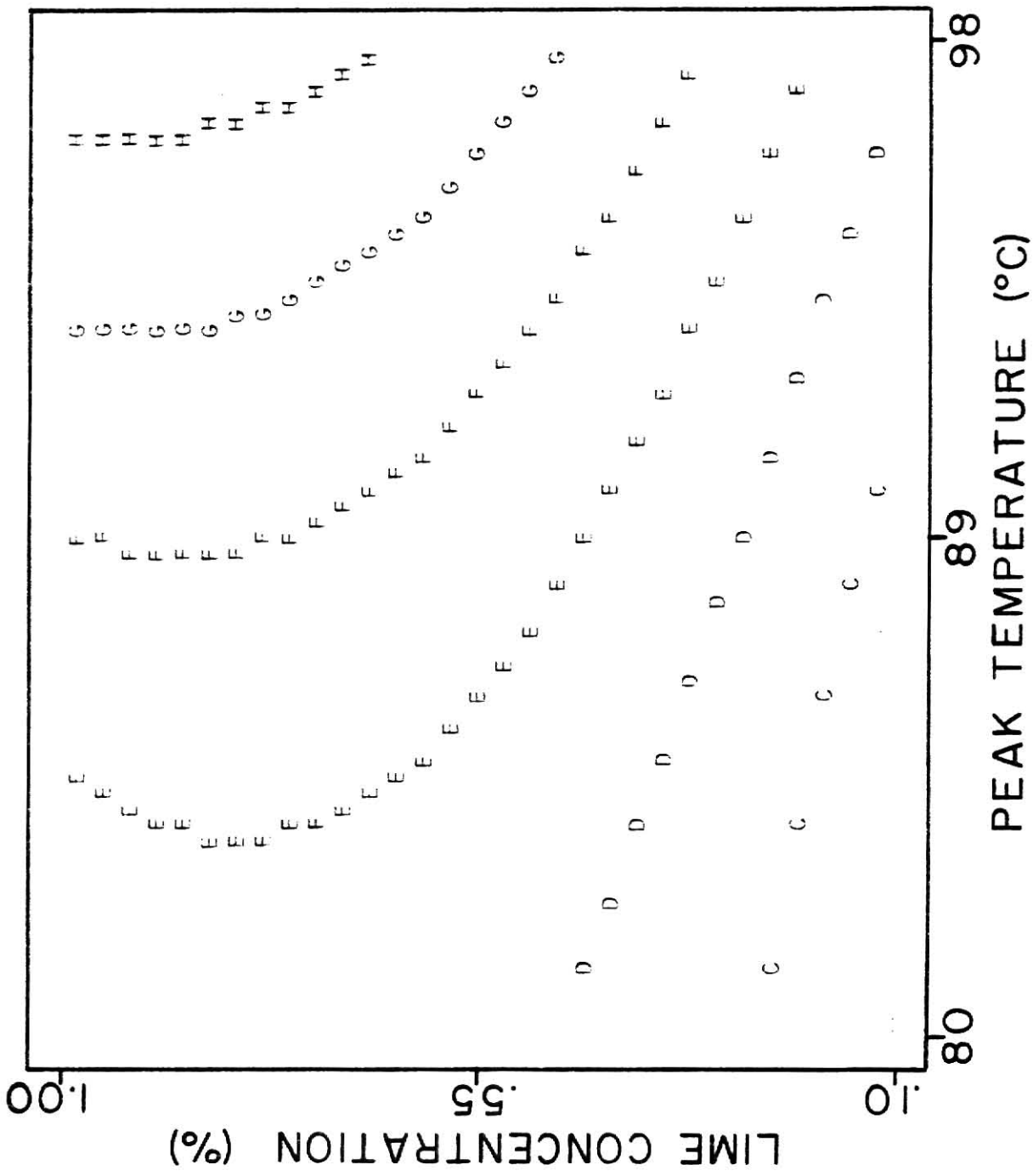

LIME CONCENTRATION (%)
1.00
.55
.10
80
89
98
PEAK TEMPERATURE (°C)

Fig. 11 Contour plot of nixtamal moisture content versus peak temperature and hold time at a lime concentration of 1.0%. Moisture content code values are:

D = 44 (%)
E = 46
F = 48
G = 50
H = 52
J = 54
K = 56

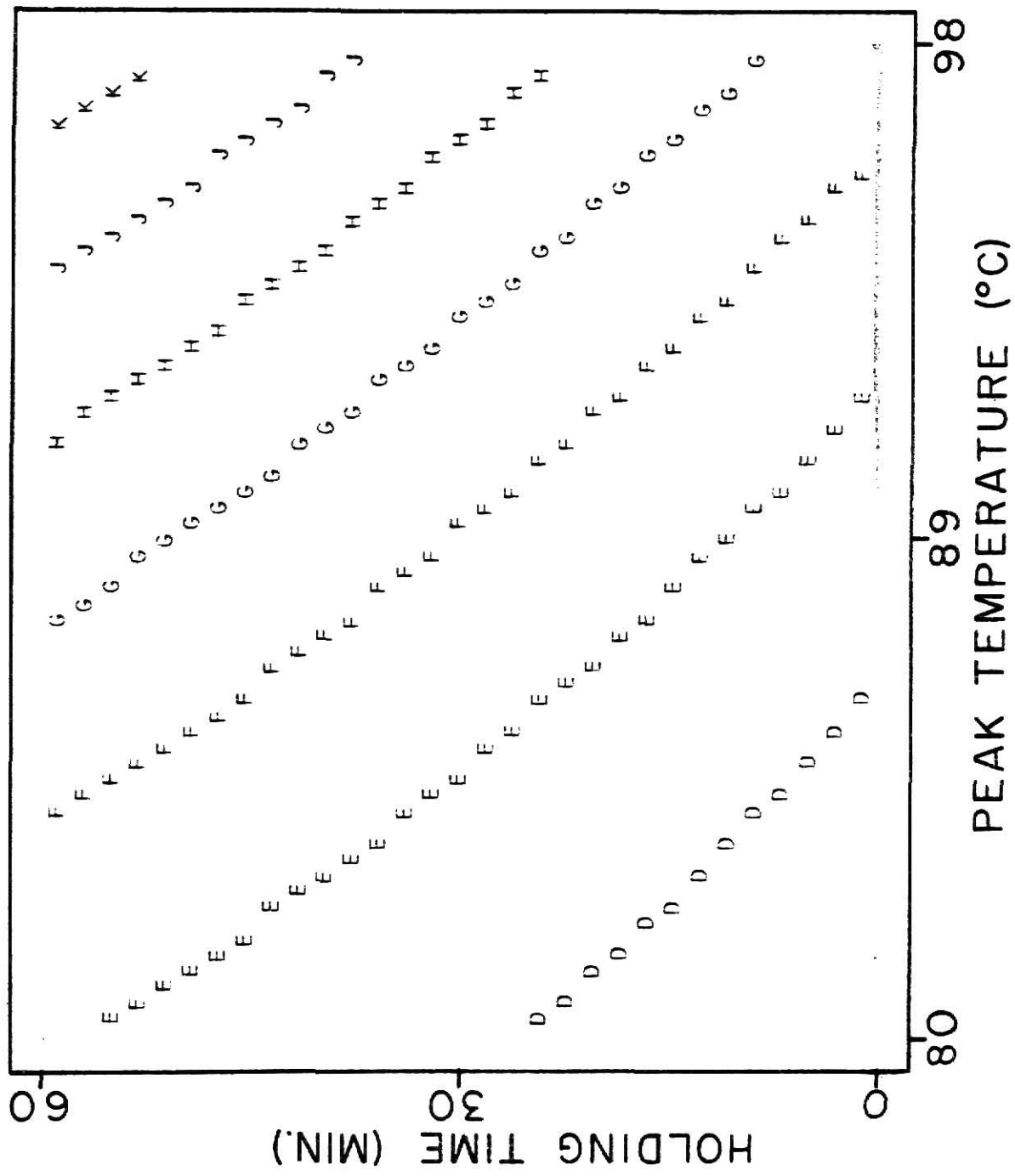
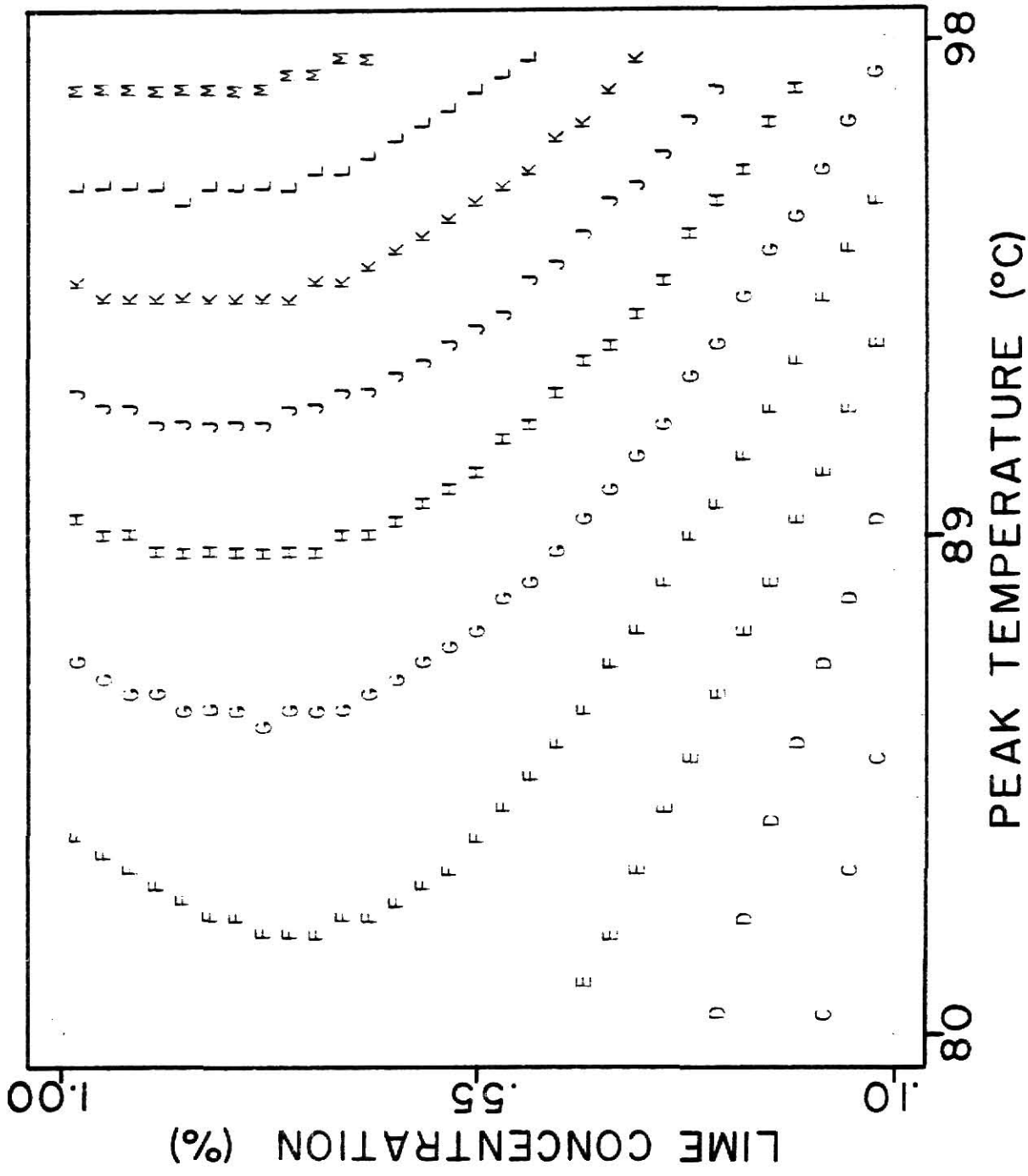

HOLDING TIME (MIN.)
0
30
60
80
89
98
PEAK TEMPERATURE (°C)

Fig. 12 Contour plot of masa 2 moisture content versus peak temperature and lime concentration at 30 min. hold time. Moisture content code values are:

C = 48 (%)
D = 49
E = 50
F = 51
G = 52
H = 53
J = 54
K = 55
L = 56
M = 57


LIME CONCENTRATION (%)
1.00
.55
.10
80
89
98
PEAK TEMPERATURE (°C)

0.89 and 0.96). Time had no effect on masa pH (r = 0.01 and 0.02), while peak temperature was very slightly correlated (r = 0.18 and 0.20). At low peak temperatures (80 - 90°C) and a 30 minute hold time, a lime content of approximately 0.7 or greater was needed to result in a final steep liquor pH of 12.0 or more (Figure 13). The plots of pH for the nixtamal are not listed since they were almost identical to the plots for pH of the steep liquor, except for being about 0.5 pH units lower per test.

Figure 14 shows the effect of lime concentration and peak temperature on pH in the masa 1 samples; pH is almost solely a function of the lime concentration. Whereas Figure 10 indicates a slightly decreasing moisture content for nixtamal samples with lime concentrations increasing beyond about 0.8%, Figure 14 shows no such decrease for pH. Indeed, in Figure 14 no approaching pH limit can be seen as lime is increased to a concentration of 1.0%. Figure 15 demonstrates the effect of temperature and holding time at a lime concentration of 1.0%. Peak temperature does have a significant effect on pH, though far less than the effect of lime. The data plots of pH for masa 2 were very similar to those of masa 1, and are not included or discussed.

Production Rate of Masa. The rate at which masa was extruded from the grinder was evaluated as a production rate. If Figure 10 (nixtamal moisture content) is compared with Figure 16 (production rate), it can be seen that the increases in moisture content are roughly paralleled by increases in production rate. Figure 17 illustrates the relationship between masa 1 moisture content and production rate. The correlation was r = 0.87 (r = 0.92 if one out of place data point was eliminated) indicating a very direct relationship between nixtamal weight and rate of material flow through the grinder. Normally, when nixtamal is ground into masa water is added. With the masa 1 samples, however, no such water was added. Therefore the results

Fig. 13 Contour plot of steep liquor pH versus peak temperature and lime concentration at 30 min. hold time. pH code values are:

B = 6.5 (units)
C = 7.0
D = 7.5
E = 8.0
F = 8.5
G = 9.0
H = 9.5
J = 10.0
K = 10.5
L = 11.0
M = 11.5
N = 12.0

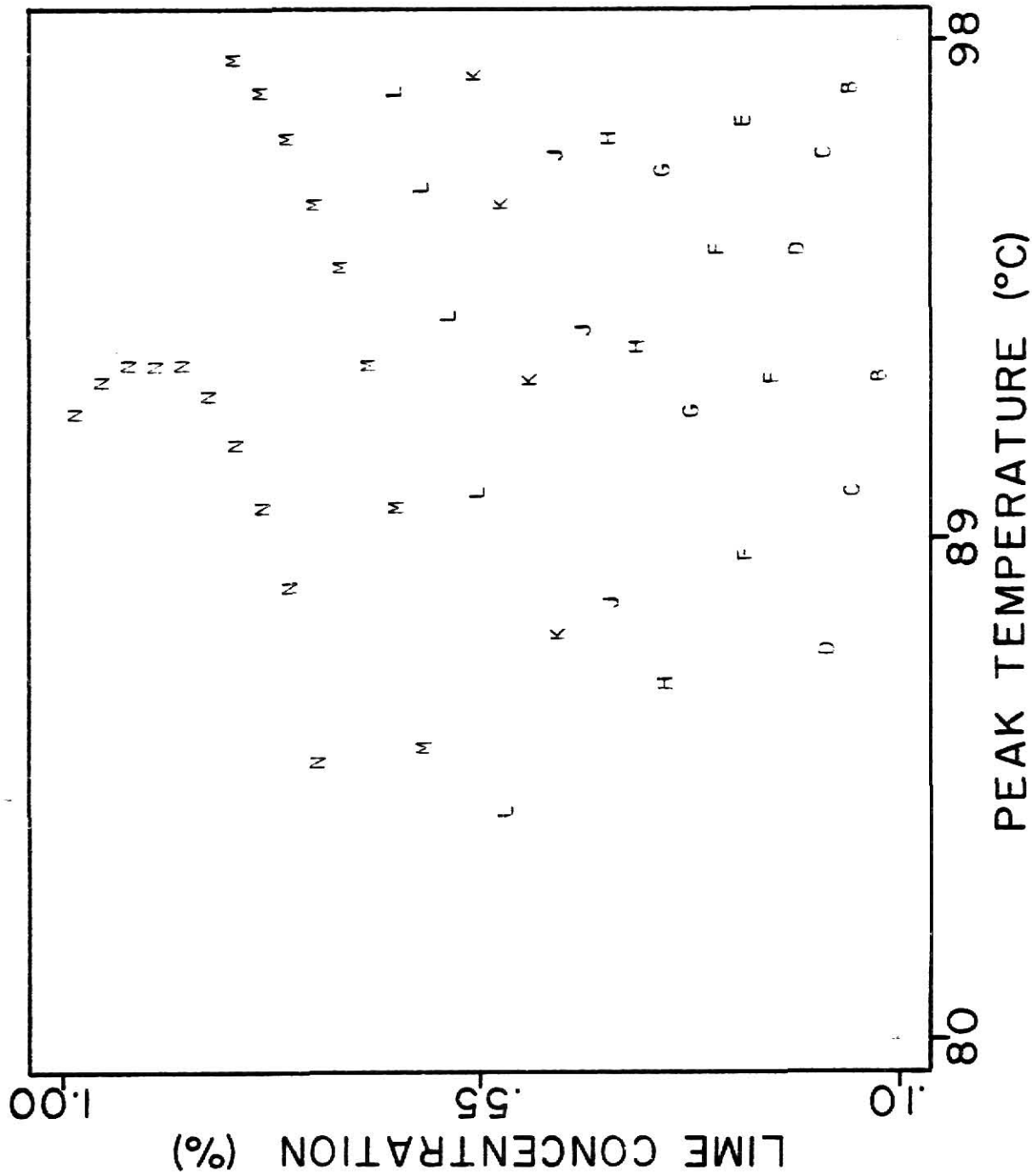

LIME CONCENTRATION (%)
1.00
.55
.10
PEAK TEMPERATURE (°C)
80
89
98

Fig. 14 Contour plot of masa 1 pH versus peak temperature and lime concentration at a hold time of 30 min. pH code values are:

C = 6.50 (units)
D = 6.75
E = 7.00
F = 7.25
G = 7.50
H = 7.75
J = 8.00
K = 8.25
L = 8.50
M = 8.75
N = 9.00
O = 9.25
P = 9.50

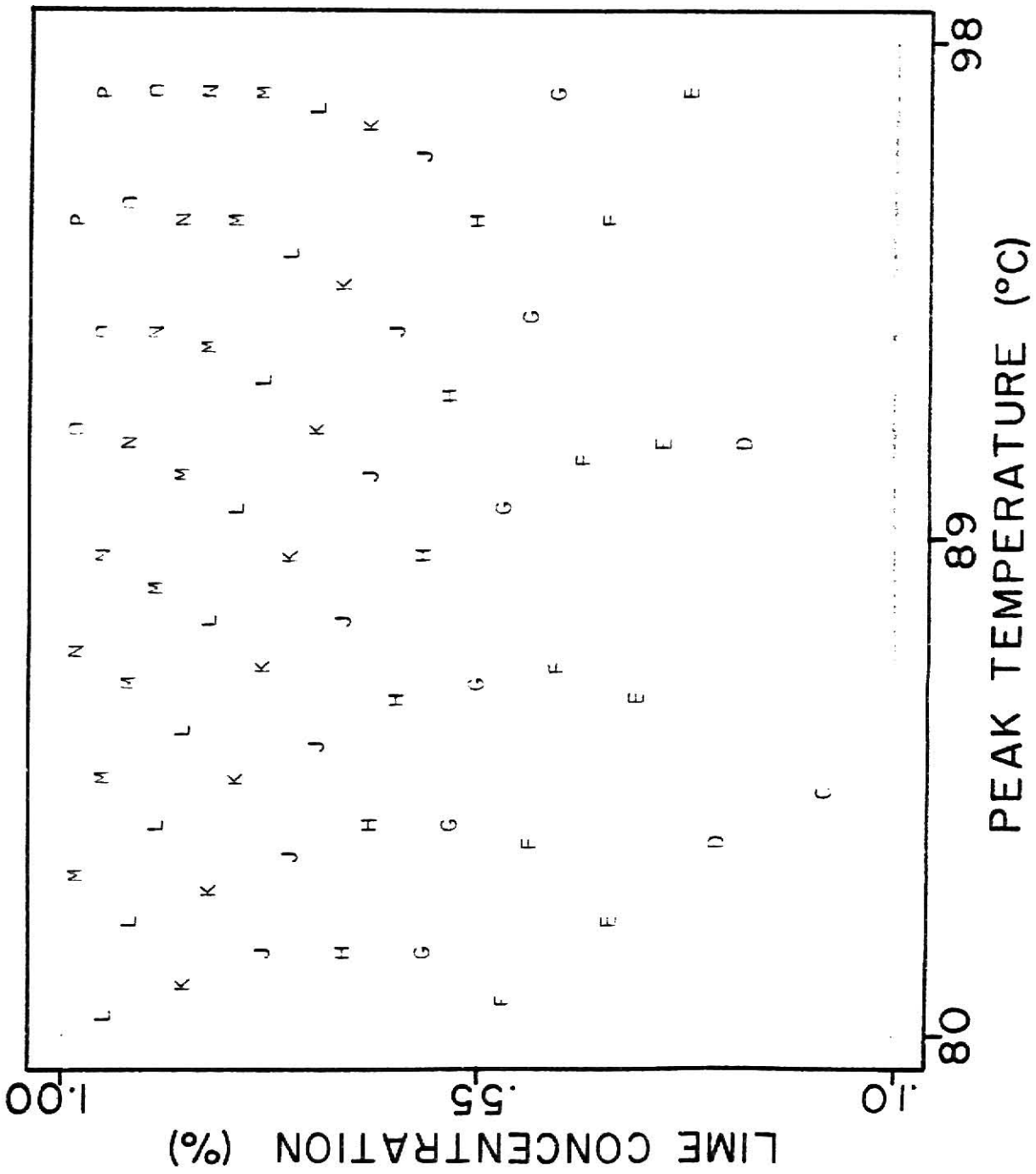

LIME CONCENTRATION (%)
1.00
.55
.10
80
89
98
PEAK TEMPERATURE (°C)

Fig. 15 Contour plot of masa 1 pH versus peak temperature and hold time at 1.0% lime concentration. pH code values are:

L = 8.50 (units)
M = 8.75
N = 9.00
O = 9.25
P = 9.50
Q = 9.75

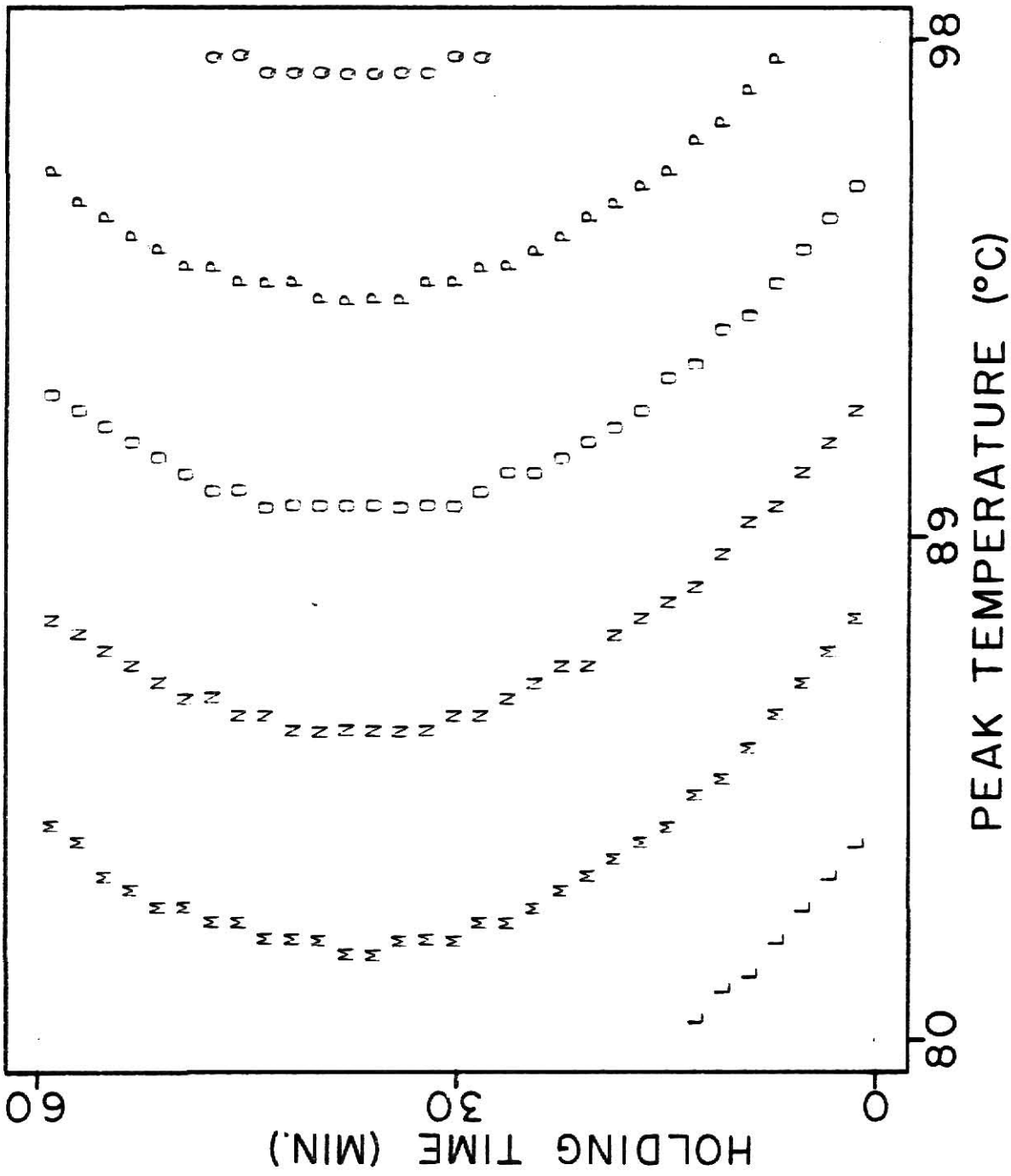

HOLDING TIME (MIN.)
0
30
60
80
89
98
PEAK TEMPERATURE (°C)

Fig. 16 Contour plot of masa 1 production rate versus peak temperature and lime concentration at a hold time of 30 min. Product rate code values are:

C = 540 (grams/minute)
D = 560
E = 580
F = 600
G = 620
H = 640
J = 660
K = 680
L = 700

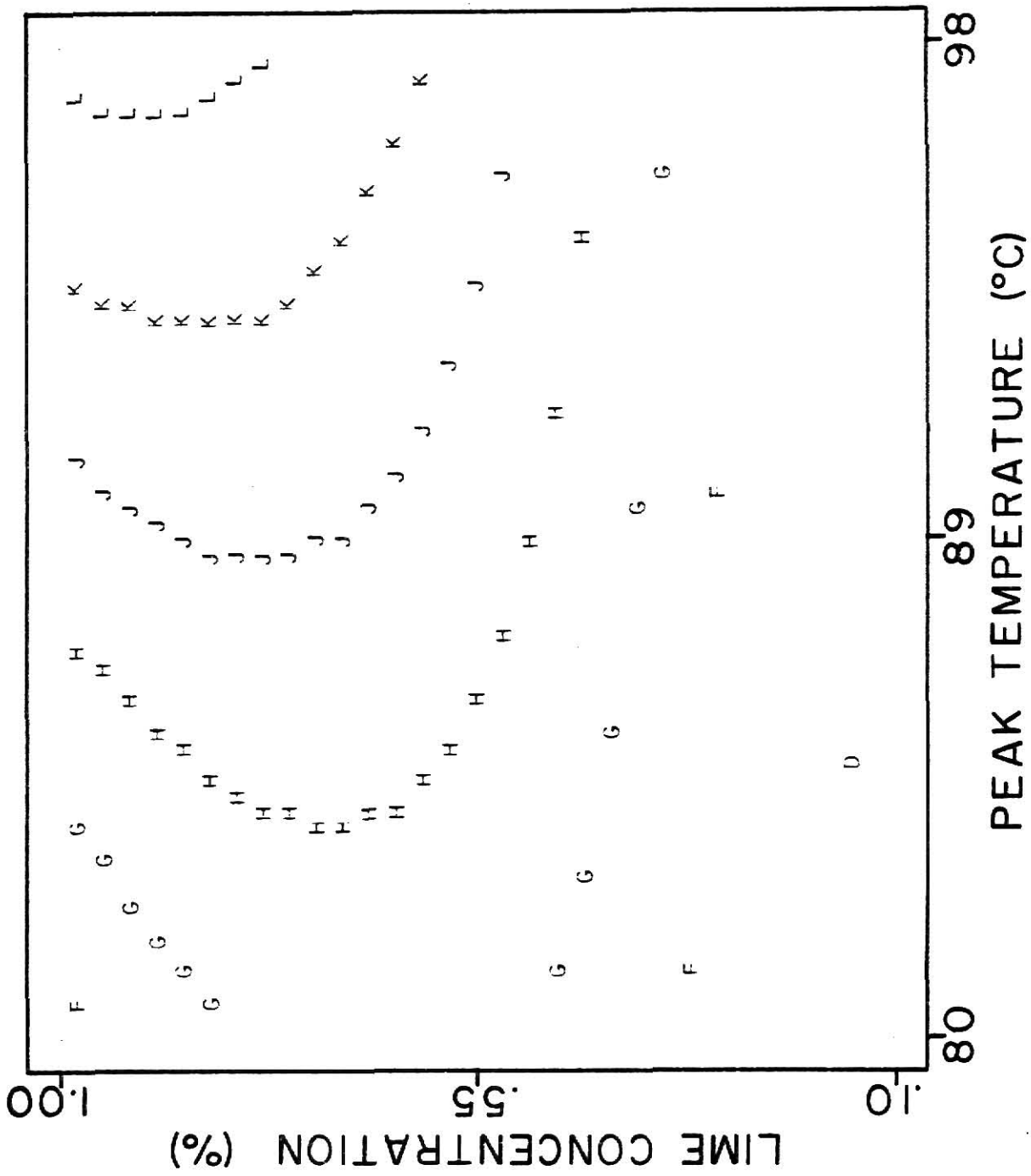
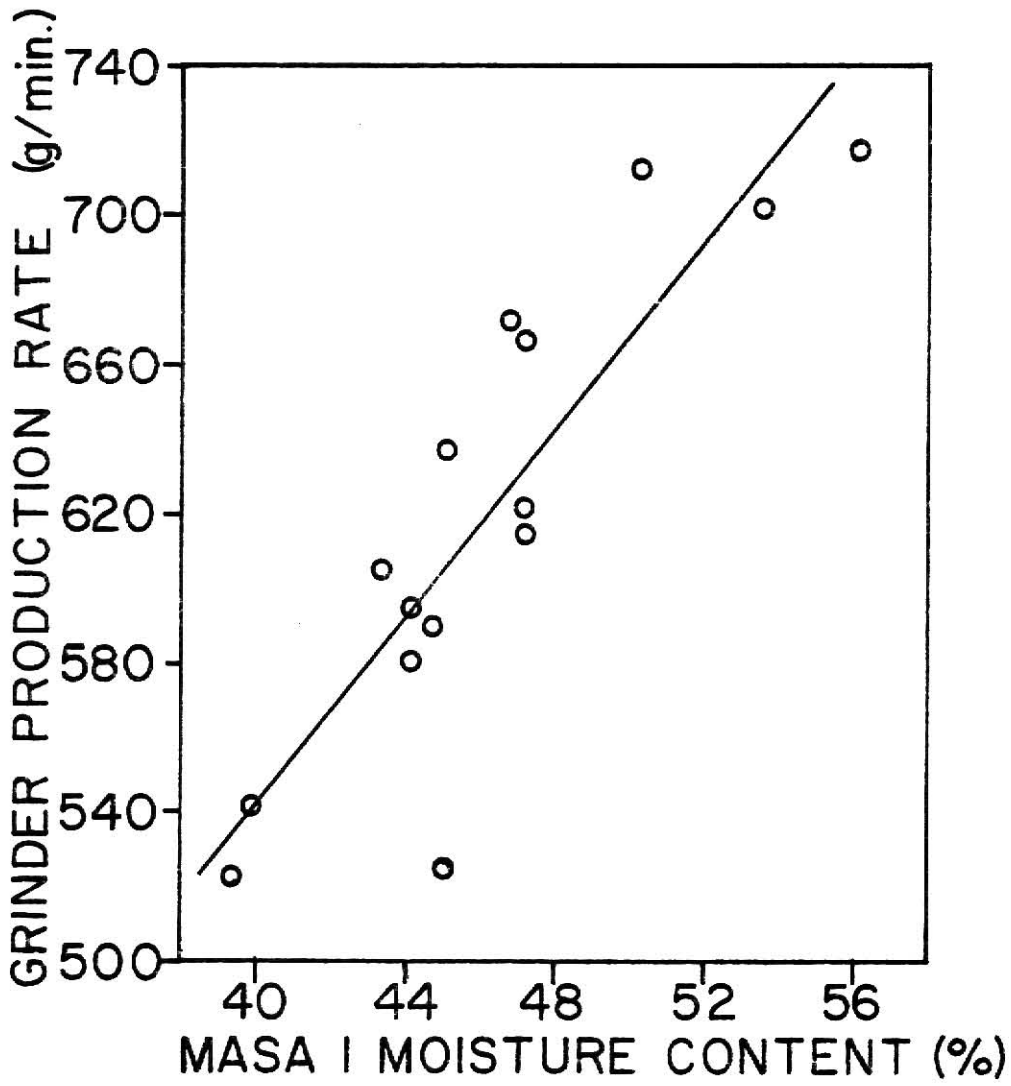

LIME CONCENTRATION (%)
1.00
.55
.10
80
89
98
PEAK TEMPERATURE (°C)

Fig. 17 Masa 1: Moisture content versus grinder production rate.

$Y = 12.4X + 45.6$
$r = 0.87$


GRINDER PRODUCTION RATE (g/min.)
740
700
660
620
580
540
500
40
44
48
52
56
MASA I MOISTURE CONTENT (%)

cannot be directly applied to normal tortilla processing. The data from masa 2 samples resulted in a low determination coefficient, so the data is not further discussed.

Mixograph Data. Samples of masa 2 were placed in a mixograph and the peak resistance measured in relative units from 1 to 10) as water increments were added to the sample. Addition of water caused either (1) an initial increase followed by a decrease, or (2) a continual decrease in resistance value. The peak resistance value for each test was measured (Figure 18). Peak resistance reaches a maximum at around 0.6 - 0.7% lime. Increasing lime beyond this point results in decreased peak resistance. The correlation data in Table 1 demonstrate all three independent variables as having similar correlations (r approximately equals 0.4). Since the R^2 value was only 0.85, the data presented in Figure 18 is not regarded as strong evidence.

The total moisture content of each sample at the peak resistance was calculated, and a plot of it shown in Figure 19. Table 1 lists a very high R^2 (0.99), with temperature having the highest correlation (r = 0.62) with the moisture content. Figure 20 exhibits the effect of temperature and holding time at 1.0% lime. If Figure 19 (moisture content of masa 2) is compared with Figure 12 (moisture content at mixograph peak of masa 2), the similarity is evident. A plot of these two moistures shows high correlation, indicating that mixograph properties seem to be highly dependent upon masa moisture contents.

Un-evaluated Response Parameters. The temperature of the masa extruding from the grinder minus the temperature of the nixtamal was calculated as the grinding differential. Differentials were not obtained for all 15 tests, therefore RSM analysis was not possible. In general the masa 2 samples, in which water was added during grinding, possessed slightly lower temperature

Fig. 18 Contour plot of mixograph peak of masa 2 versus peak temperature and lime concentration at 30 min. hold time. Peak code values are:

D = 2.25 (units)
E = 2.50
F = 2.75
G = 3.00
H = 3.25
J = 3.50
K = 3.75
L = 4.00

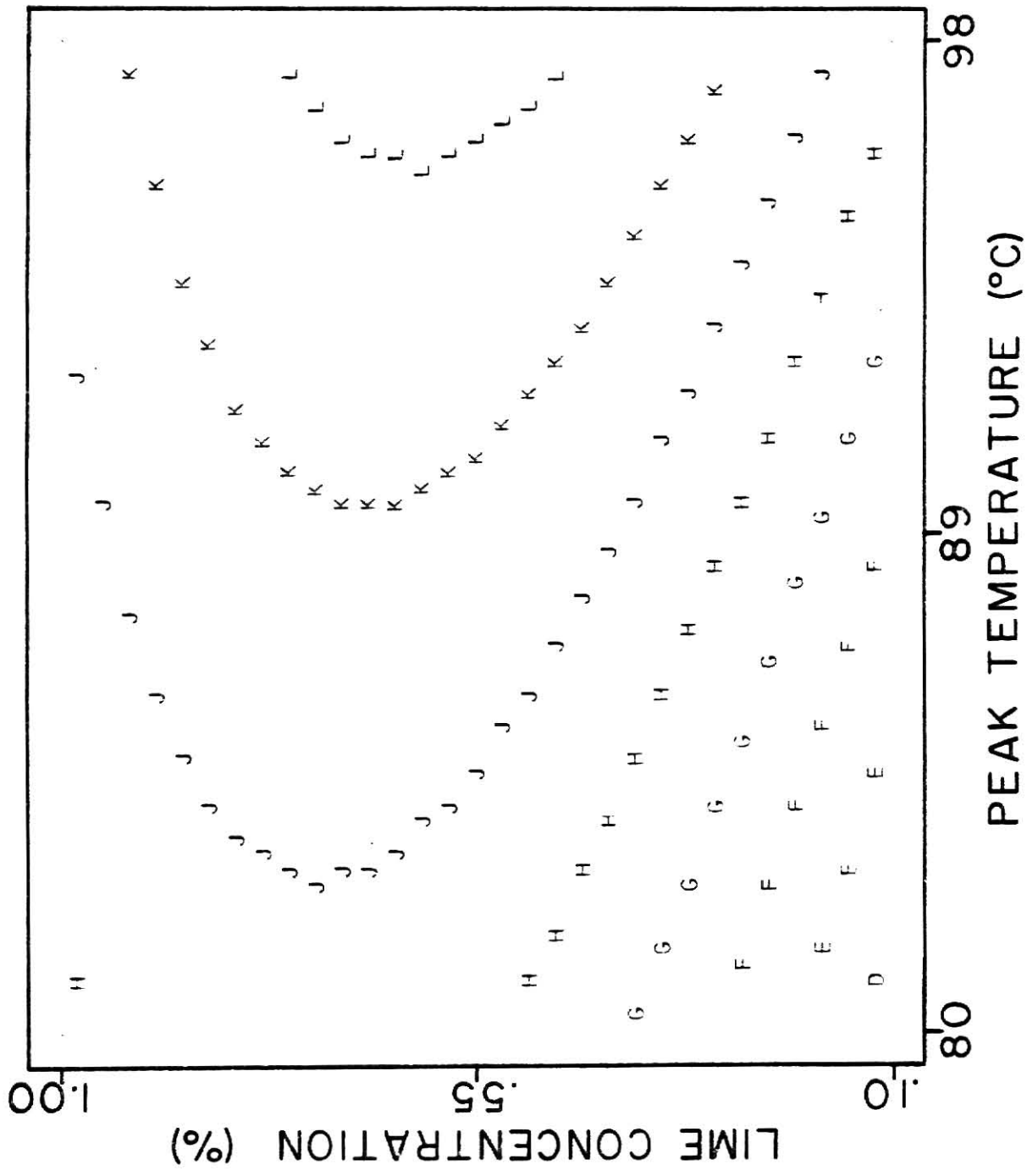

LIME CONCENTRATION (%)
1.00
.55
.10
PEAK TEMPERATURE (°C)
80
89
98

Fig. 19 Contour plot of moisture content at the mixograph peak of masa 2 versus peak temperature and lime concentration at 30 min. hold time. Moisture content code values are:

C = 51(%)
D = 52
E = 53
F = 54
G = 55
H = 56
J = 57
K = 58

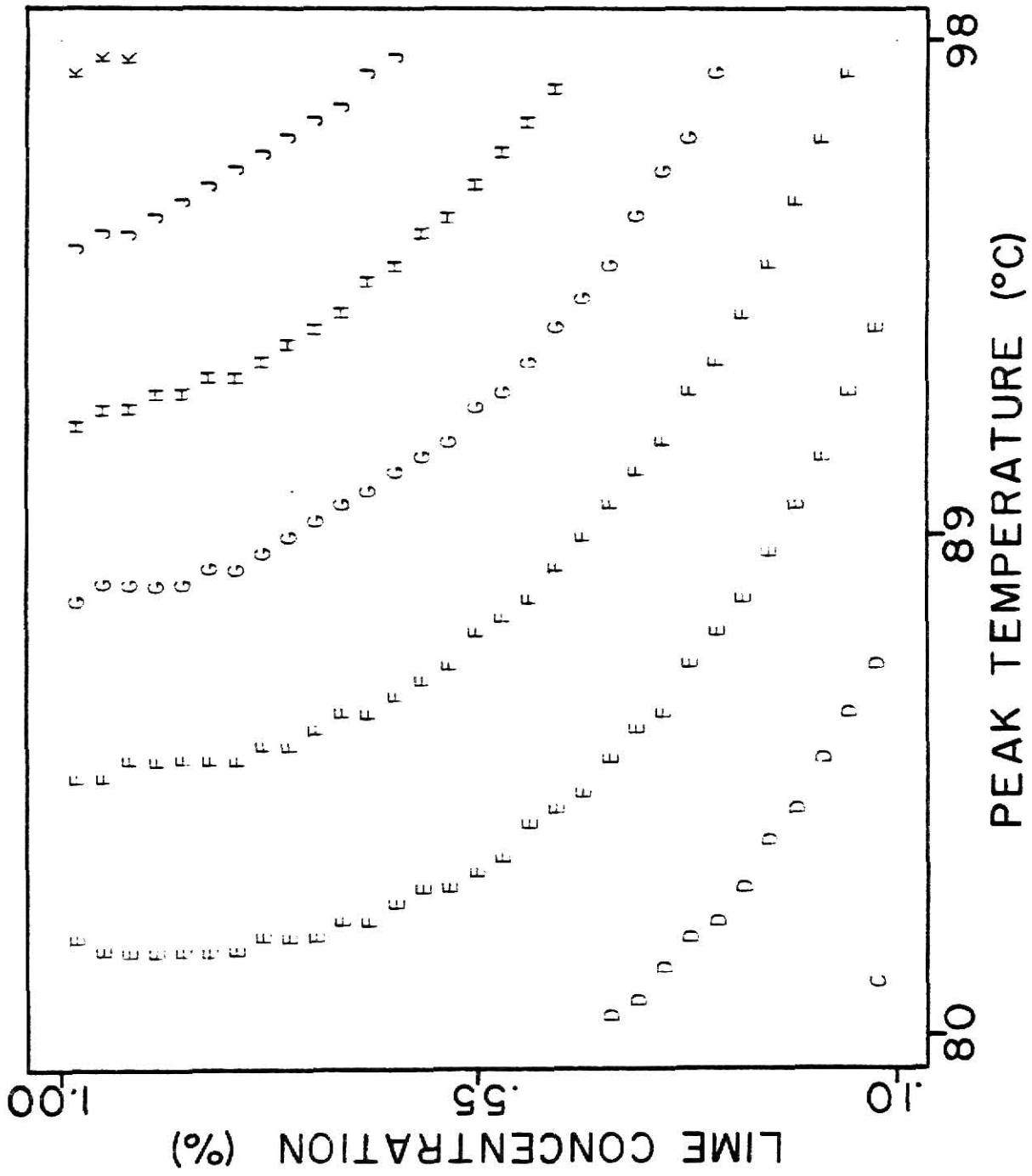
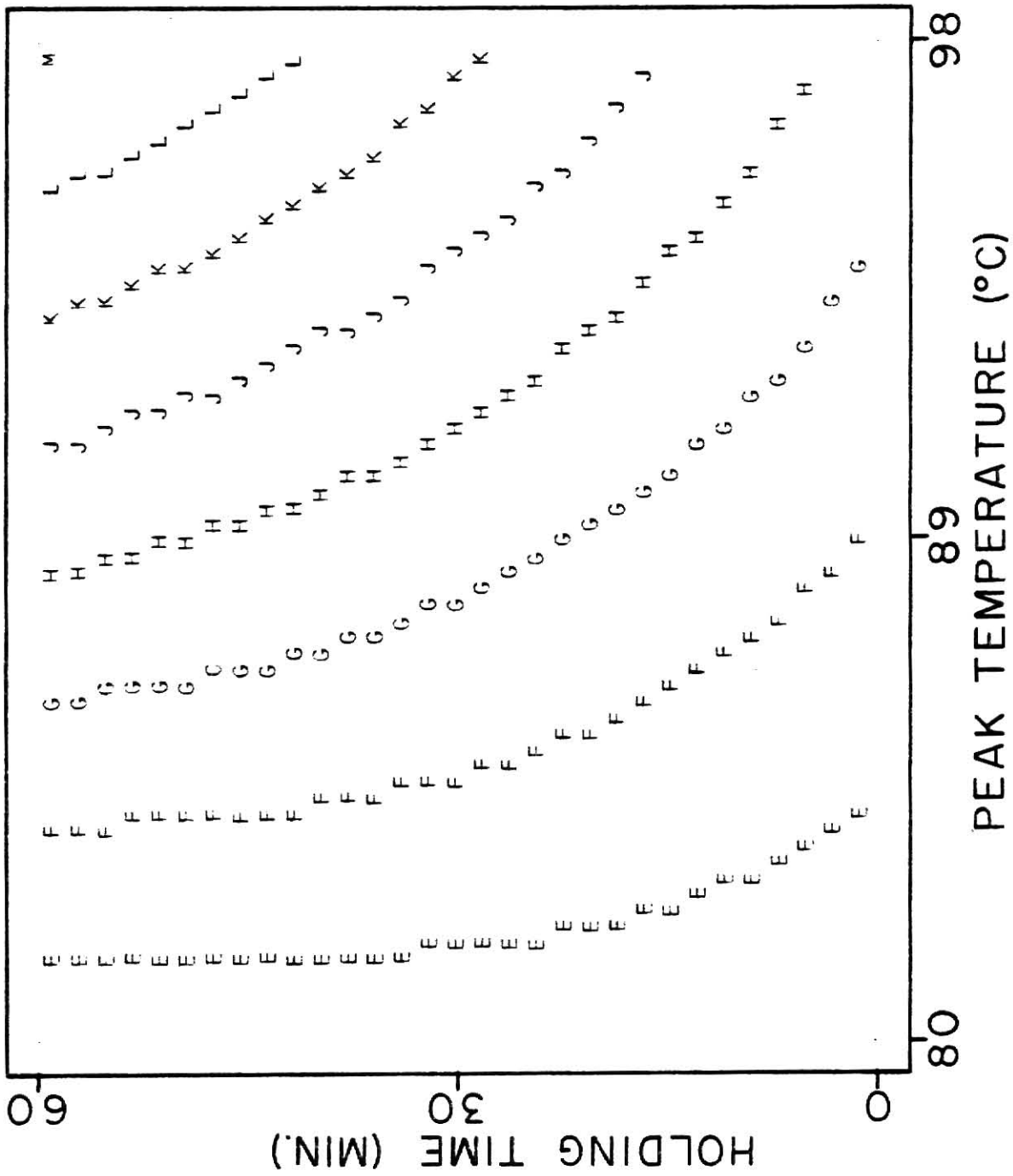

LIME CONCENTRATION (%)
1.00
.55
.10
80
89
98
PEAK TEMPERATURE (°C)

Fig. 20 Contour plot of moisture content at the mixograph peak of masa 2 versus peak temperature and hold time at a lime concentration of 1.0%. Moisture content code values are:

E = 53(%)
F = 54
G = 55
H = 56
J = 57
K = 58
L = 59
M = 60


HOLDING TIME (MIN.)
0
30
60
80
89
98
PEAK TEMPERATURE (°C)

differentials. At 89°C temperature, 0.55% lime, and 30 minute holding temperature, the three masa 1 sample temperature differentials averaged 9.9°C, whereas that for the three masa 2 samples averaged 9.2°C.

Particle size was evaluated for only part of the 15 tests. Therefore it could not be analyzed by RSM. At the 0.1% lime level, two tests showed that 82 and 84% of the dry material remained over the 104 micron mesh. Visual observation of this masa showed it to be too coarse to produce good tortillas. At the 0.55 and 1.0% lime levels, percent of overs on the 104 micron mesh ranged from 45 - 53%. Lime at 0.1% therefore appeared insufficient for preparing corn to be produced for tortillas as evidenced by particle size.

When masa samples were placed in the RWAM, the masa was in many of the tests too cohesive and bulky to flow through the opening, even with added pressure. Therefore, no reading was obtained for many of the tests, and no continuous trends were observable in the data.

Due to the large pieces of pericarp and chunkiness of the endosperm in the masa samples prepared with 0.1% lime, whole tortillas could not be produced with this masa. Also, all tests run with a holding time of 0 minutes at peak temperature produced a masa 1 that was too dry and coarse to form a tortilla. That meant that only the tests using 0.55 or 1.0% lime and 30 or 60 minute holding time produced a masa 1 that could be made into a tortilla. No trends could be observed in the few masa 1 tortillas produced. Tortilla texture (produced from masa 2) was rated best at holding times of 0 and 30 minutes, and lime contents of 0.55 and 1.0%. Color usually was rated best at 30 and 60 minute holding time.

Tortillas were evaluated for axis ratio and thickness. Three samples were run for each sample at the midpoint design of 89°C, 0.55% lime, and

30 minute holding time. Tortillas from masa 1 possessed an average axis ratio of 0.898, while those from masa 2 had a ratio average of 0.942. The average thickness decreased from 2.16 mm in tortillas made from masa 1 to 2.03 mm in masa 2. It appears that increasing the moisture in the masa produces a more plastic dough that does not deform laterally as much under pressure as a masa of lower moisture, thereby causing a rounder, flatter tortilla to be produced.

The results of the first RSM series did not establish the limits desired for the most important variables effecting tortilla production. The 0.1% lime level was too low, resulting in a coarse masa that could not be formed into a tortilla. Since tortillas could not be produced from these low-lime tortillas, not all of the experimental points for the RSM design were filled, resulting in an incomplete model that could not be analyzed by RSM. Also, the gas-fired griddle used to bake tortillas in RSM-S1 was found inadequate for research requiring consistent duplication.

A second series was therefore planned that would bypass the above shortcomings. A higher (constant) lime level of 1.0% was chosen for the second series, with steep time replacing lime concentration as the third independent variable to study. A commercial tortilla oven was prepared for the second series with enough controls on it to be able to duplicate forming and baking of tortillas.

Series 2 - Response Surface Methodology. The three independent variables used for series 2 were: (1) peak temperature; (2) time at peak temperature (or holding time); and (3) time of steep (or steep time). Twenty-four different responses from each of the twenty tests were analyzed by RSM. The response parameters, determination coefficients (R^2), and simple linear correlations are listed in Table 2.

TABLE 2

Response Parameter	Determination Coefficient (R^2)	Linear Correlation of Response With: Temperature	Hold Time	Steep Time
Nixtamal:				
weight	1.00	0.85	0.36	0.23
moisture content	0.99	0.84	0.40	0.25
Masa:				
production rate	0.94	0.51	0.33	0.48
moisture content (2-stage)	0.99	0.84	0.39	0.25
pH	0.98	0.80	0.35	0.43
color (Agtron reflectance)	1.00	-0.82	-0.29	-0.29
particle size:				
% over 417 micron	0.93	-0.32	-0.20	-0.70
% over 104 micron	0.93	-0.19	-0.23	-0.73
amylograph parameters:				
arrival time (min)	0.83	0.65	0.44	0.28
peak (BU's)	0.95	-0.87	-0.40	-0.02
slope index (BU/min)	0.96	-0.83	-0.42	-0.13
curve index (BU^2/min)	0.96	-0.83	-0.41	-0.10
Tortilla:				
moisture content (infra-red)	0.85	0.66	0.44	0.25
weight (g)	0.83	-0.71	-0.36	-0.42
axis ratio	0.94	0.90	0.18	0.18
thickness (mm)	0.82	-0.58	-0.43	-0.36
shear force:				
fresh tortillas (Kg)	0.98	-0.81	-0.41	-0.28
frozen tortillas (Kg)	0.98	-0.81	-0.43	-0.30
shear force/thickness (Kg/mm) - fresh tortillas	0.97	-0.84	-0.38	-0.22
organoleptic tests:				
aroma	0.89	0.53	0.12	0.25
flexibility	0.50	-0.63	0.27	-0.12
mouthfeel	0.76	0.55	0.19	0.55
taste	0.78	0.40	0.44	0.43

Nixtamal Weight and Moisture Content. Except for some weight loss due to hydrolyzed pericarp that is lost in rinsing of the nixtamal, all weight change in the nixtamal is effected by absorption of water into the kernel during cooking and steeping. Therefore nixtamal weight and moisture content data should experience similar trends as evidenced by the results in Table 2. The determination coefficient of 1.00 for nixtamal weight (0.99 for moisture content) indicates that all experimental error is accounted for by the modified equation. Peak temperature has the largest linear correlation with the nixtamal weight ($r = 0.85$), less with peak time (0.36), and least with steep time (0.23).

The data for nixtamal weight, nixtamal moisture content, and masa moisture content with respect to correlations (Table 2) for temperature, hold time, and steep time are almost identical. Also, the RSM plots are very similar, therefore only the masa moisture content plots are discussed further.

Masa Moisture Content. Figure 21 is a plot of masa moisture content versus peak temperature and holding time at a steep time of 9 hours. Figure 22 is a similar plot, except that steep time is varied and hold time was left at 30 minutes. Moisture content is primarily dependent upon peak temperature.

Steep times greater than 12 - 13 hours have no effect on moisture content in the masa when a hold time of 30 minutes is used. At 60 minutes holding time (Figure 23), steep times longer than 9 - 12 hours (the longer time required at lower temperatures), resulted in negligible change in masa moisture content. At hold times near 0 minutes increasing steep time does significantly contribute to moisture content, especially at temperatures below 88°C (Figure 24).

Fig. 21 Masa moisture content versus peak temperature and hold time at 9 hr. steep time. Moisture content code values are:

C = 51(%)
D = 52
E = 53
F = 54
G = 55
H = 56
J = 57
K = 58
L = 59

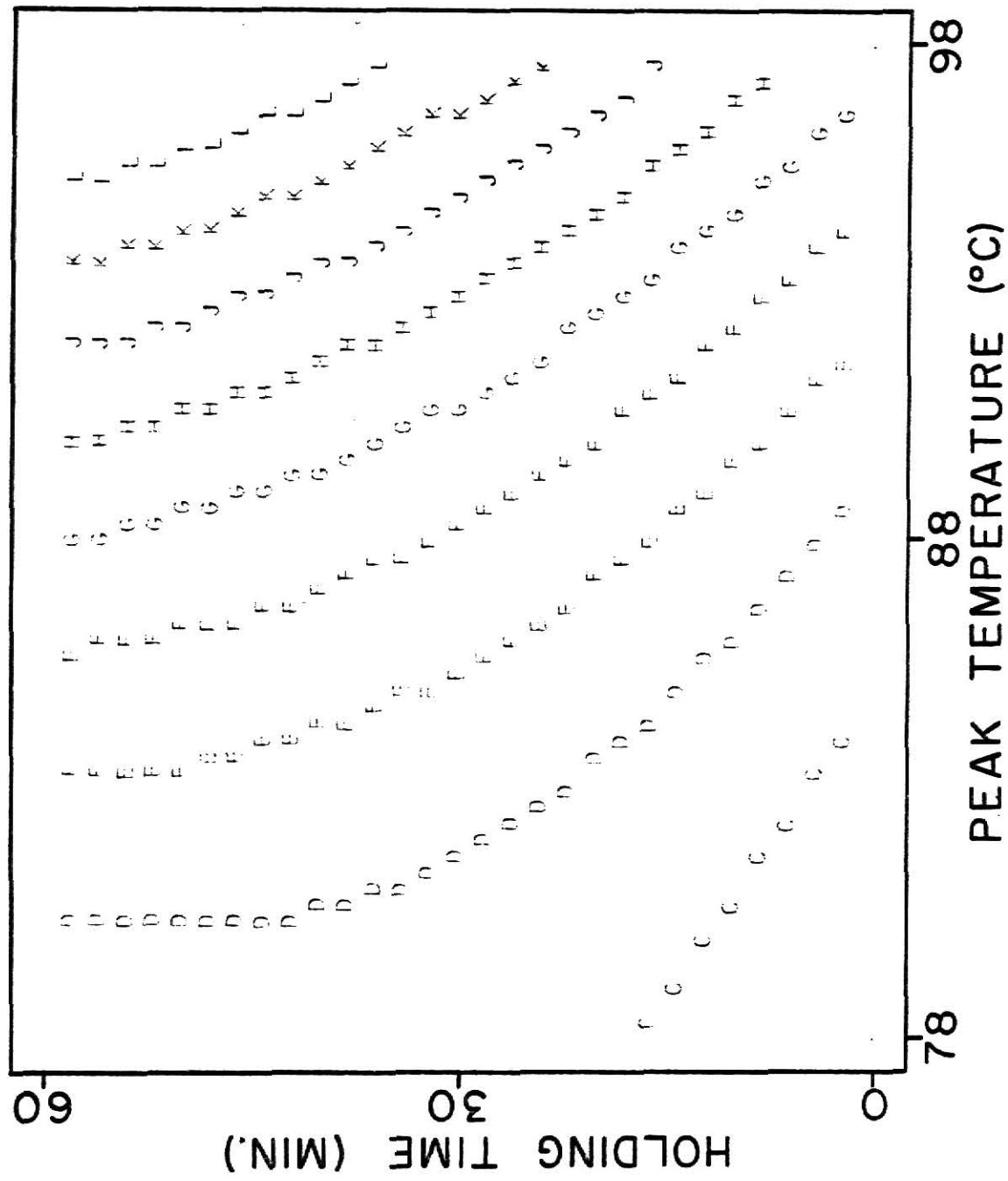

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 22 Contour plot of masa moisture content versus peak temperature and steep time at 30 min. hold time. Moisture content code values are:

B = 50(%)
C = 51
D = 52
E = 53
F = 54
G = 55
H = 56
J = 57
K = 58
L = 59

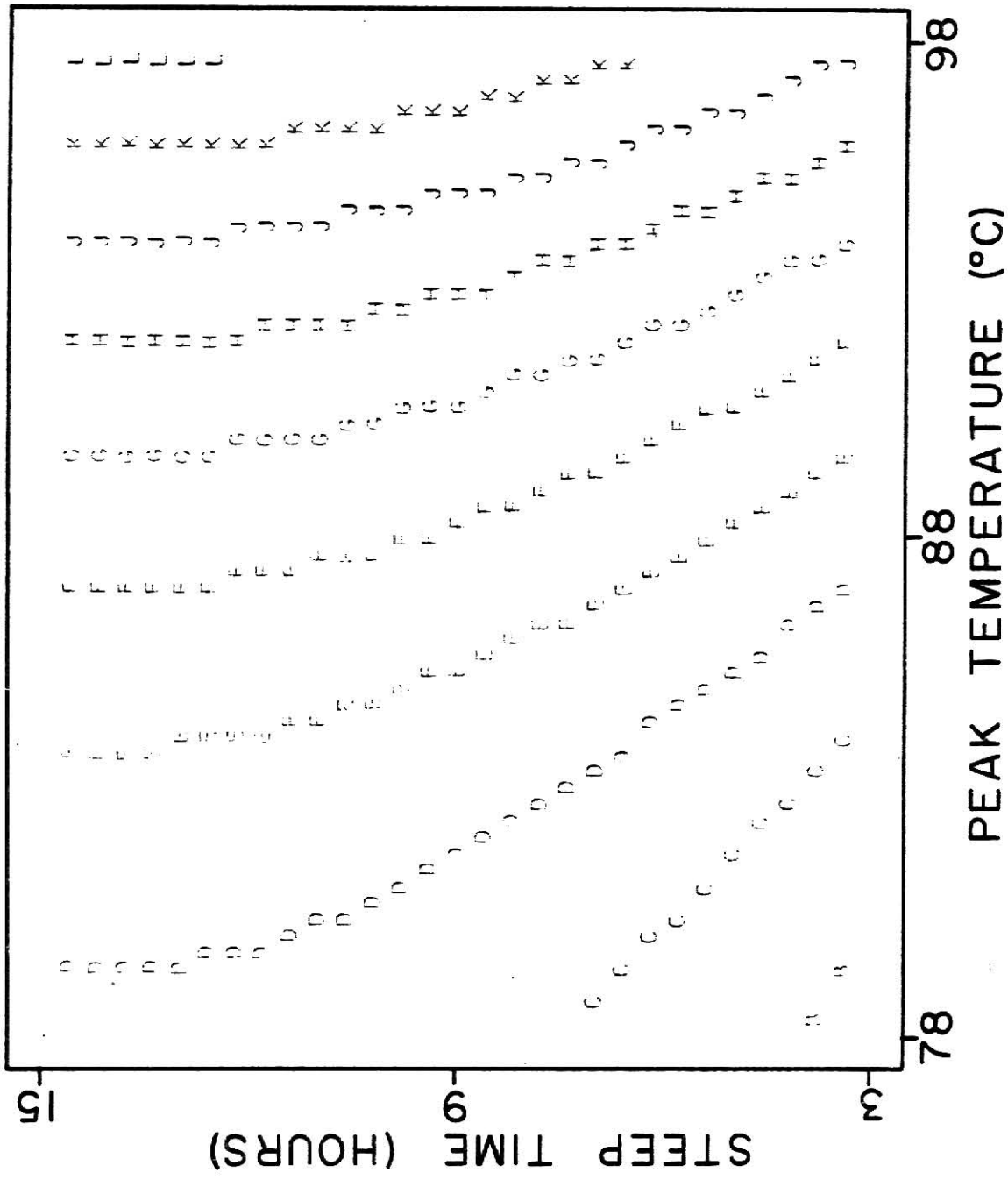

STEEP TIME (HOURS)
15
9
3
78
88
98
PEAK TEMPERATURE (°C)

Fig. 23 Contour plot of masa moisture content versus peak temperature and steep time at 60 min. hold time. Moisture content code values are:

C = 51(%)
D = 52
E = 53
F = 54
G = 55
H = 56
J = 57
K = 58
L = 59

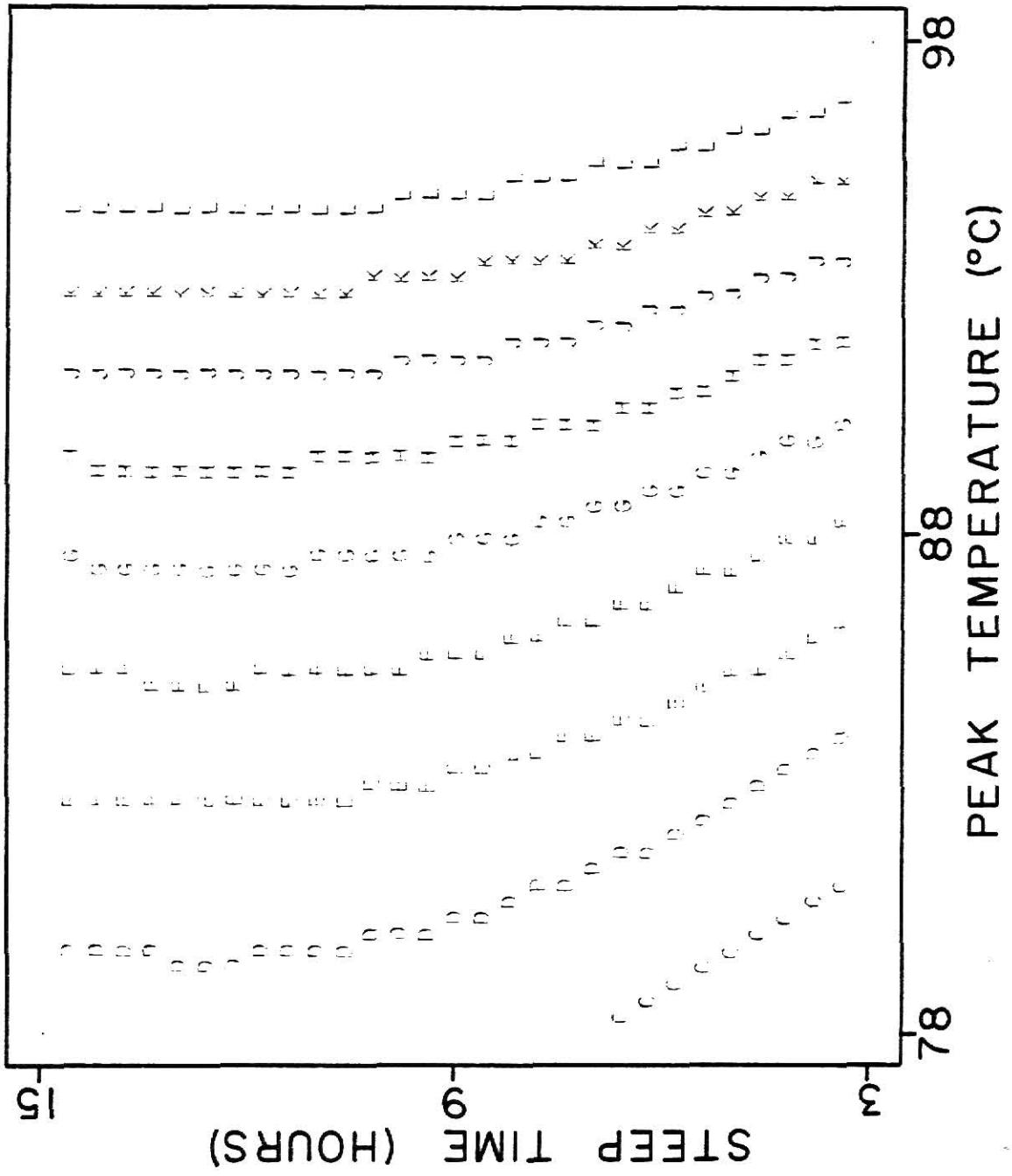
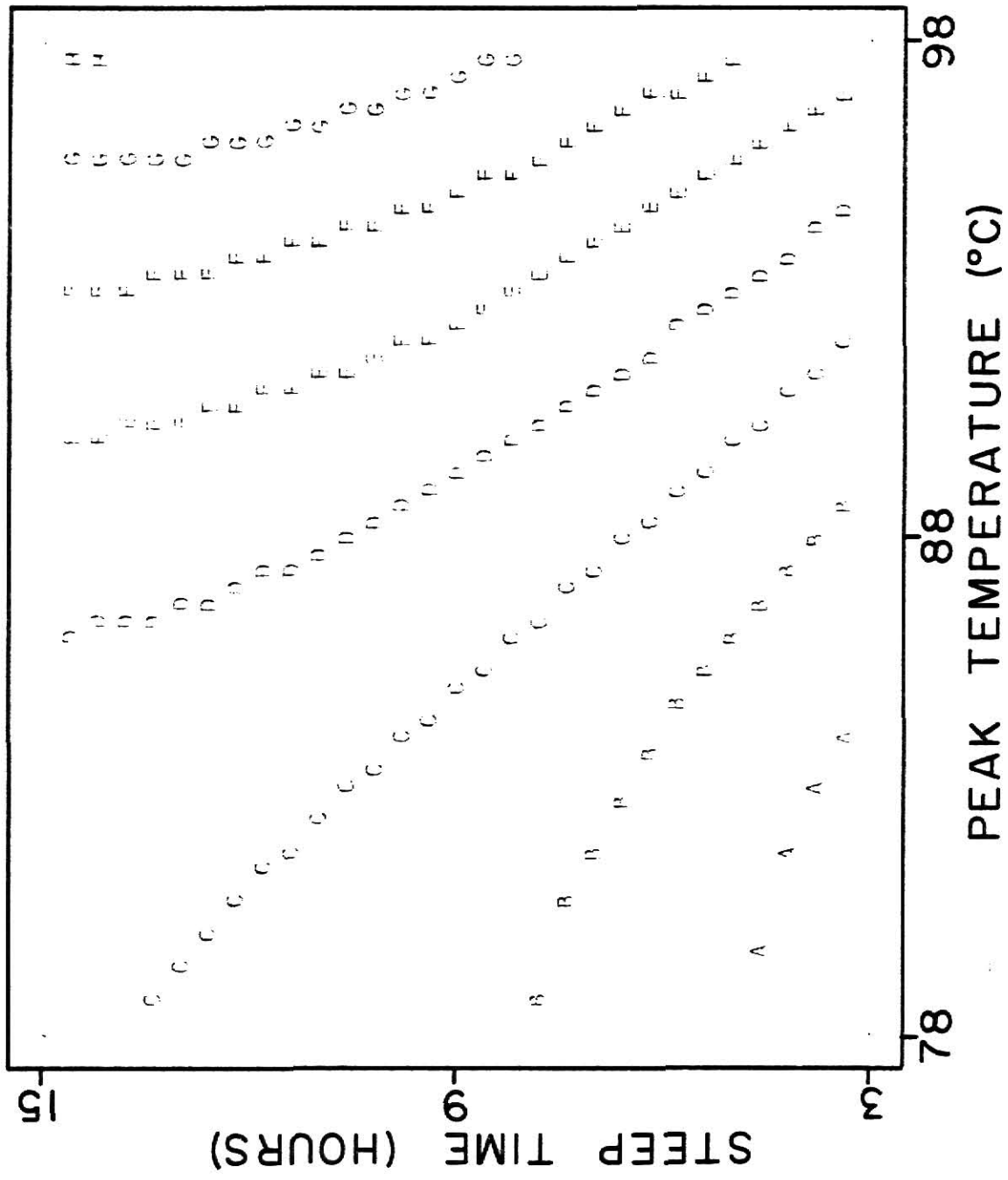

STEEP TIME (HOURS)
15
9
3
78
88
98
PEAK TEMPERATURE (°C)

Fig. 24 Contour plot of masa moisture content versus peak temperature and steep time at 0 min. hold time. Moisture content code values are:

A = 49(%)
B = 50
C = 51
D = 52
E = 53
F = 54
G = 55
H = 56


STEEP TIME (HOURS)
3
9
15
78
88
98
PEAK TEMPERATURE (°C)

Infra-red moisture contents were measured concurrent with two-stage moisture contents for the masa to determine accuracy of the infra-red moisture method. Correlation for the data was r = 0.995 (Figure 25), establishing the infra-red determination as an accurate substitution for two-stage moisture determination tests.

Masa Production Rate. Linear correlations from Table 2 reveal that peak temperature had much less effect (r = 0.51) on production rate than on nixtamal and masa moisture content (r = 0.85). In grinding the different test samples the grinder setting was altered to provide a constant pressure between the stones. If the grinder setting had not been varied, the temperature-production rate correlation might have been higher. In Figures 26 and 27 a production rate minimum occurs at a temperature range of 83 - 87°C. An increasing rate occurs on either side of this range. Increasing the steep time (Figure 27) from 3 - 9 hours does significantly increase production rate, but times beyond 10 hours do not change the rate. Figure 28 is a plot of masa moisture content versus production rate. The two factors are positively correlated, though not too closely.

Masa pH. In this series, lime concentration was held constant at 1.0%. The determination coefficient (Table 2) of 0.98 revealed a reliable model for the pH tests. Correlation of pH with temperature was best (0.80), and less with steep time (0.43). Except in the area of temperatures greater than 90°C and steep times longer than 10 hours, pH is a linear function of both steep time and temperature (Figure 29). Above the limits described, only temperature linearly effected pH. pH is easily observed as a linear function of either peak temperature or time at peak temperature, although temperature again is the overriding function (Figure 30). Therefore, increasing steep times up to 10 hours, increasing holding time between 0 and 60 minutes, and

Fig. 25 Masa moisture content -- two-stage method versus infra-red method.

$Y = 1.02X - 1.28$
$r = 0.995$

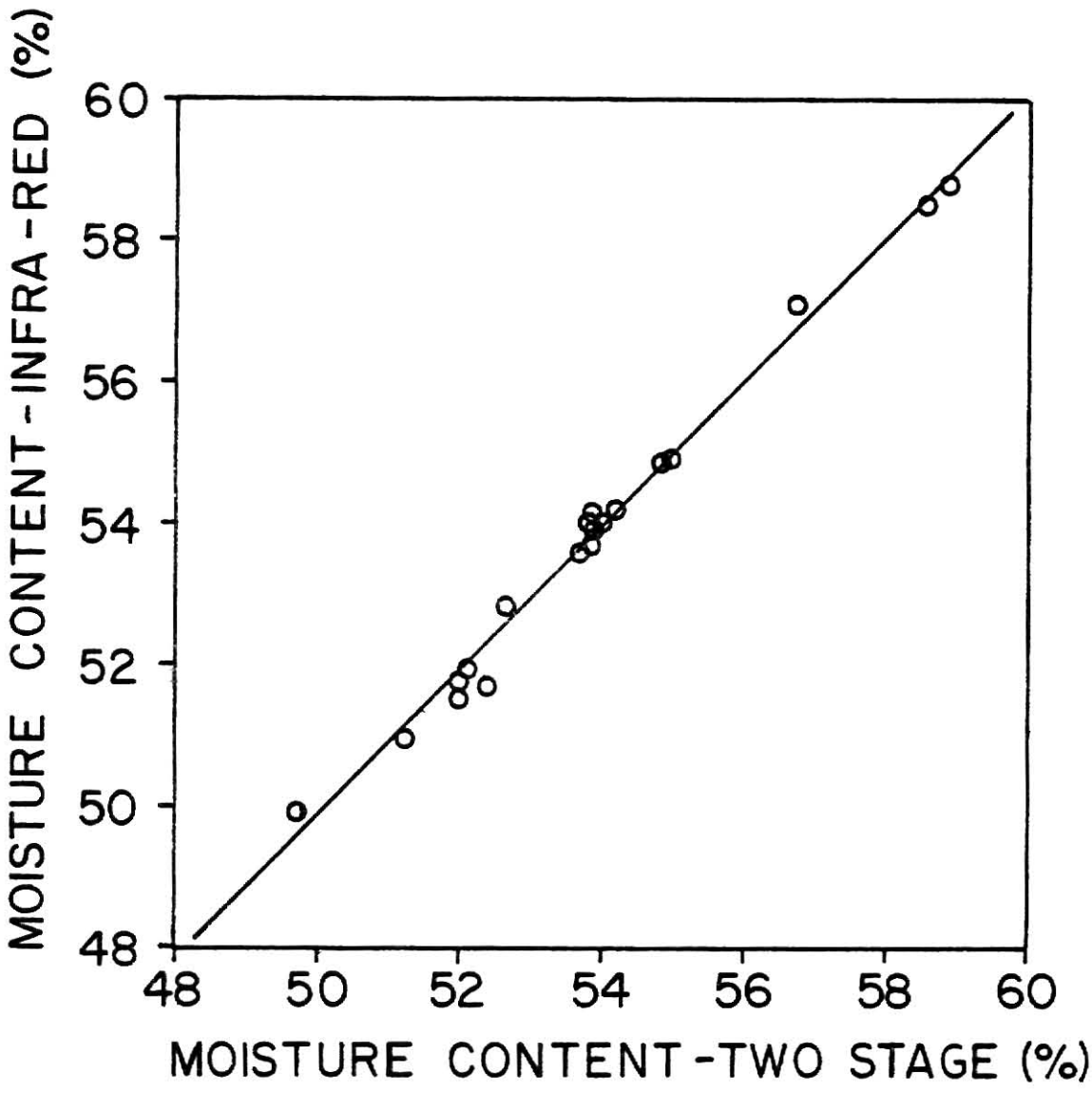

MOISTURE CONTENT-INFRA-RED (%)
60
58
56
54
52
50
48
48
50
52
54
56
58
60
MOISTURE CONTENT-TWO STAGE (%)

Fig. 26 Masa production rate versus peak temperature and hold time at 9 hr. steep time. Production rate code values are:

D = 820 (grams/min.)
E = 830
F = 840
G = 850
H = 860
J = 870
K = 880
L = 890

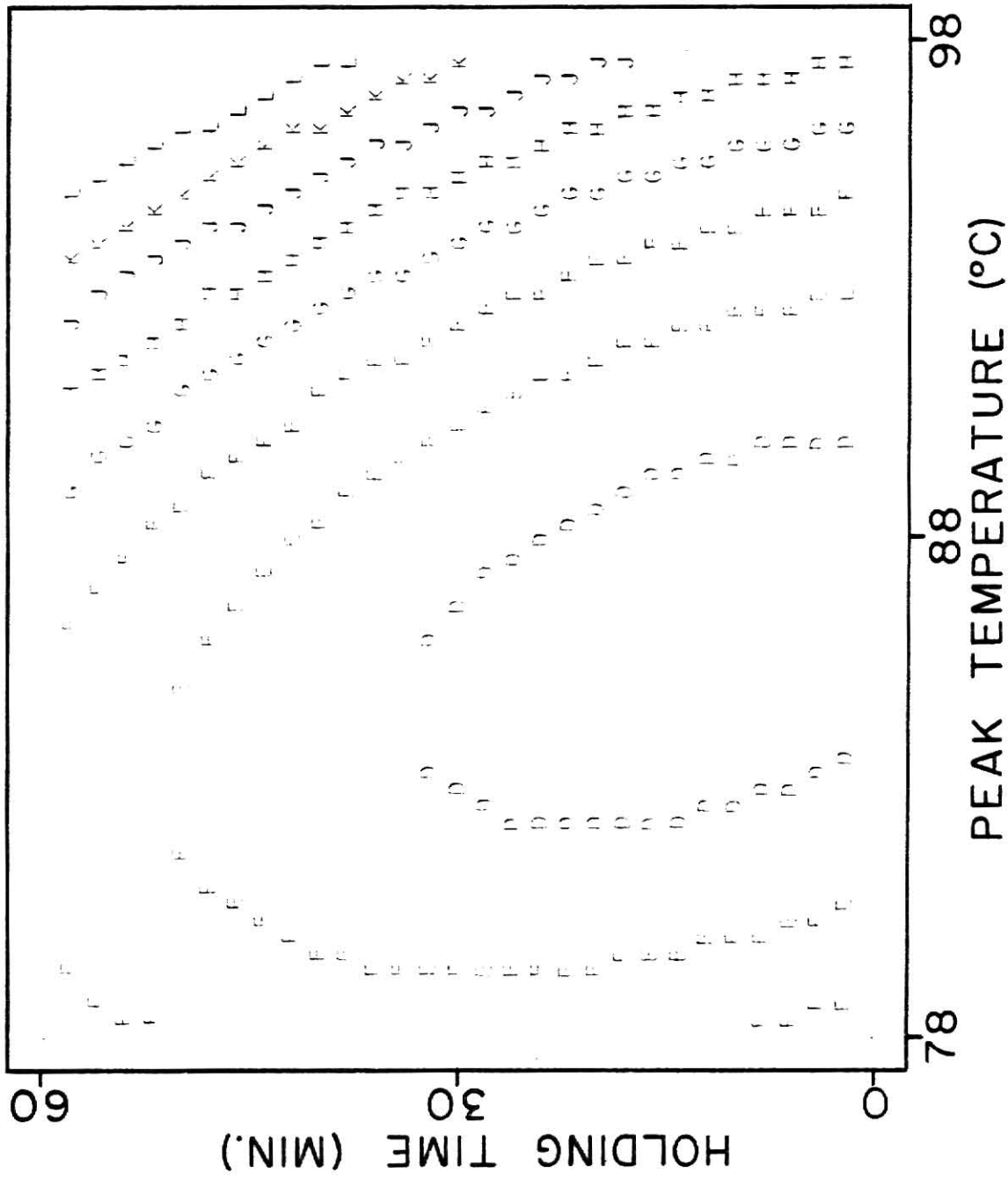

HOLDING TIME (MIN.)
60
30
0
78
88
98
PEAK TEMPERATURE (°C)

Fig. 27 Contour plot of masa production rate versus peak temperature and steep time at 30 min. hold time. Production rate code values are:

A = 790 (grams/min.)
B = 800
C = 810
D = 820
E = 830
F = 840
G = 850
H = 860
J = 870
K = 880
L = 890

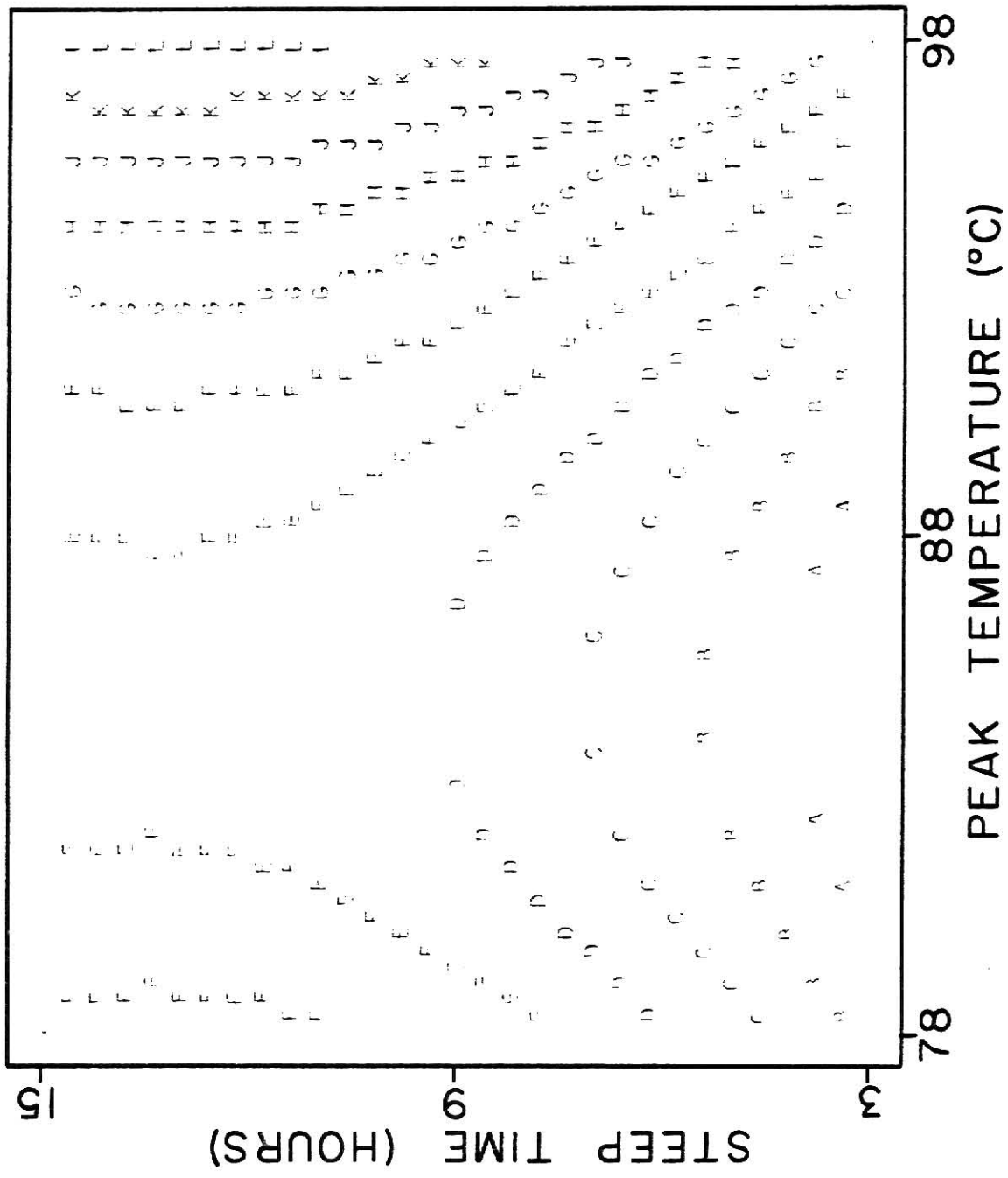

STEEP TIME (HOURS)
3
9
15
78
88
98
PEAK TEMPERATURE (°C)

Fig. 28 Masa: Moisture content versus production rate.

$Y = 8.41X + 377$
$r = 0.79$

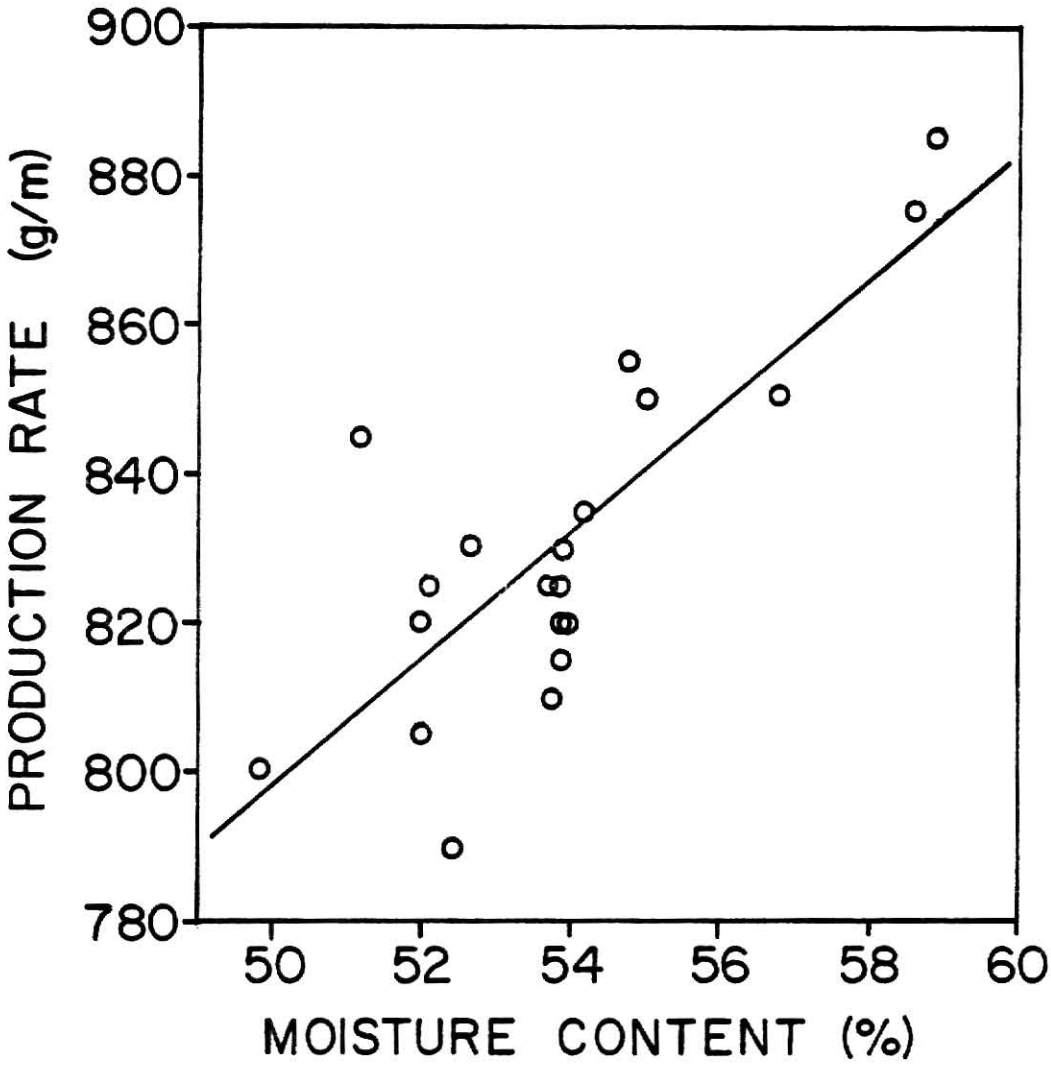

900
880
860
840
820
800
780
PRODUCTION RATE (g/m)
50
52
54
56
58
60
MOISTURE CONTENT (%)

Fig. 29 Contour plot of masa pH versus peak temperature and steep time at 30 min. hold time. pH code values are:

A = 8.4 (units)
B = 8.6
C = 8.8
D = 9.0
E = 9.2
F = 9.4
G = 9.6

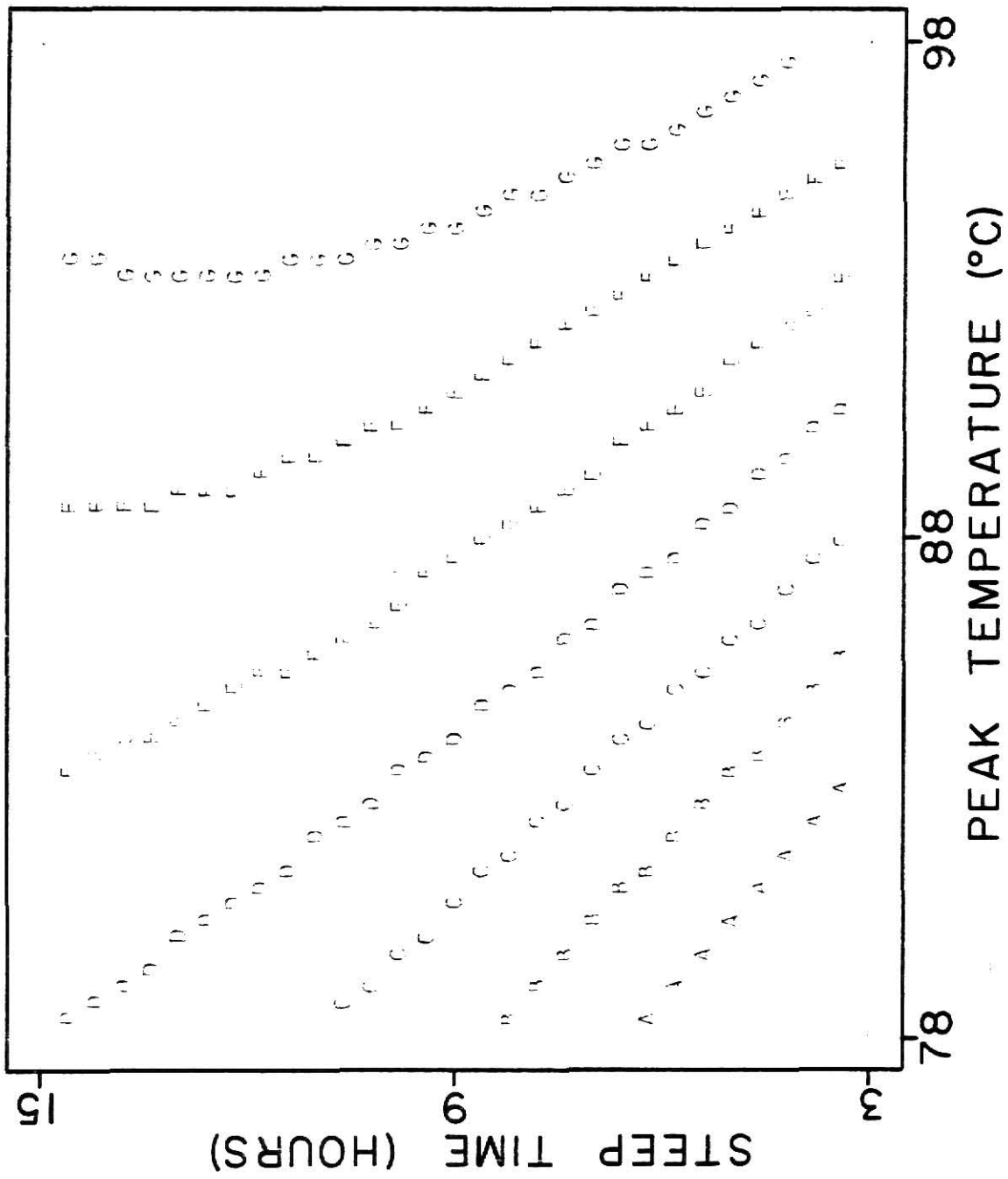
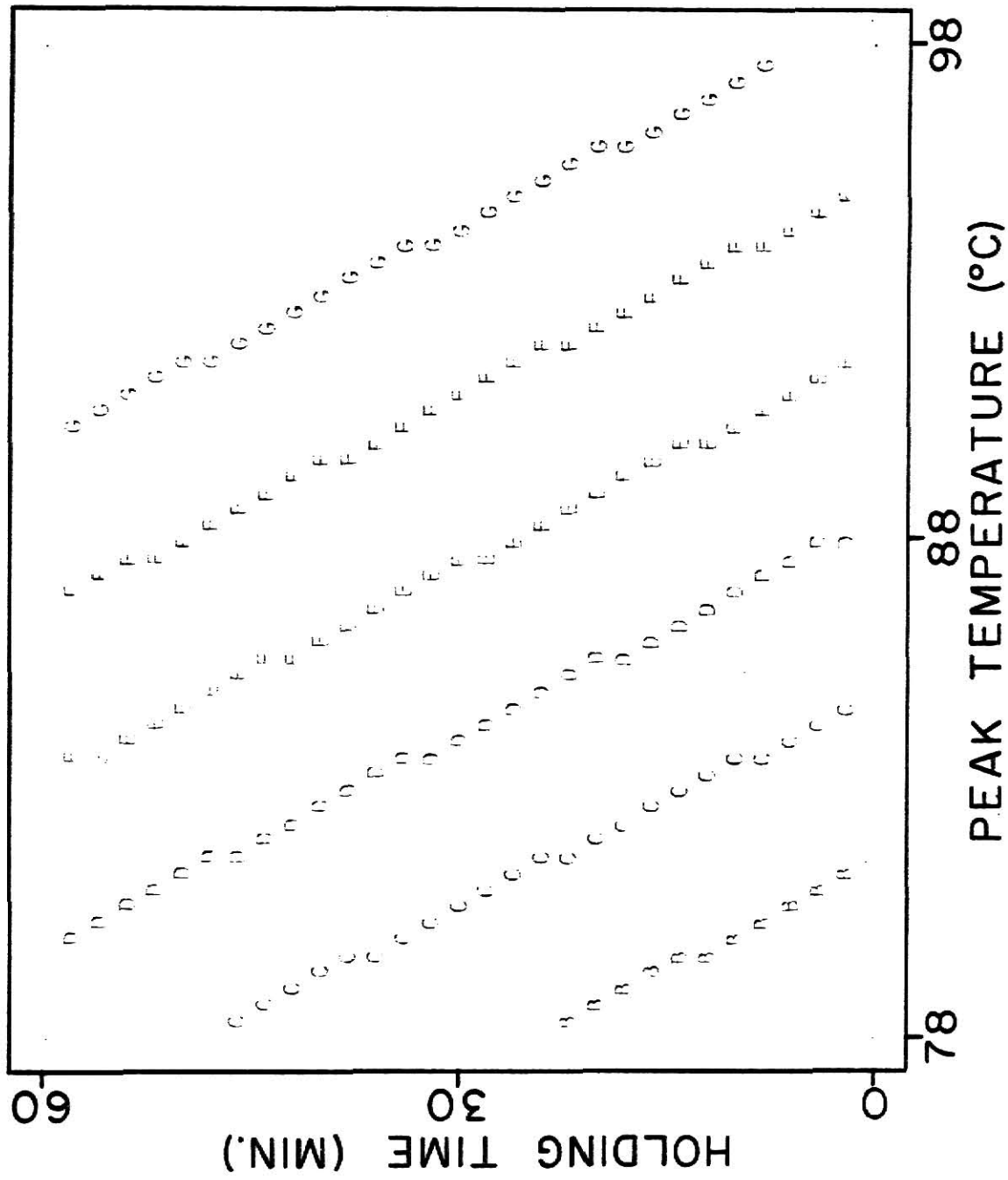

STEEP TIME (HOURS)
15
9
3
78
88
98
PEAK TEMPERATURE (°C)

Fig. 30 Contour plot of masa pH versus peak temperature and hold time at 9 hr. steep time. pH code values are:

B = 8.6 (units)
C = 8.8
D = 9.0
E = 9.2
F = 9.4
G = 9.6


HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

increasing peak temperature at any value between 78 and 98°C will result in an increased masa pH when lime concentration is held constant at 1.0%.

Masa Color. Comparisons between the pH and color of their linear correlation with temperature shows both are similar, but oppositely correlated ($r = 0.80$ and $r = -0.81$, respectively) (Table 2). Figure 31 is a plot of color versus pH, with correlation of the two data sets being $r = 0.946$. Linear correlations for holding time and steep time are lower than for pH. In the region of temperatures less than about 90°C, color is almost a negative linear function of any of the three variables (Figures 32 and 33). Above these levels color becomes more solely a function of peak temperature. The lowest Agtron color value (the most yellow) in Figure 32 was 25. As steep time is increased to 15 hours (Figure 34) the minimum color is 35, indicating that a maximum yellow color is reached prior to 15 hours of steep time (Figure 33). Figure 35, at 3 hours steep time, indicates a minimum color (and maximum yellow) at high peak temperatures and long holding times. However at longer steep times (Figure 36), excessive hold times and high temperatures can result in a reduction of yellow color.

Masa Particle Size. Linear correlations of particle size versus steep time were high (-0.70 and -0.73) whereas those for size versus peak temperature were very low in comparison to the rest of the responses in Table 2. This establishes the importance of time in allowing equilibration of moisture content throughout the kernel, which in turn affects grinding of the corn and the resultant particle size of the masa. At 0 minute holding time, percentage of material retained over the 400 micron screen was at a minimum for steep times of 11 - 14 hours, shorter times being required at higher temperatures (Figure 37). As holding time was increased to 60 minutes, lower peak temperatures and longer steep times resulted in a minimum value of overs

Fig. 31 Masa: pH versus color (Agtron).

$Y = -30.9X + 322$
$r = 0.95$

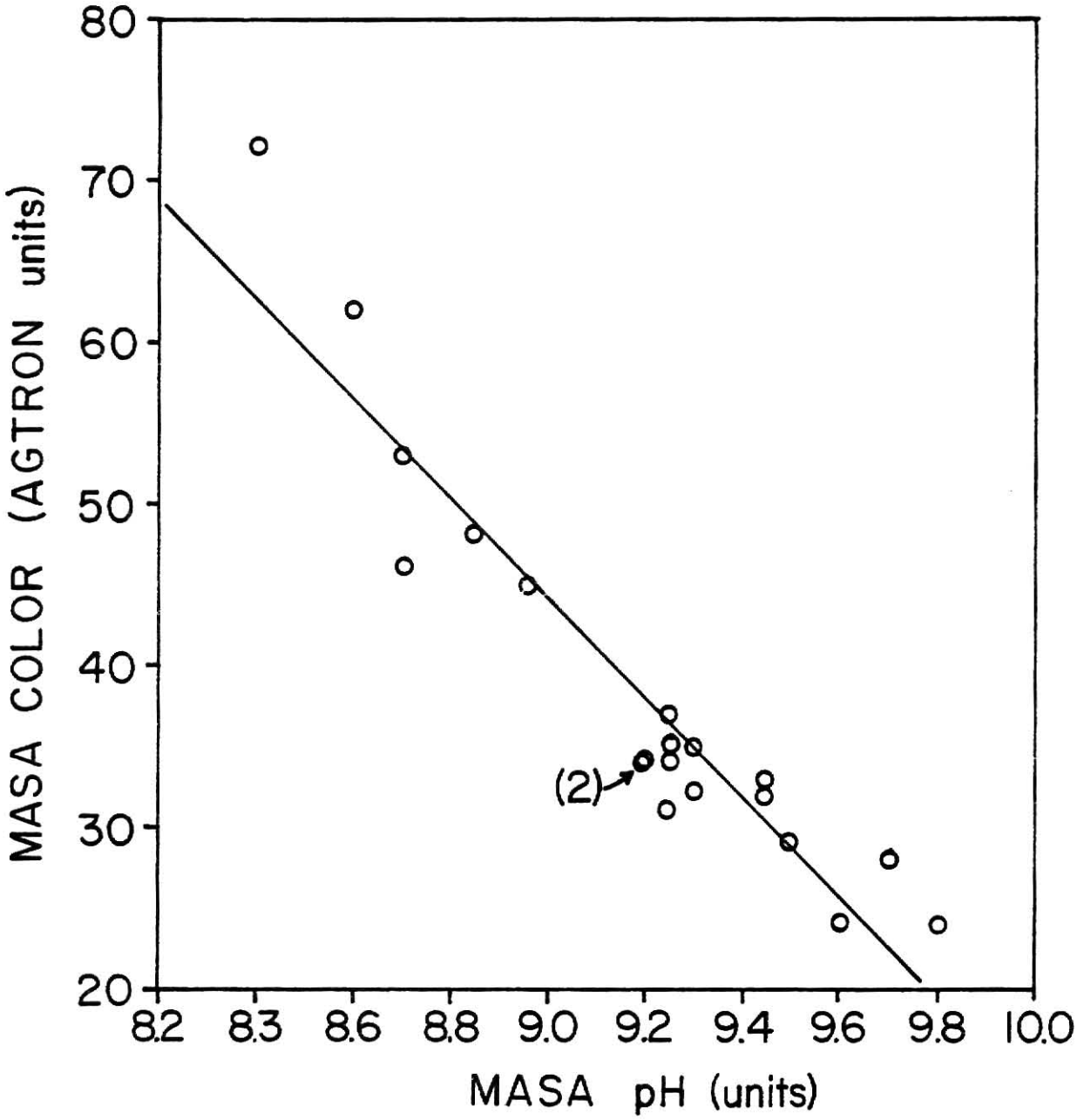

80
70
60
50
40
30
20
MASA COLOR (AGTRON units)
8.2
8.3
8.6
8.8
9.0
9.2
9.4
9.6
9.8
10.0
MASA pH (units)
(2)

Fig. 32 Contour plot of masa color (Agtron) versus peak temperature and hold time at 9 hr. steep time. Color code values are:

B = 25 (units)
C = 30
D = 35
E = 40
F = 45
G = 50
H = 55
J = 60
K = 65
L = 70
M = 75

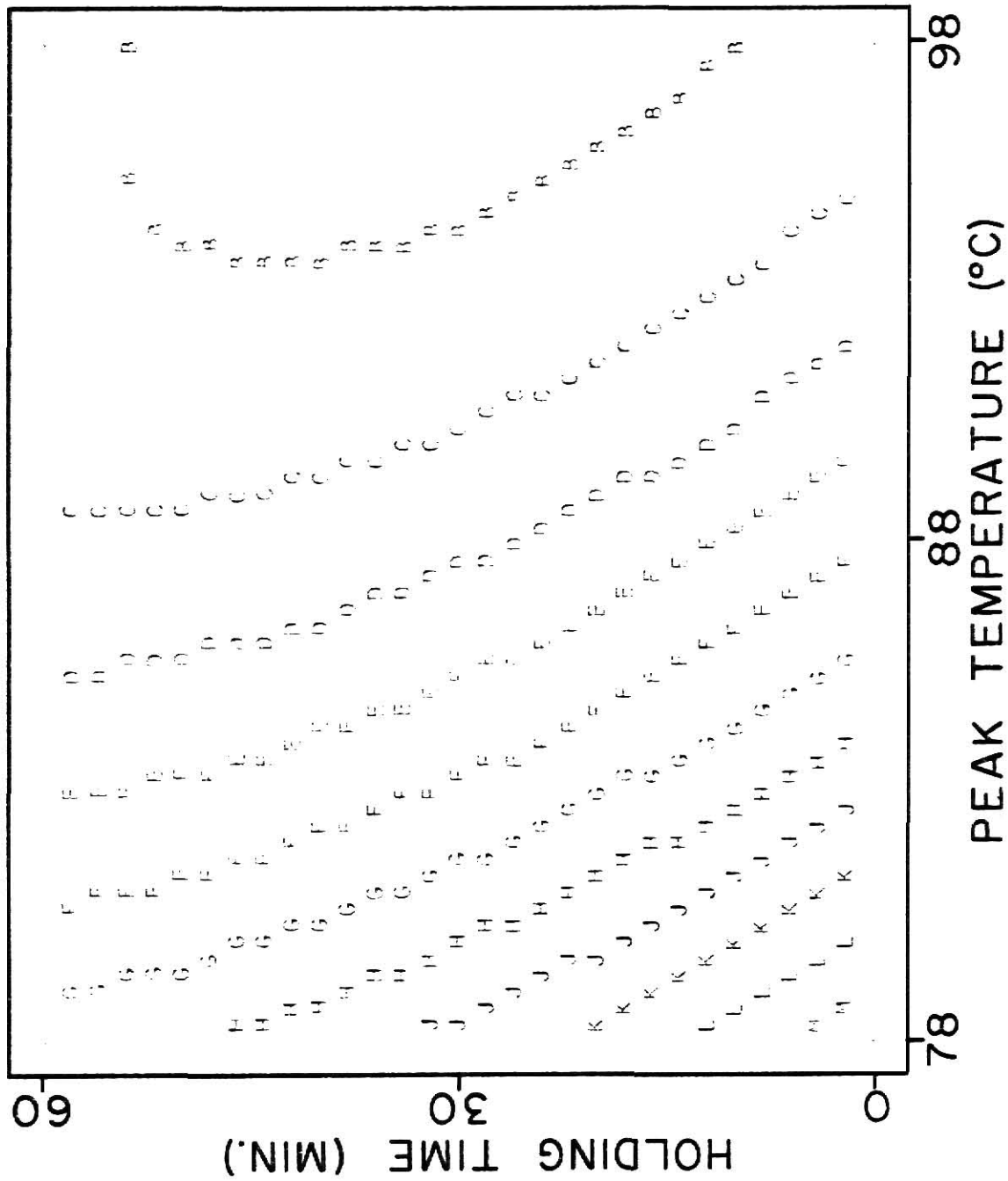

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 33 Contour plot of masa color (Agtron) versus peak temperature and steep time at 30 min. peak time. Color code values are:

B = 25 (units)
C = 30
D = 35
E = 40
F = 45
G = 50
H = 55
J = 60
K = 65
L = 70
M = 75

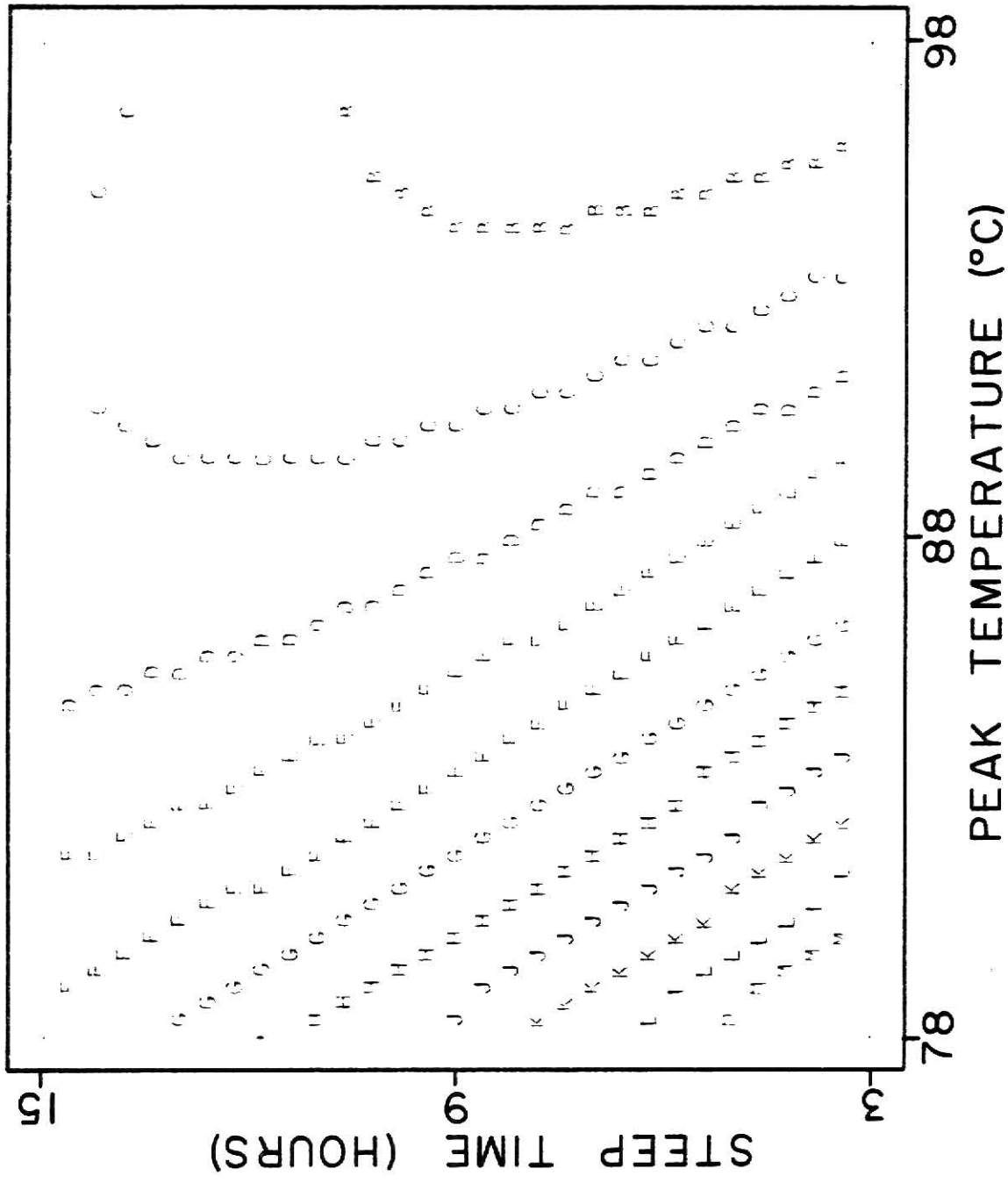

STEEP TIME (HOURS)
15
9
3
78
88
98
PEAK TEMPERATURE (°C)

Fig. 34 Contour plot of masa color (Agtron) versus peak temperature and hold time at 15 hr. steep time. Color code values are:

D = 35 (units)
E = 40
F = 45
G = 50
H = 55

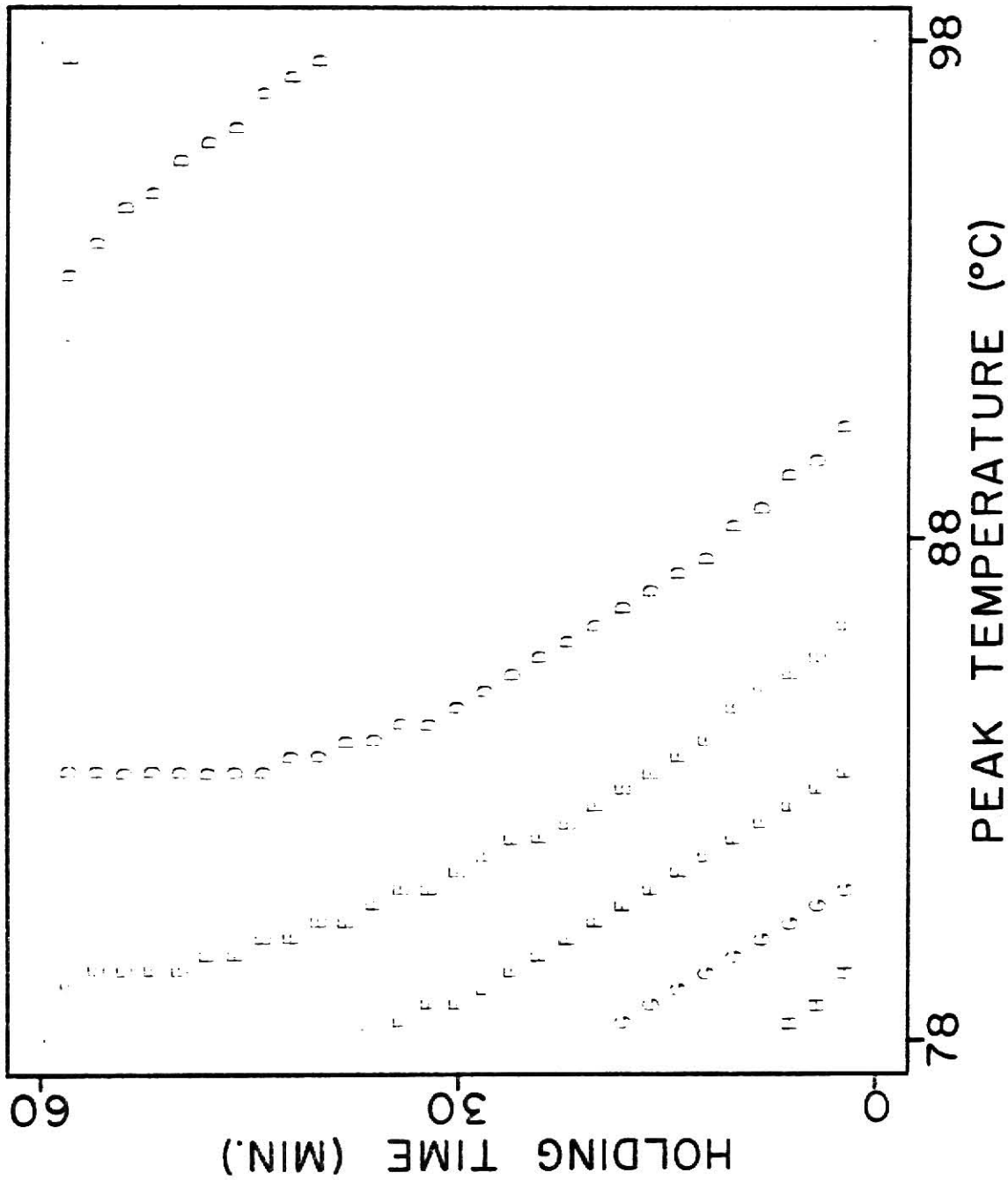

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 35 Contour plot of masa color (Agtron) versus peak temperature and hold time at 3 hr. steep time. Color code values are:

B = 25 (units)
C = 30
D = 35
E = 40
F = 45
G = 50
H = 55
J = 60
K = 65
L = 70
M = 75

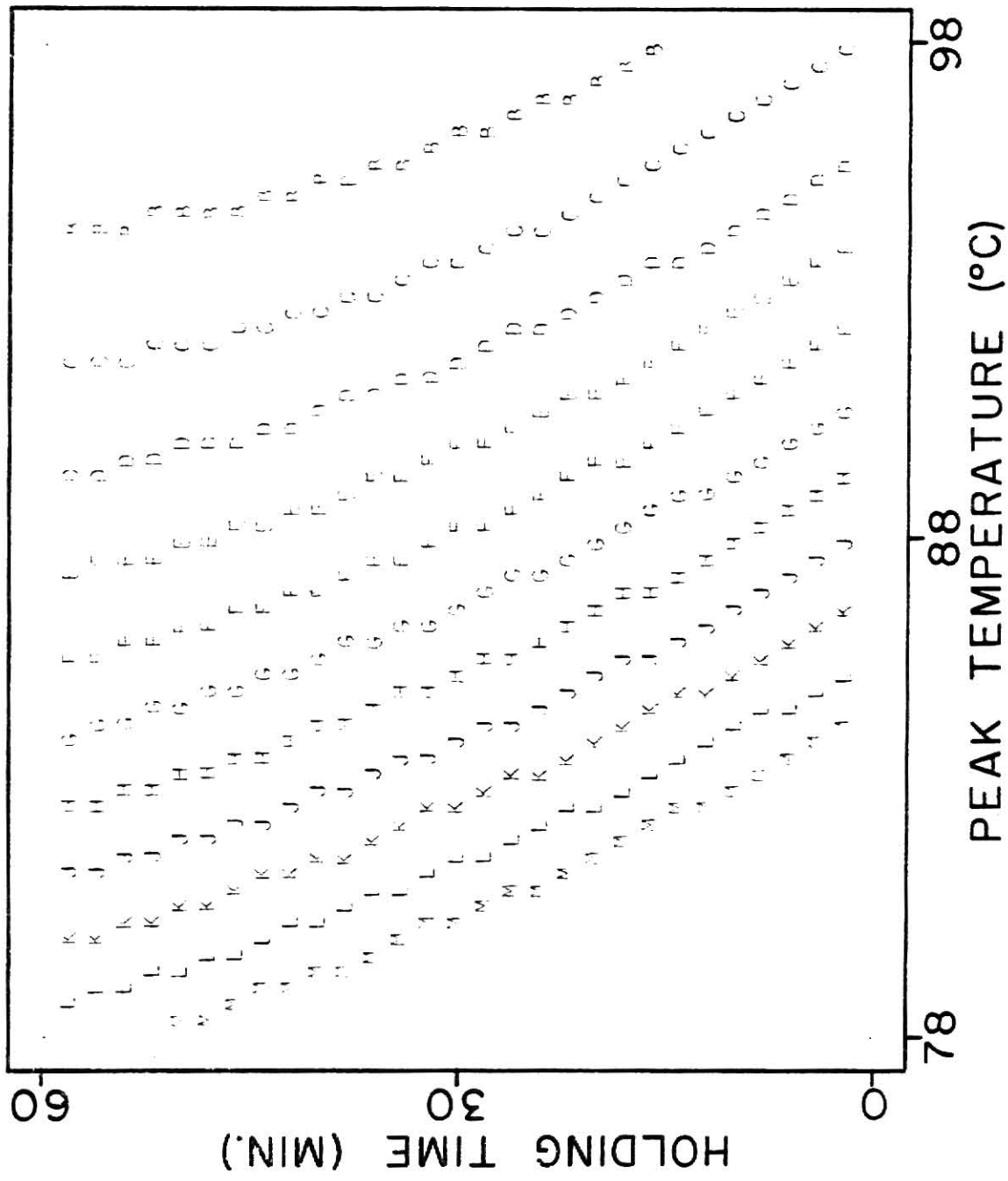

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 36 Contour plot of masa color (Agtron) versus peak temperature and steep time at 60 min. hold time. Color code values are:

B = 25 (units)
C = 30
D = 35
E = 40
F = 45
G = 50
H = 55
J = 60
K = 65
L = 70

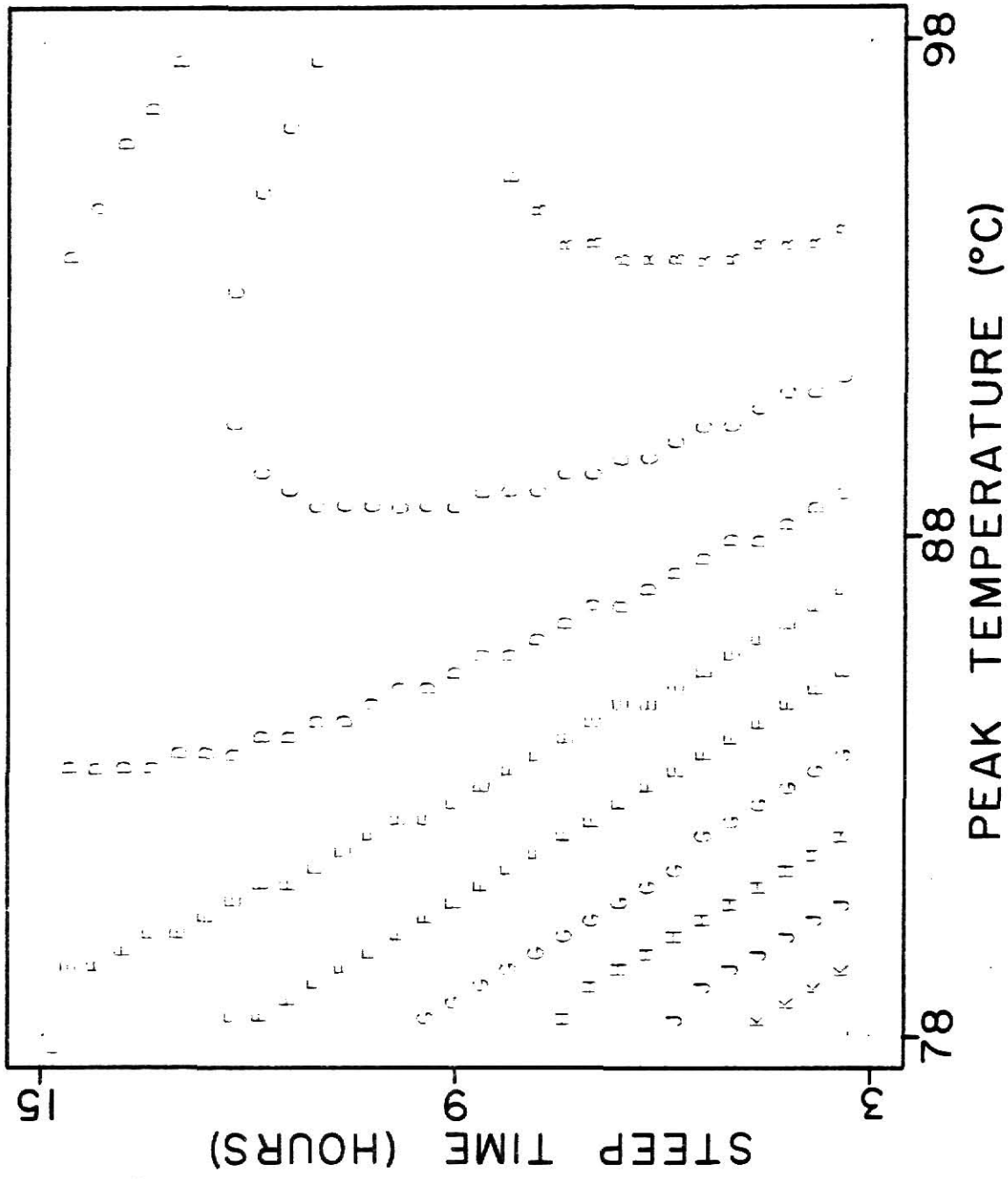
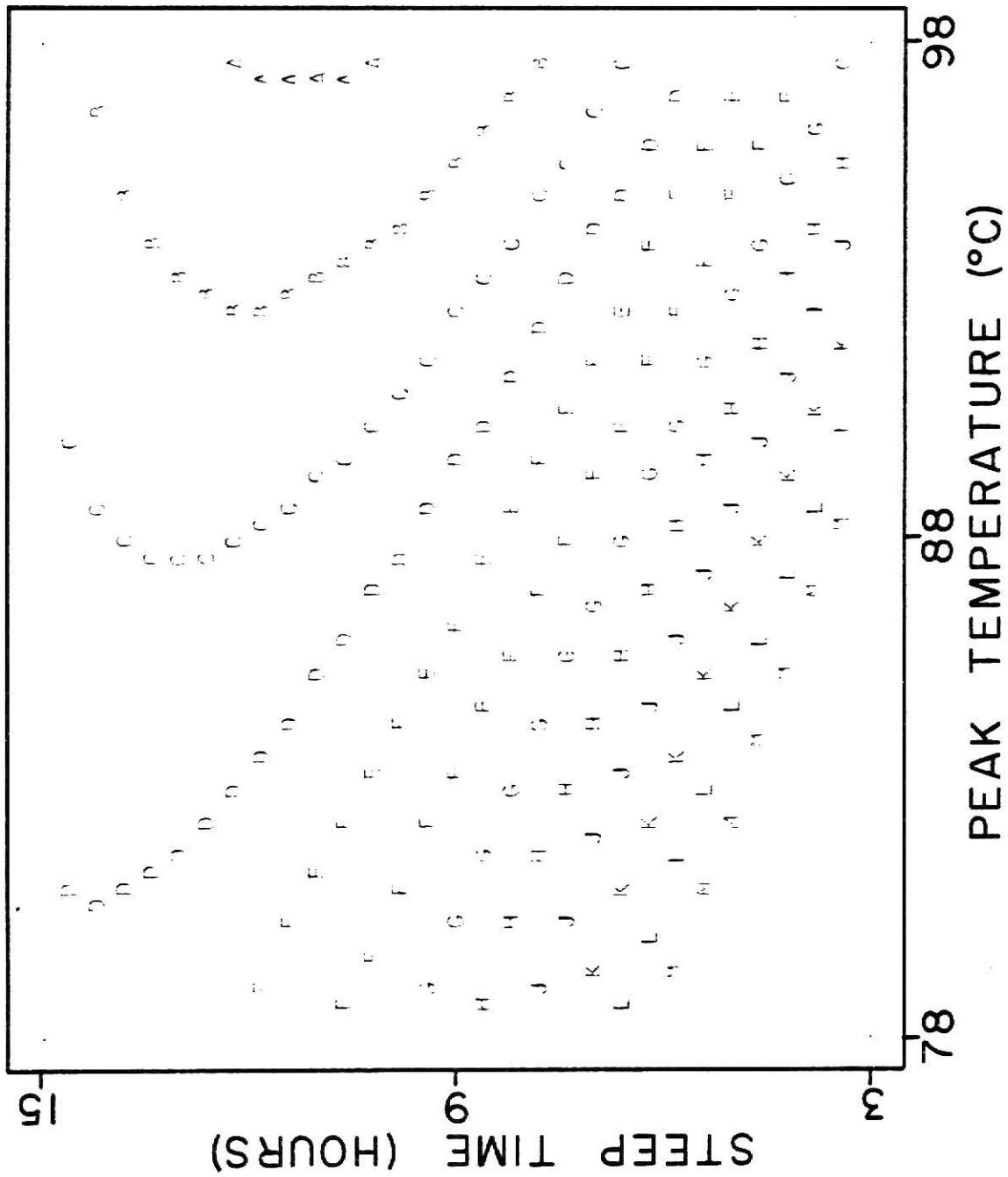

STEEP TIME (HOURS)
15
9
3
78
88
98
PEAK TEMPERATURE (°C)

Fig. 37 Masa particle size (overs of 417 micron mesh) versus peak temperature and steep time at 0 min. hold time. Particle size code values are:

A = 6(%)
B = 8
C = 10
D = 12
E = 14
F = 16
G = 18
H = 20
J = 22
K = 24
L = 26
M = 28


STEEP TIME (HOURS)
3
9
15
78
88
98
PEAK TEMPERATURE (°C)

(Figure 38). The increase in particle size at increased holding times might be explained through increased hydration and swelling of the endosperm particles, which could results in increased particle size. Overs of the 100 micron screen followed a pattern very similar to that for overs of the 400 micron screen and will not be discussed.

Amylograph Parameters. Changes in endosperm (starch) characteristics are often evaluated by amylograph testing. The amylograph was used to test masa samples to see if changes in the cooking parameters effected changes in any amylograph parameters, and if so to see if they could indicate improved quality in the final tortilla. Four different amylograph parameters were evaluated to determine which parameter(s), if any, resulted in better accuracy (in this case, R^2 values). Arrival time possessed the lowest determination coefficient (0.83) with the remaining three being close to 0.96. The steep time versus arrival time correlation was 0.28, with the other three correlations being very low (-0.02 to -0.13). Values of amylograph peak and the slope index appear to be the most reliable indexes. The curve index was calculated from these two values, but does not result in an improved R^2 value and is not discussed.

Amylograph Arrival Time. Arrival time shows a fairly linear dependence upon temperature and holding time at 9 hours steep time (Figure 39). As steep time increases to 15 hours, holding time appears to be a more important factor than temperature, especially at temperatures below 88°C (Figure 40). At 30 minutes holding time, steep time appears to have very small effect on arrival time except at low peak temperatures (below 85°C) (Figure 41).

Amylograph Peak. Peak temperature is most highly correlated with the peak value ($r = -0.87$), with hold time being less important ($r = -0.40$). At 3 hours steep time (Figure 42), variations in hold time have little effect

Fig. 38 Contour plot of masa particle size (overs of 417 micron mesh) versus peak temperature and steep time at 60 min. hold time. Particle size code values are:

B = 8(%)
C = 10
D = 12
E = 14
F = 16
G = 18
H = 20
J = 22
K = 24

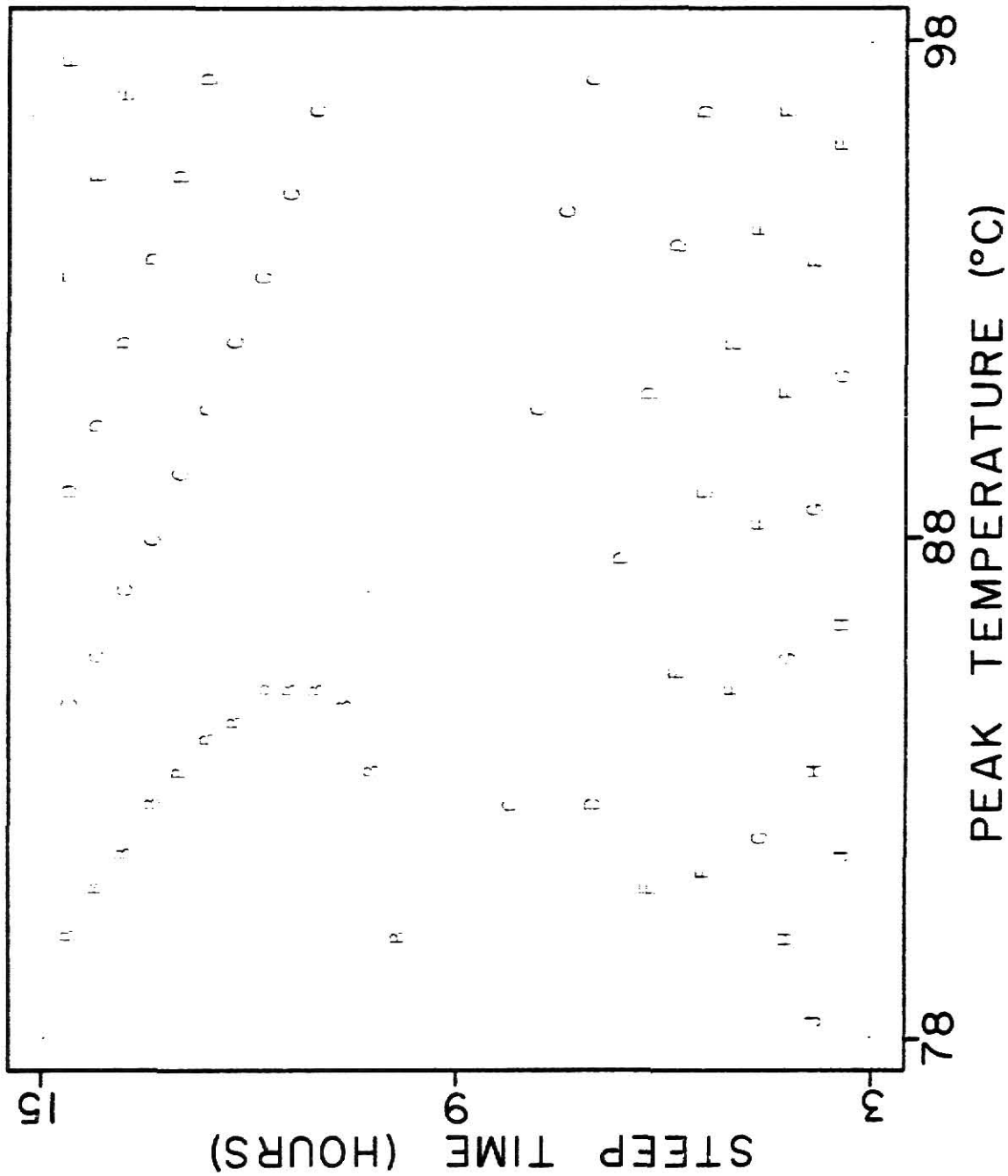

STEEP TIME (HOURS)
3
9
15
PEAK TEMPERATURE (°C)
78
88
98

Fig. 39 Contour plot of amylograph arrival time (at 100 BU line) versus peak temperature and hold time at 9 hr. steep time. Arrival time code values are:

D = 7.5 (min.)
E = 8.0
F = 8.5
G = 9.0
H = 9.5
J = 10.0
K = 10.5
L = 11.0

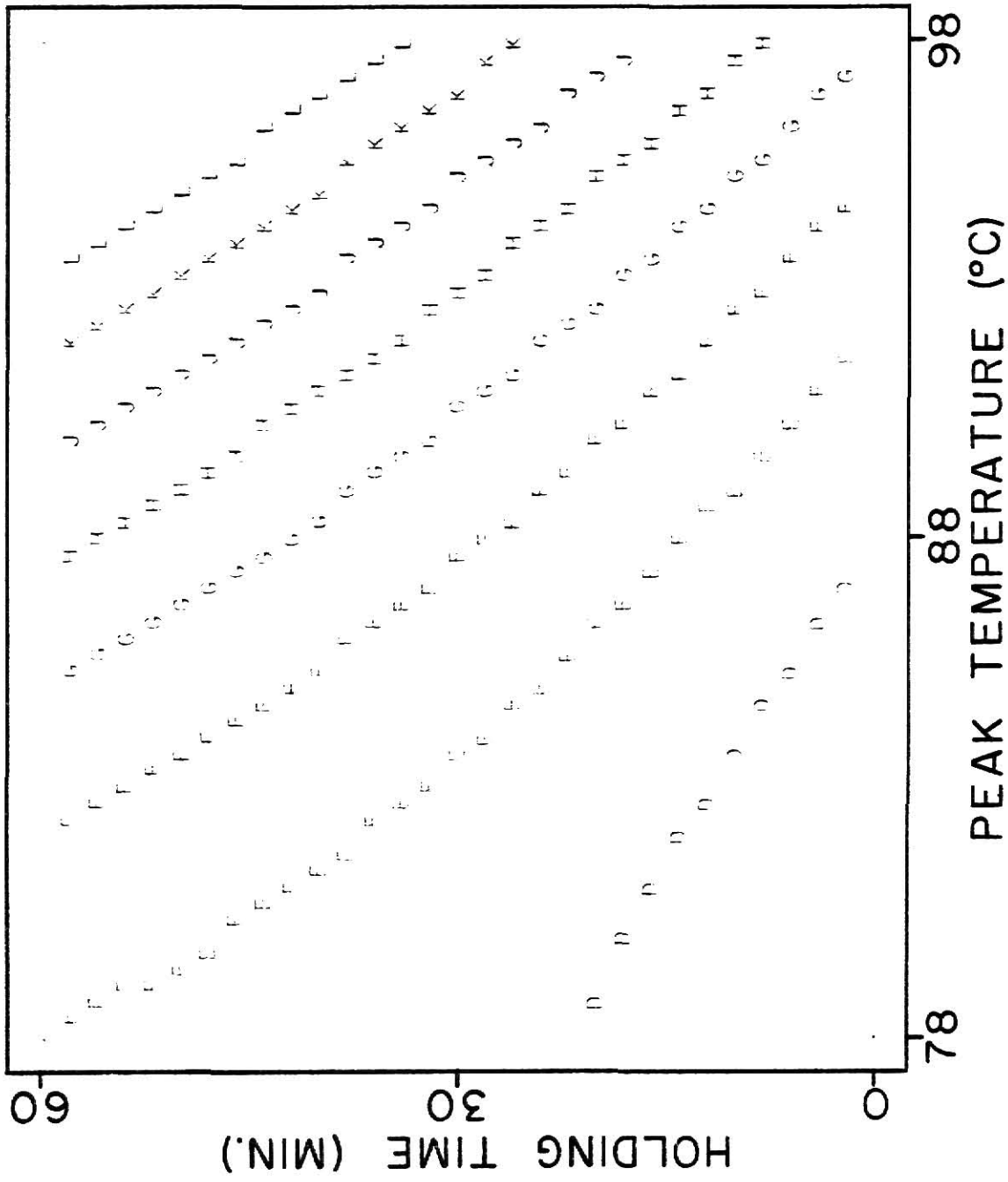

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 40 Contour plot of amylograph arrival time (at 100 BU line) versus peak temperature and hold time at 15 hr. steep time. Arrival time code values are:

D = 7.5 (min.)
E = 8.0
F = 8.5
G = 9.0
H = 9.5
J = 10.0
K = 10.5
L = 11.0

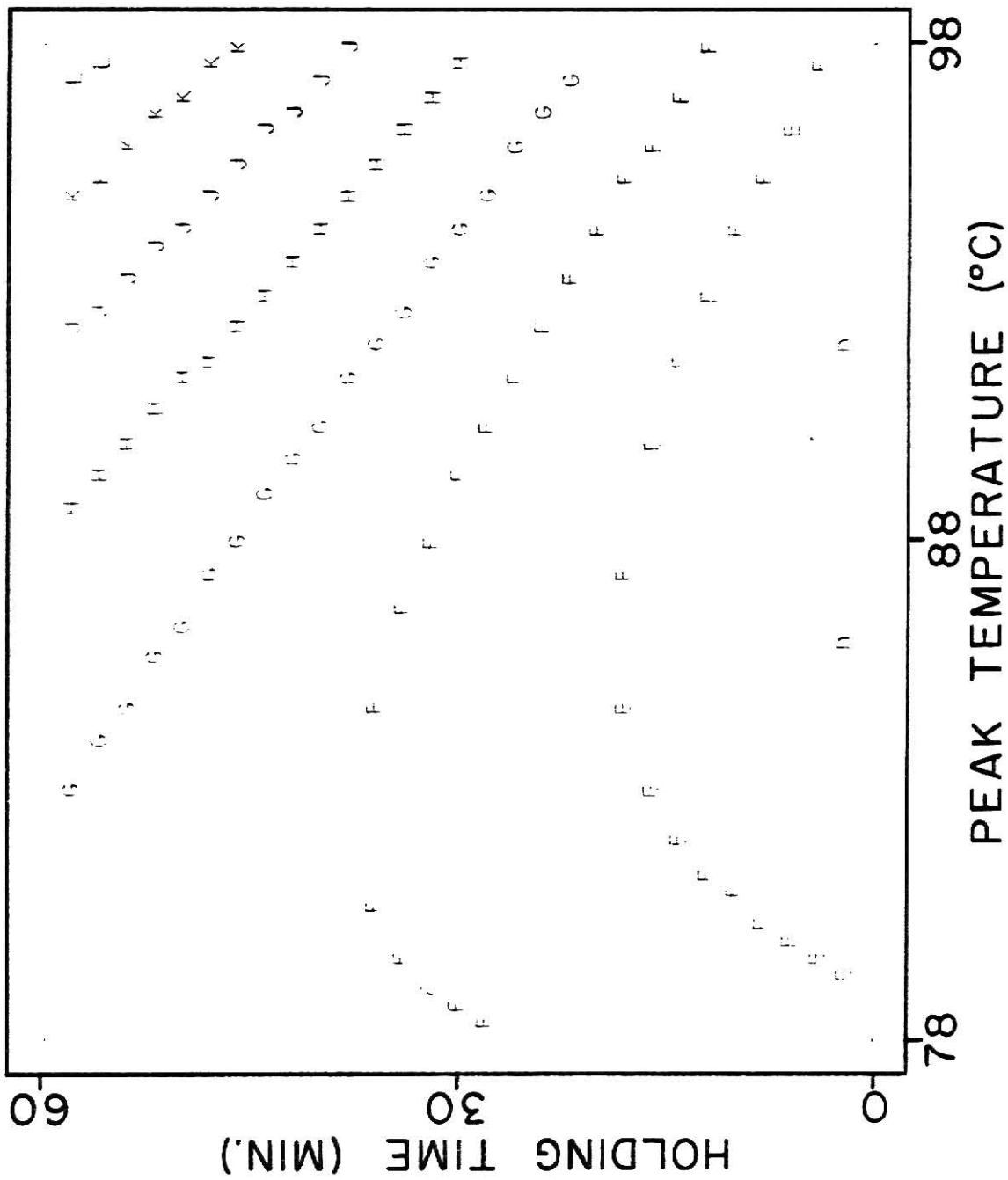

HOLDING TIME (MIN.)
60
30
0
78
88
98
PEAK TEMPERATURE (°C)

Fig. 41 Contour plot of amylograph arrival time (at 100 BU line) versus peak temperature and steep time at 30 min. hold time. Arrival time code values are:

A = 6.0 (min.)
B = 6.5
C = 7.0
D = 7.5
E = 8.0
F = 8.5
G = 9.0
H = 9.5
J = 10.0
K = 10.5

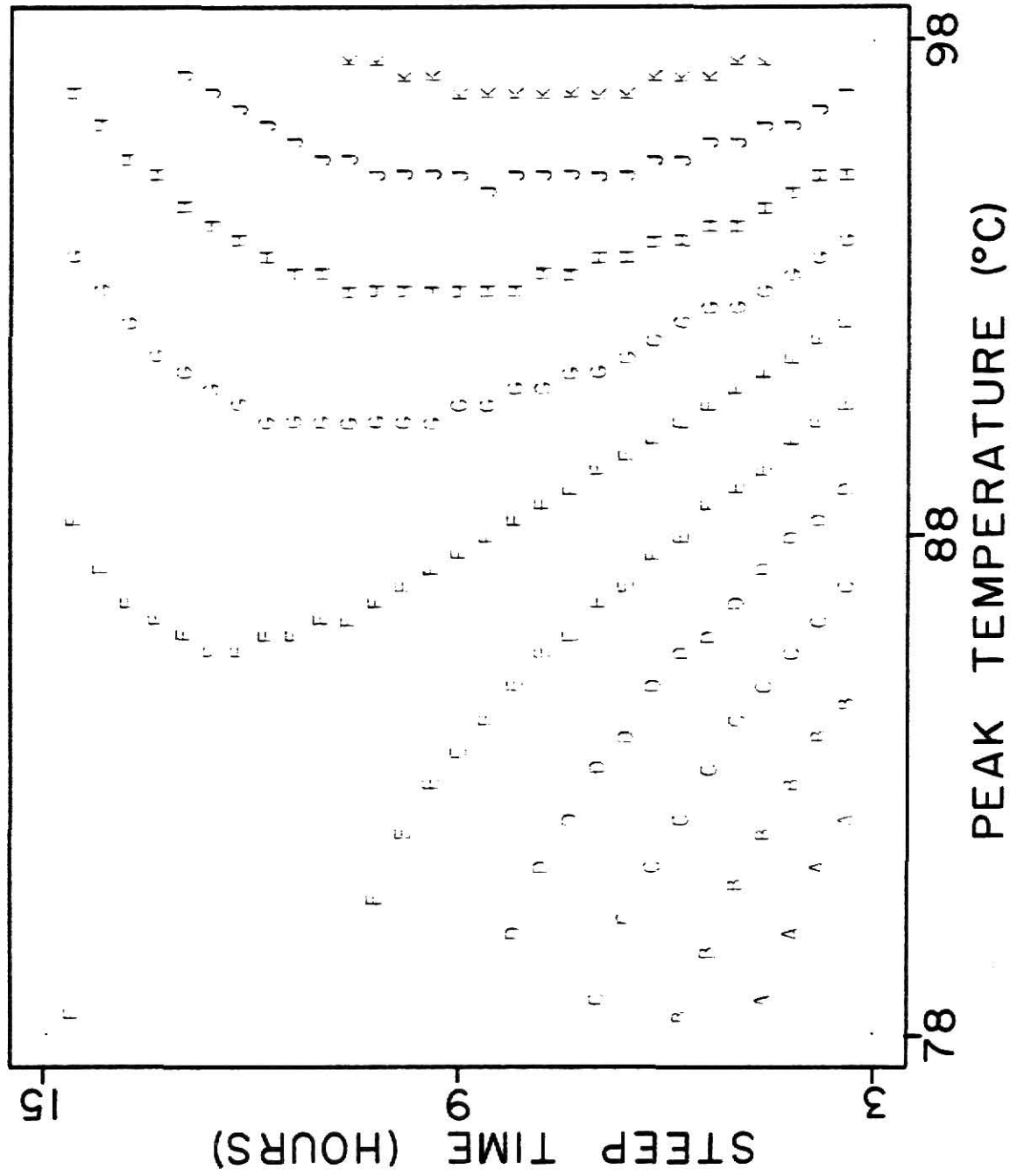
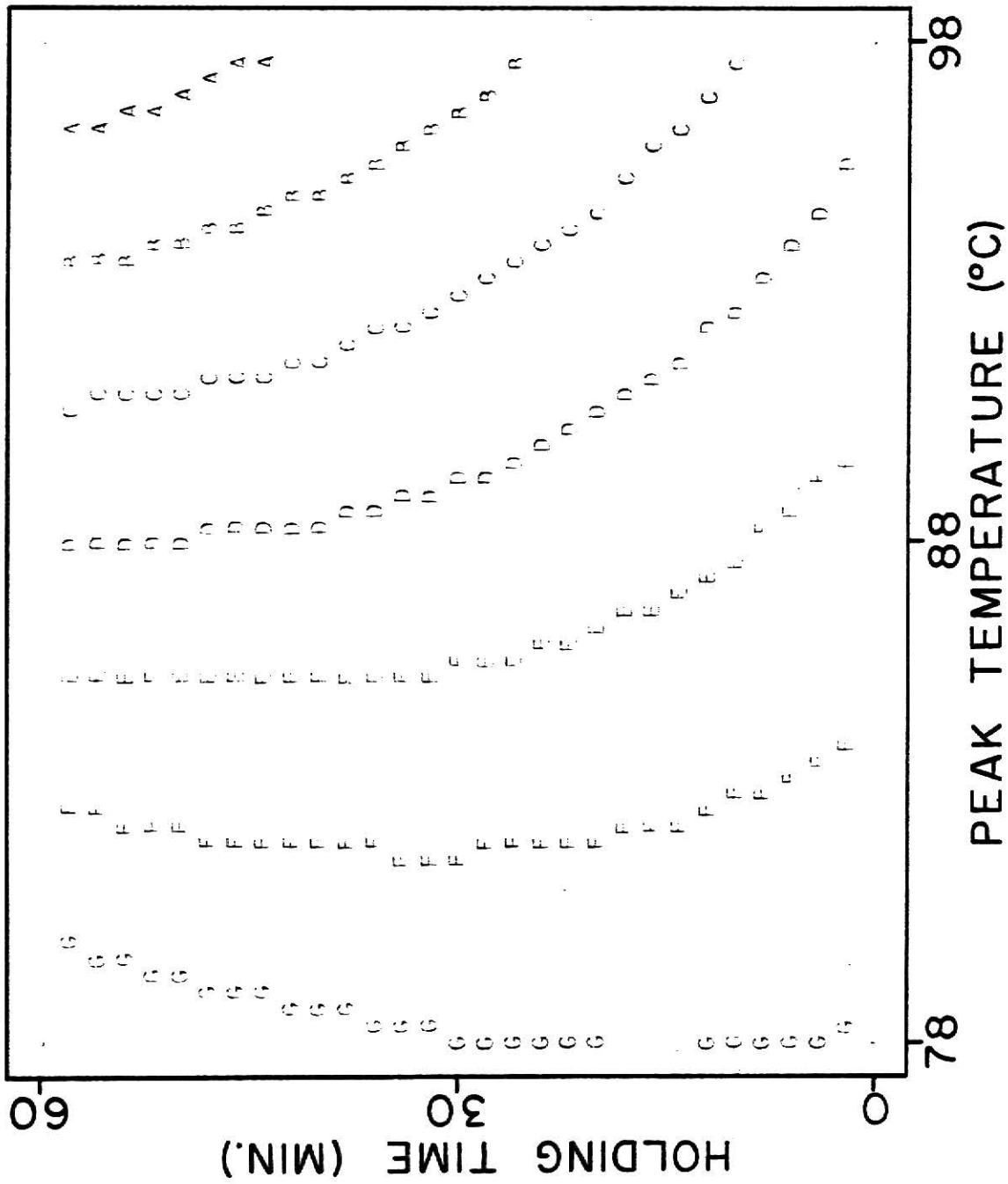

STEEP TIME (HOURS)
3
9
15
78
88
98
PEAK TEMPERATURE (°C)

Fig. 42 Contour plot of amylograph peak (at 18 min.) versus peak temperature and hold time at 3 hr. steep time. Peak code values are:

A = 250 (Brabender Units)
B = 350
C = 450
D = 550
E = 650
F = 750
G = 850


HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

on peak values at temperatures below 85°C. However at 15 hours steep time (Figure 43), holding times exhibit a larger effect on the peak values. Figure 44, a plot of amylograph peak versus peak temperature and steep time at a constant hold time of 30 minutes, visually exhibits the lack of correlation between steep time and amylograph peak, and the dependence of the amylograph peak upon the temperature used.

Amylograph Slope Index. In reference to the amylograph curves, the greater the slope index (i.e., the faster the increase), the higher was the resultant amylograph peak. Conversely, the lower the slope index, the lower the peak value. This is apparent when a slope index plot (Figure 45, slope index versus peak temperature and holding time at 3 hours steep time) is compared to any amylograph peak plot (Figure 42). Figure 46 shows the plot at 15 hours steep time for slope index, and can be compared to Figure 43 for amylograph peak. The relative importances of peak temperature, holding time, and steep time to slope index is very similar to that for the amylograph peak. It appears that either amylograph peak or slope index can successfully be utilized as an indicator of starch modification in the masa.

Tortilla Moisture. Table 2 shows that the determination coefficient is low ($R^2 = 0.85$). Temperature is most important with peak time next. Figure 47 shows the effect of temperature and hold time on moisture at 9 hours of steep time. When compared to masa moisture content (Figure 21) it is observable that masa moisture content is approximately 15 - 20% higher than in the tortilla. Figure 48 is a plot of masa versus tortilla moisture content. The correlation coefficient of the two data sets was $r = 0.88$. Figure 49 shows that changes in steep time have little effect on tortilla moisture content above 9 hours of steep time.

Tortilla Weight. Weight is most highly correlated ($r = -0.71$) with peak temperature, with holding time and steep time about equivalent (Table 2).

Fig. 43 Contour plot of amylograph peak (at 18 min.) versus peak temperature and hold time at 15 hr. steep time. Peak code values are:

A = 250 (Brabender Units)
B = 350
C = 450
D = 550
E = 650
F = 750
G = 850

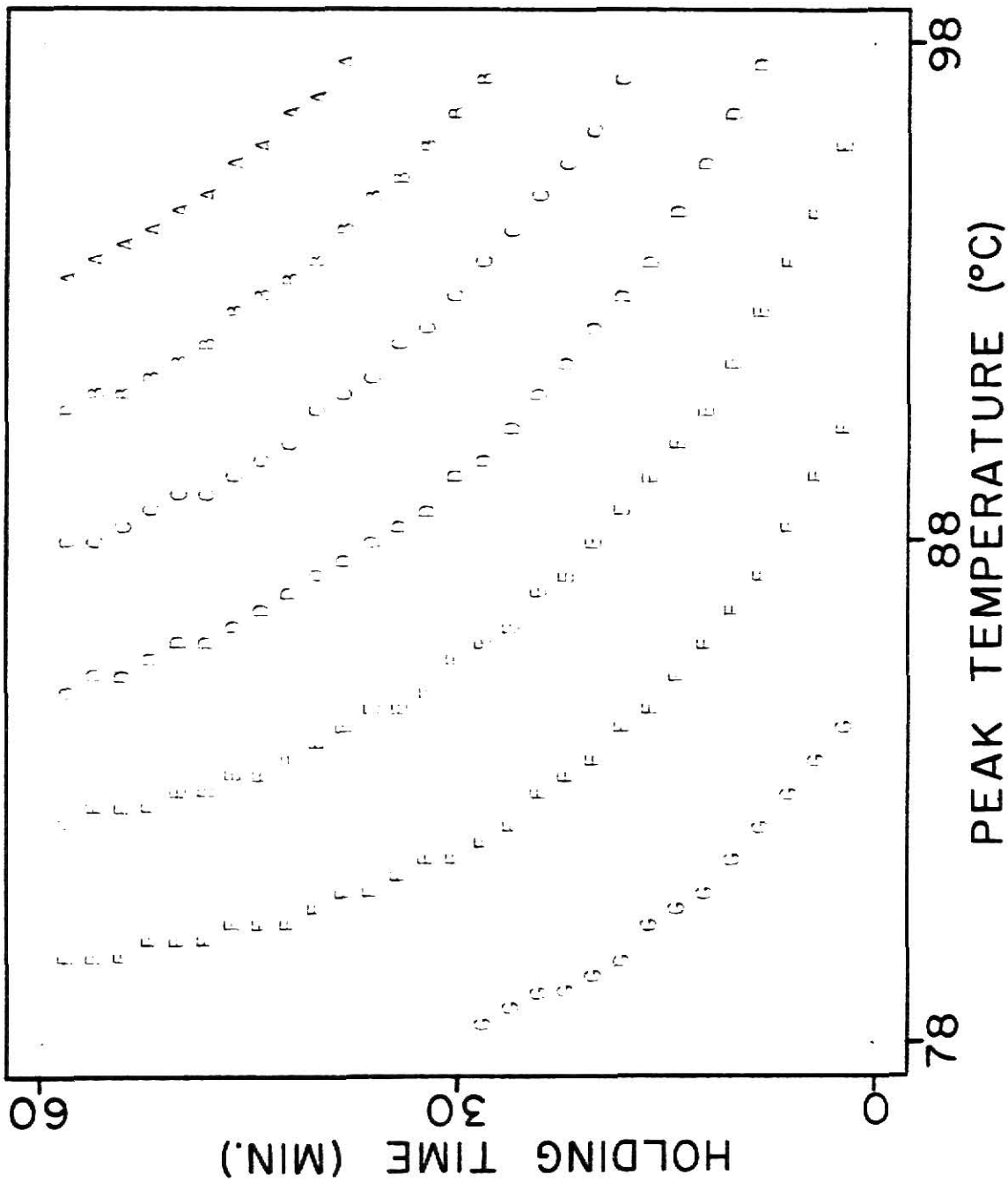

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 44 Contour plot of amylograph peak (at 18 min.) versus peak temperature and steep time at 30 min. hold time. Peak code values are:

B = 350 (Brabender Units)
C = 450
D = 550
E = 650
F = 750
G = 850

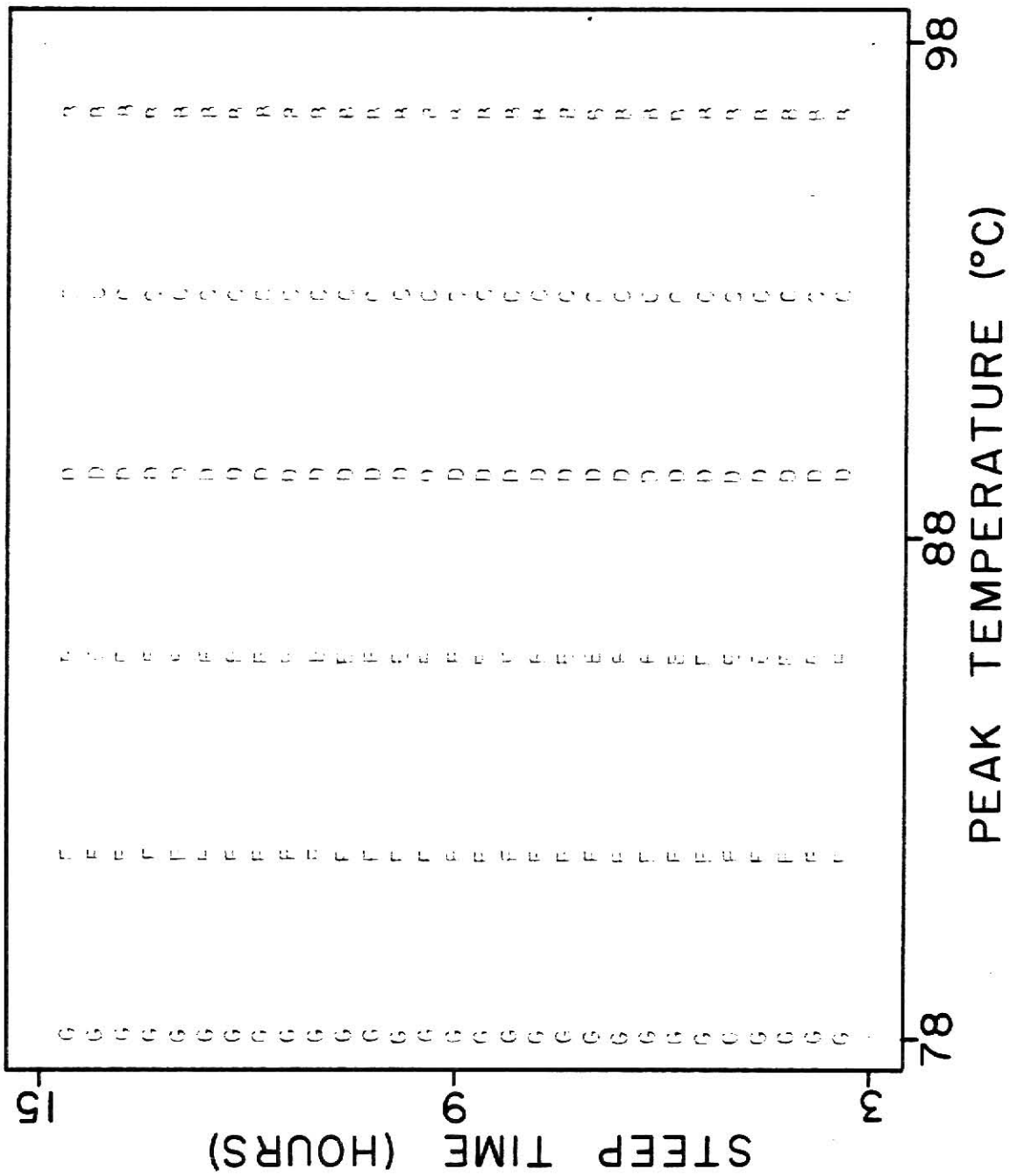

PEAK TEMPERATURE (°C)
98
88
78
STEEP TIME (HOURS)
3
9
15

Fig. 45 Contour plot of amylograph slope index versus temperature and hold time at 3 hr. steep time. Slope index code values are:

A = 0.0 (units)
B = 0.1
C = 0.2
D = 0.3
E = 0.4
F = 0.5
G = 0.6
H = 0.7
J = 0.8
K = 0.9
L = 1.0

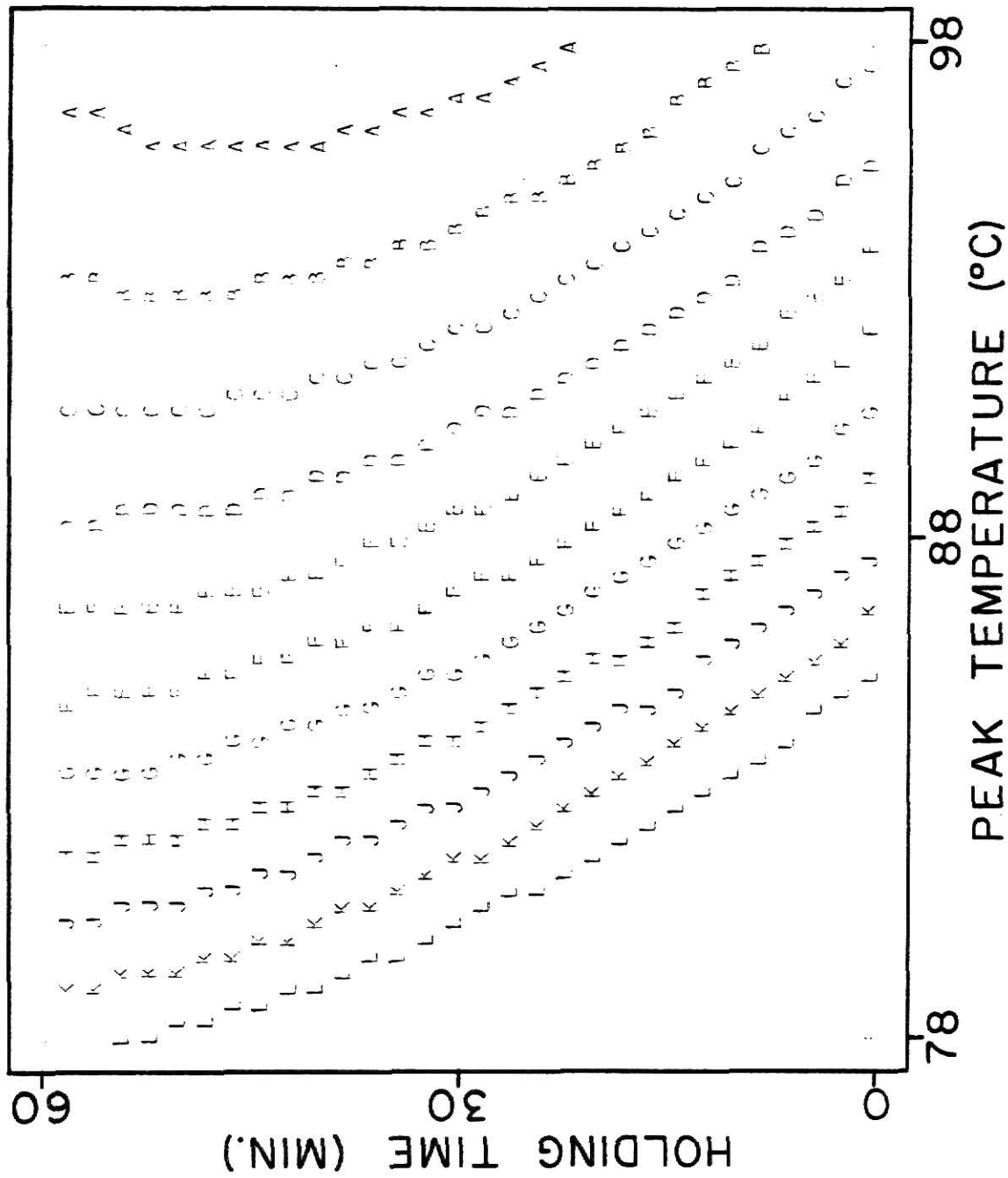

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 46 Contour plot of amylograph slope index versus temperature and hold time at 15 hr. steep time. Slope index code values are:

C = 0.2 (units)
D = 0.3
E = 0.4
F = 0.5
G = 0.6
H = 0.7
J = 0.8
K = 0.9
L = 1.0

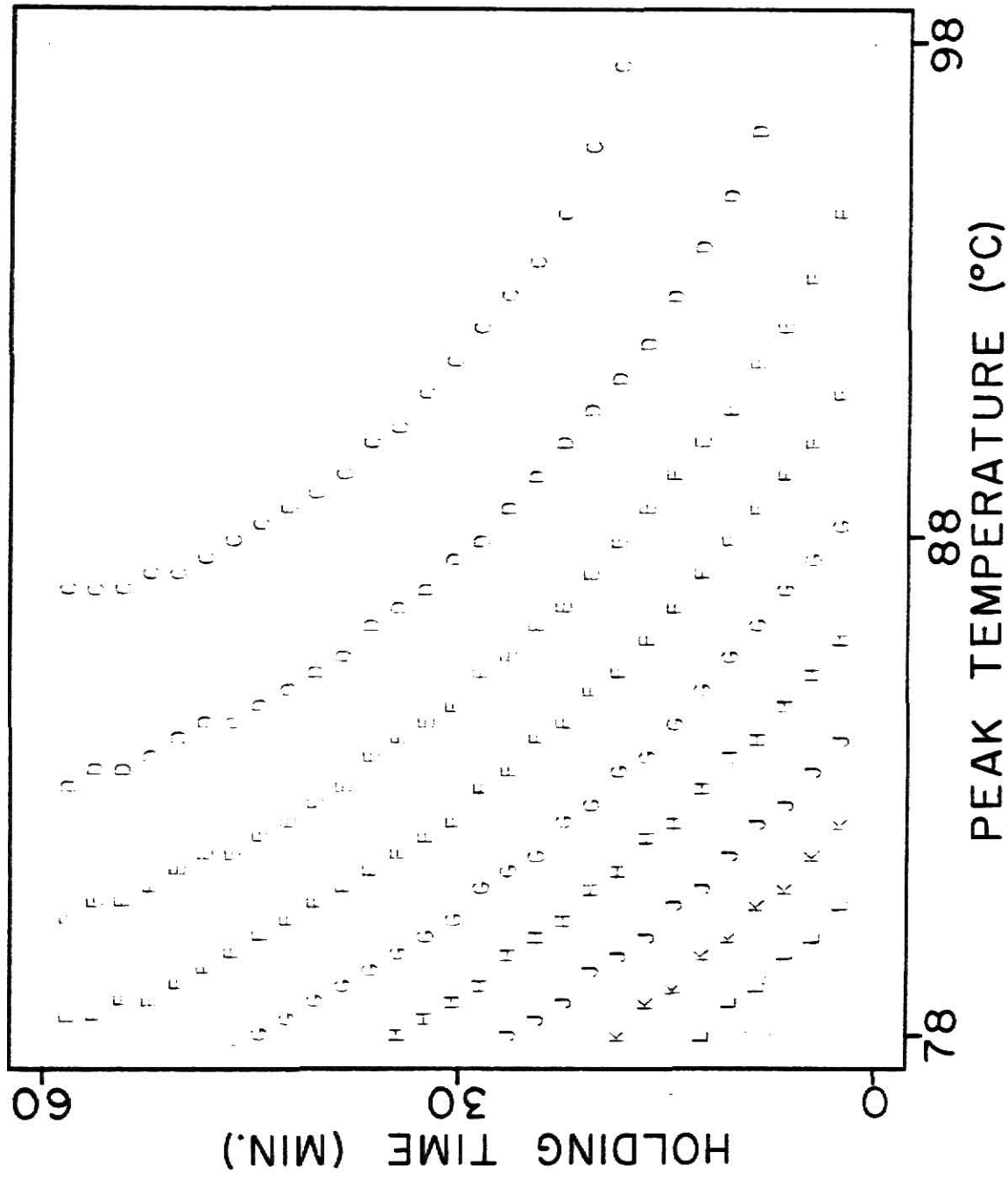

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 47 Tortilla moisture content versus temperature and hold time at 9 hr. steep time. Moisture content code values are:

D = 33 (%)
E = 34
F = 35
G = 36
H = 37
J = 38
K = 39
L = 40
M = 41
N = 42

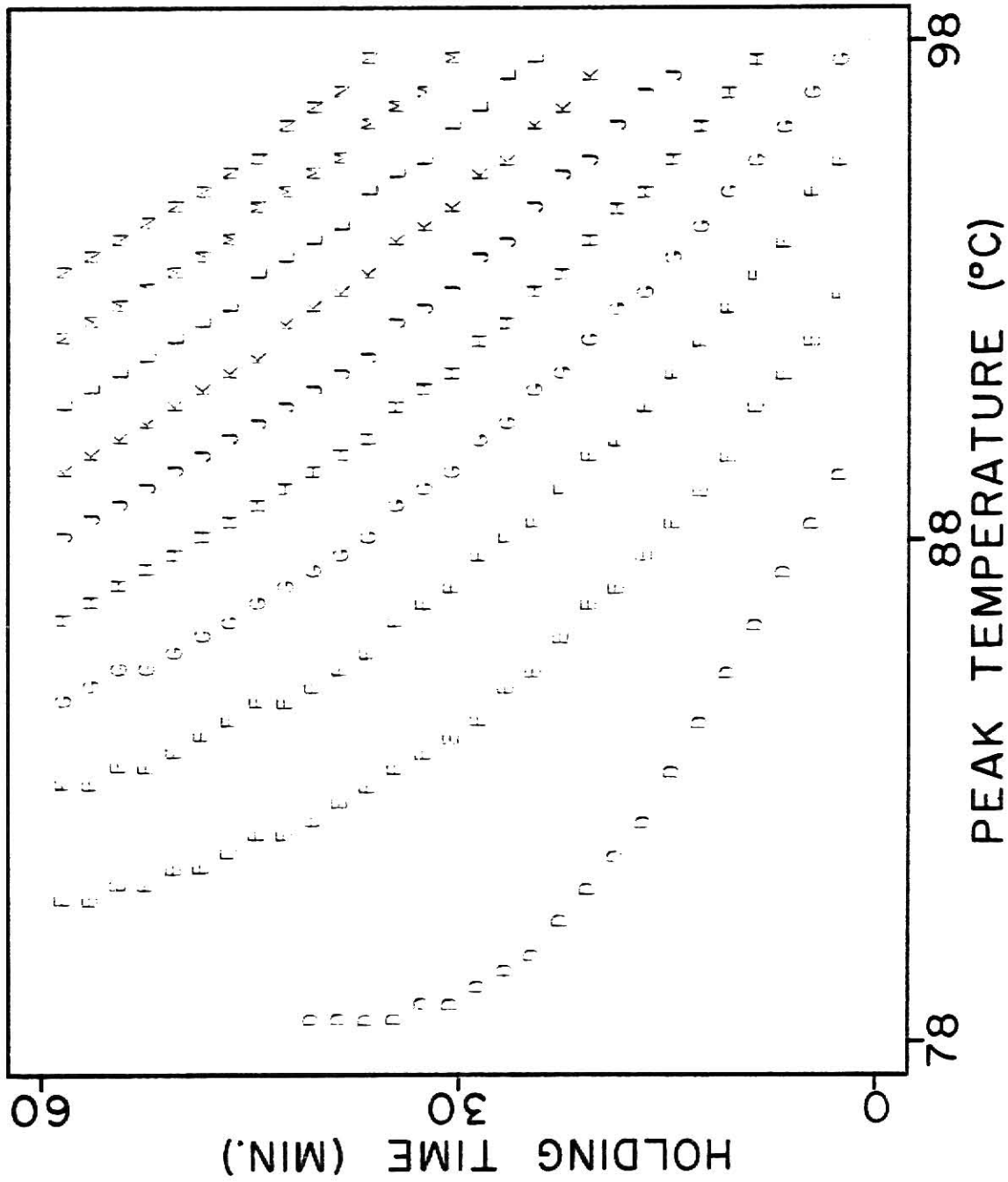

HOLDING TIME (MIN.)
60
30
0
78
88
98
PEAK TEMPERATURE (°C)

Fig. 48 Masa moisture content versus tortilla moisture content.

$Y = 1.28X - 33.5$
$r = 0.88$

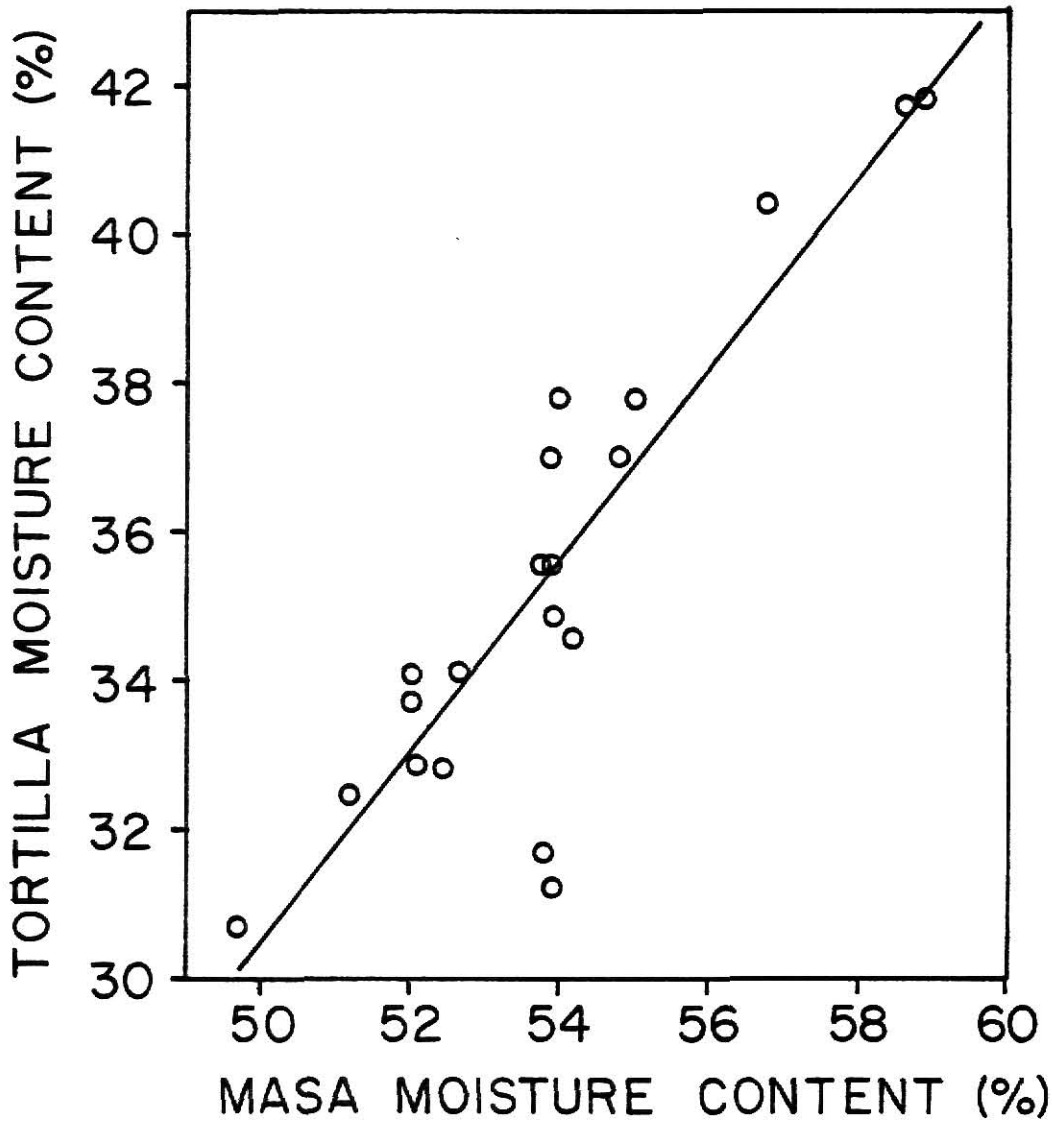
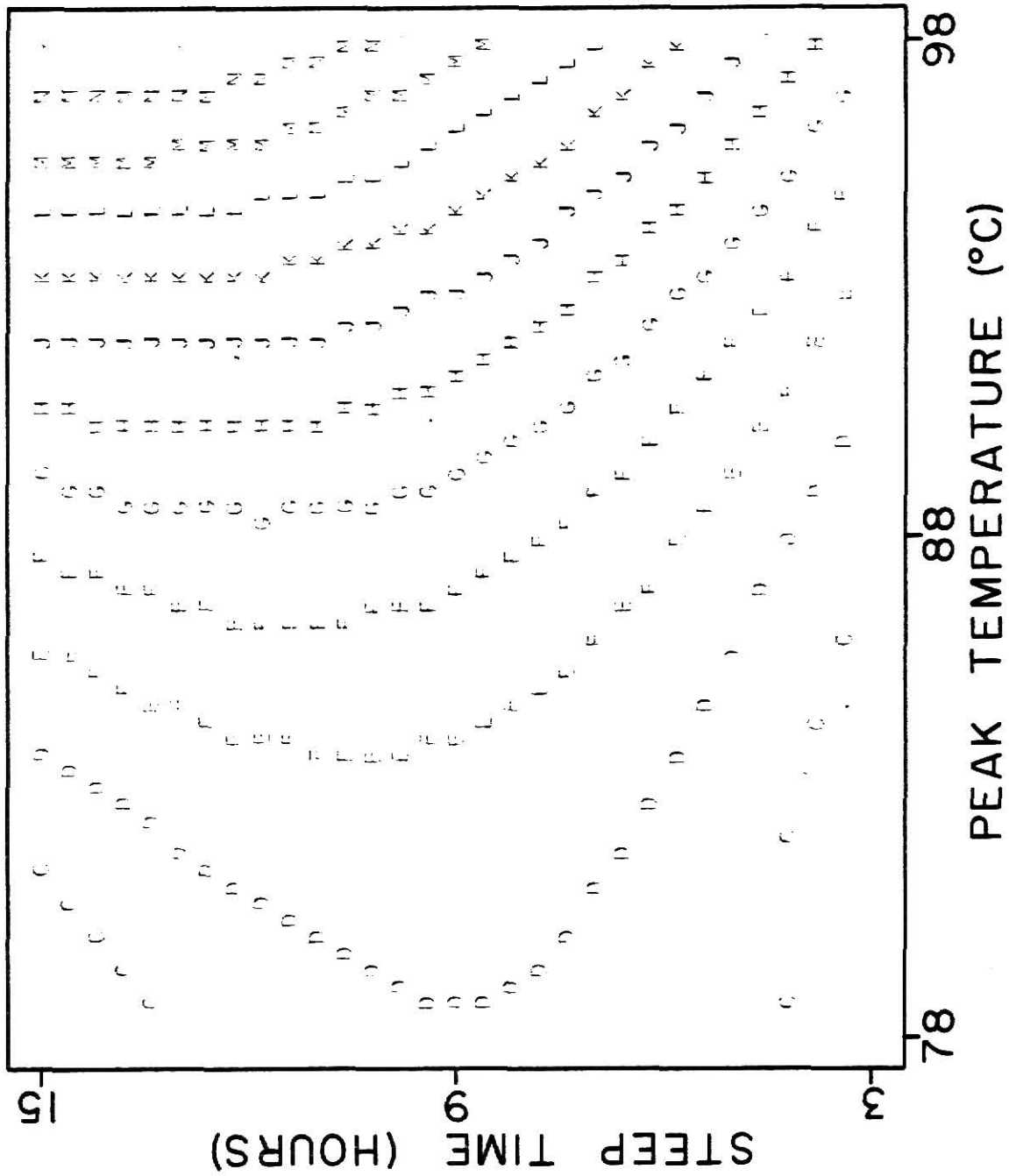

TORTILLA MOISTURE CONTENT (%)
42
40
38
36
34
32
30
50
52
54
56
58
60
MASA MOISTURE CONTENT (%)

Fig. 49 Contour plot of tortilla moisture content versus temperature and steep time at 30 min. hold time. Moisture content code values are:

C = 32 (%)
D = 33
E = 34
F = 35
G = 36
H = 37
J = 38
K = 39
L = 40
M = 41
N = 42


STEEP TIME (HOURS)
3
9
15
78
88
98
PEAK TEMPERATURE (°C)

Tortilla weight decreased as all three variables increased. As steep time increases from 3 hours (Figure 50) to 15 hours (Figure 51), the importance of hold time as an influence on tortilla weight continually decreases. A similar situation occurs in varying holding time from 0 minutes (Figure 52) to 60 minutes (Figure 53). That is, as either peak time or steep time increases, temperature becomes a more dominant parameter in influencing tortilla weight.

To evaluate the effect of masa moisture content upon the tortilla weight, a plot is shown in Figure 54. The correlation was $r = -0.871$ indicating a high dependence of weight upon the moisture content of the masa.

Tortilla Axis Ratio. The axis ratio had a high determination coefficient ($R^2 = 0.95$) with peak temperature having a very high linear correlation ($r = 0.90$) (Table 2). Figure 55 demonstrates the increase in axis ratio with increasing temperature. The short tortilla axis remained close to 5.6 - 5.8 inches in diameter for all twenty tests. The axis ratio differences were caused mainly by variations in the long axis. A symmetrical, rounder, tortilla had a high axis ratio (such as 0.960); an oblong tortilla possessed a lower ratio (such as 0.920). The higher ratios (i.e., 0.960) were produced with masa that had been subjected to more sever cooking conditions in which, consequently the masa possessed a higher moisture content (Figure 21). A plot of masa moisture content versus tortilla axis ratio is given (Figure 56) to illustrate the importance of moisture as it affects tortilla axis ratio. Correlation of the two data sets was $r = 0.914$. Higher moisture masa spreads less longitudinally when sheeted, forming tortillas with higher axis ratios (i.e., more rounded tortillas). Figure 57 illustrates the effect of temperature and steep time at a hold time of 30 minutes.

Fig. 50 Tortilla weight versus temperature and hold time at 3 hr. steep time. Weight code values are:

B = 22.5 (g)
C = 23.0
D = 23.5
E = 24.0
F = 24.5
G = 25.0
H = 25.5

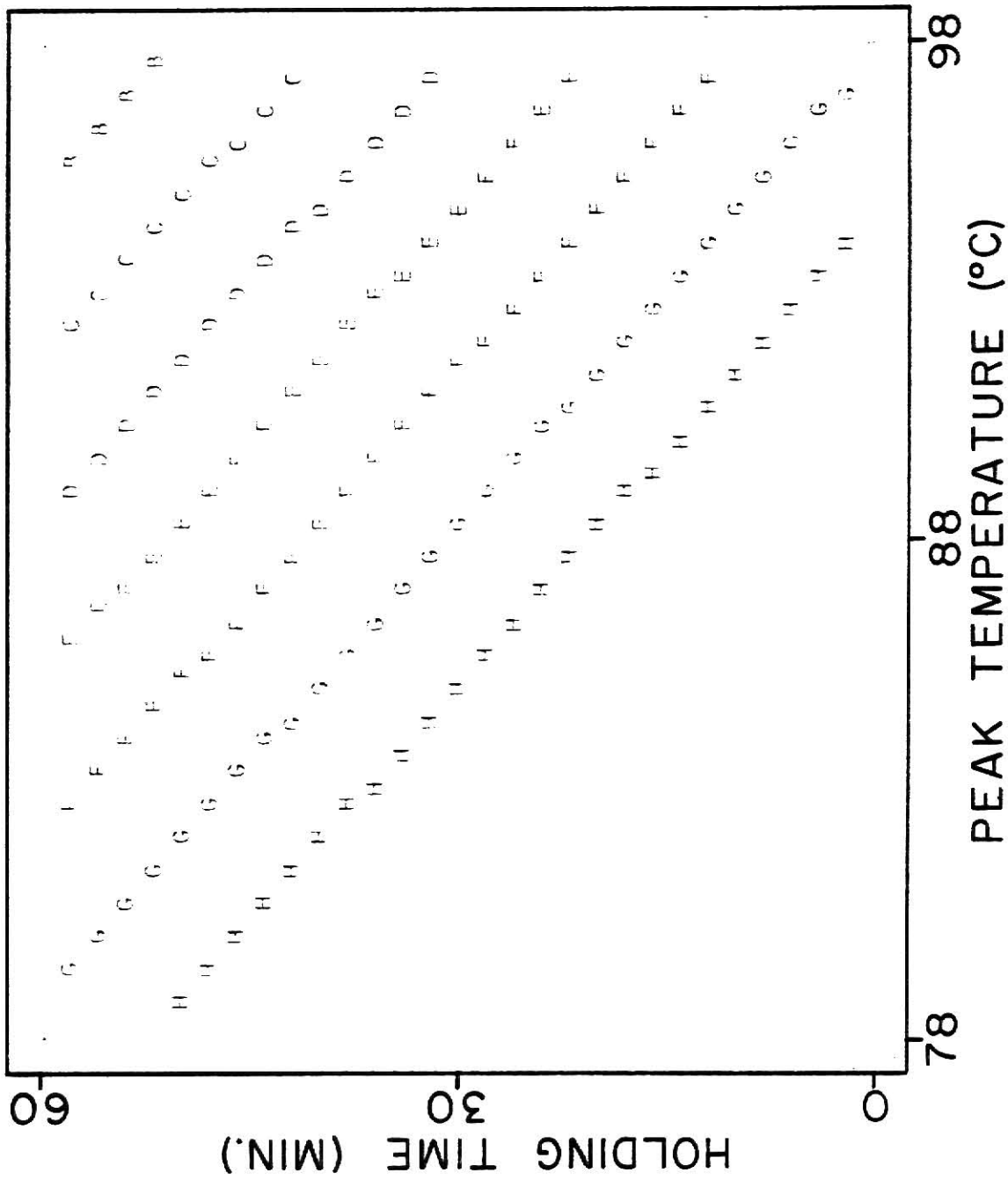

HOLDING TIME (MIN.)
60
30
0
78
88
98
PEAK TEMPERATURE (°C)

Fig. 51 Contour plot of tortilla weight versus temperature and hold time at 15 hr. steep time. Weight code values are:

A = 22.0 (g)
B = 22.5
C = 23.0
D = 23.5
E = 24.0
F = 24.5

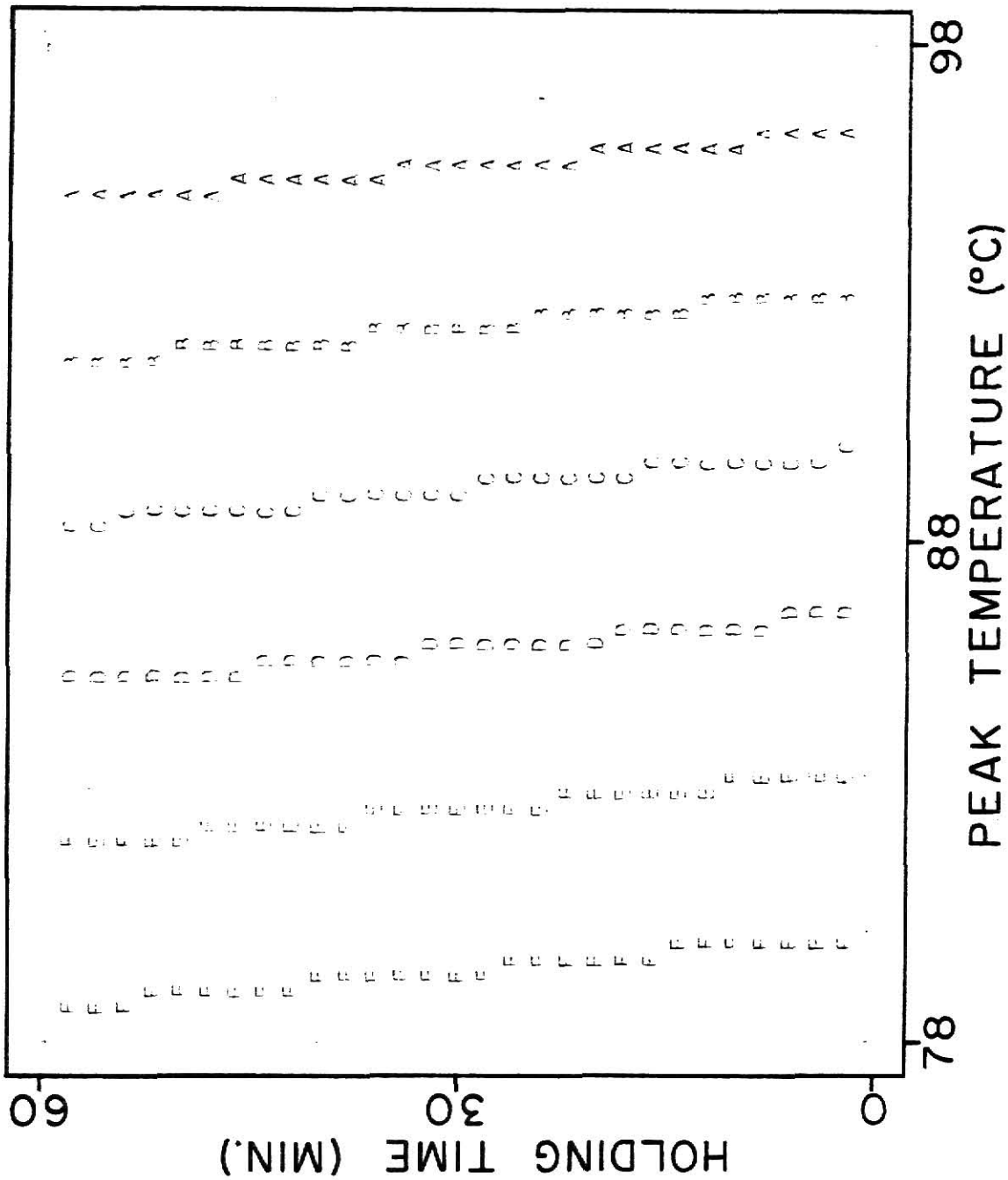

HOLDING TIME (MIN.)
0
30
60
PEAK TEMPERATURE (°C)
78
88
98

Fig. 52 Contour plot of tortilla weight versus temperature and steep time at 0 min. hold time. Weight code values are:

A = 22.0 (g)
B = 22.5
C = 23.0
D = 23.5
E = 24.0
F = 24.5
G = 25.0
H = 25.5

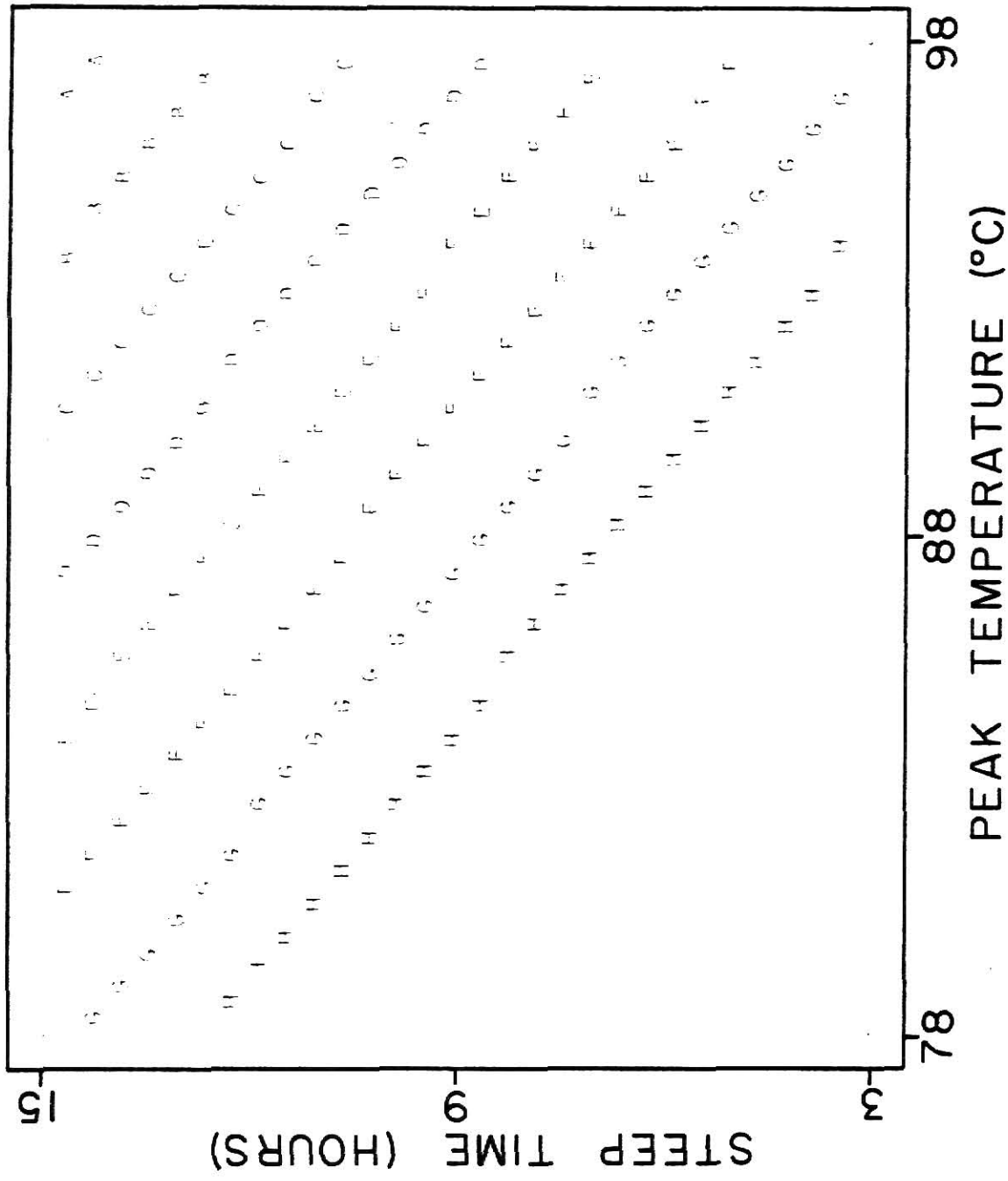

STEEP TIME (HOURS)
3
9
15
PEAK TEMPERATURE (°C)
78
88
98

Fig. 53 Tortilla weight versus temperature and steep time at 60 min. hold time. Weight code values are:

A = 22.0
B = 22.5
C = 23.0
D = 23.5
E = 24.0
F = 24.0
G = 25.0

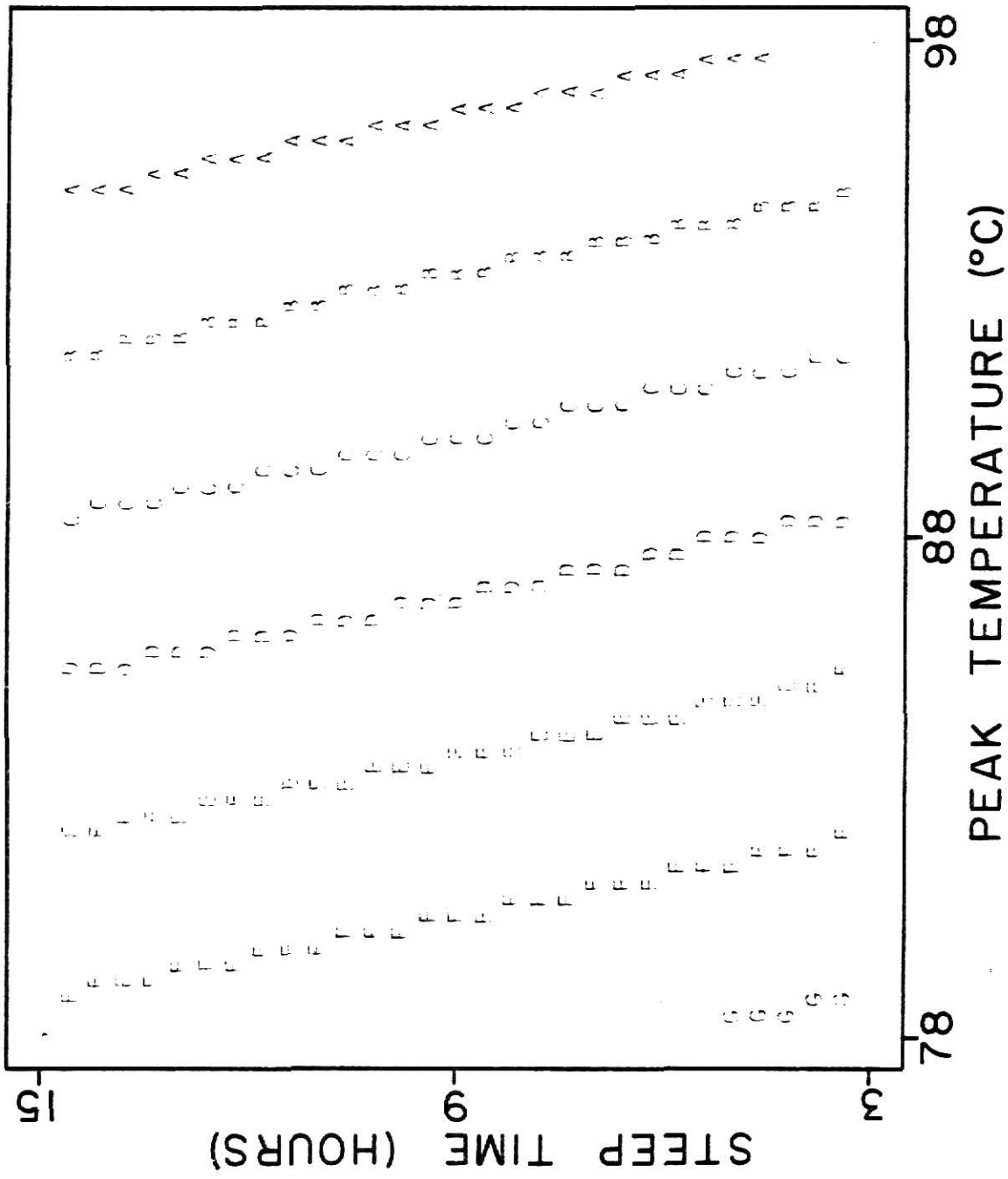

STEEP TIME (HOURS)
3
9
15
PEAK TEMPERATURE (°C)
78
88
98

Fig. 54 Masa moisture content versus tortilla weight.

$Y = -0.44.X + 47.9$
$r = -0.87$

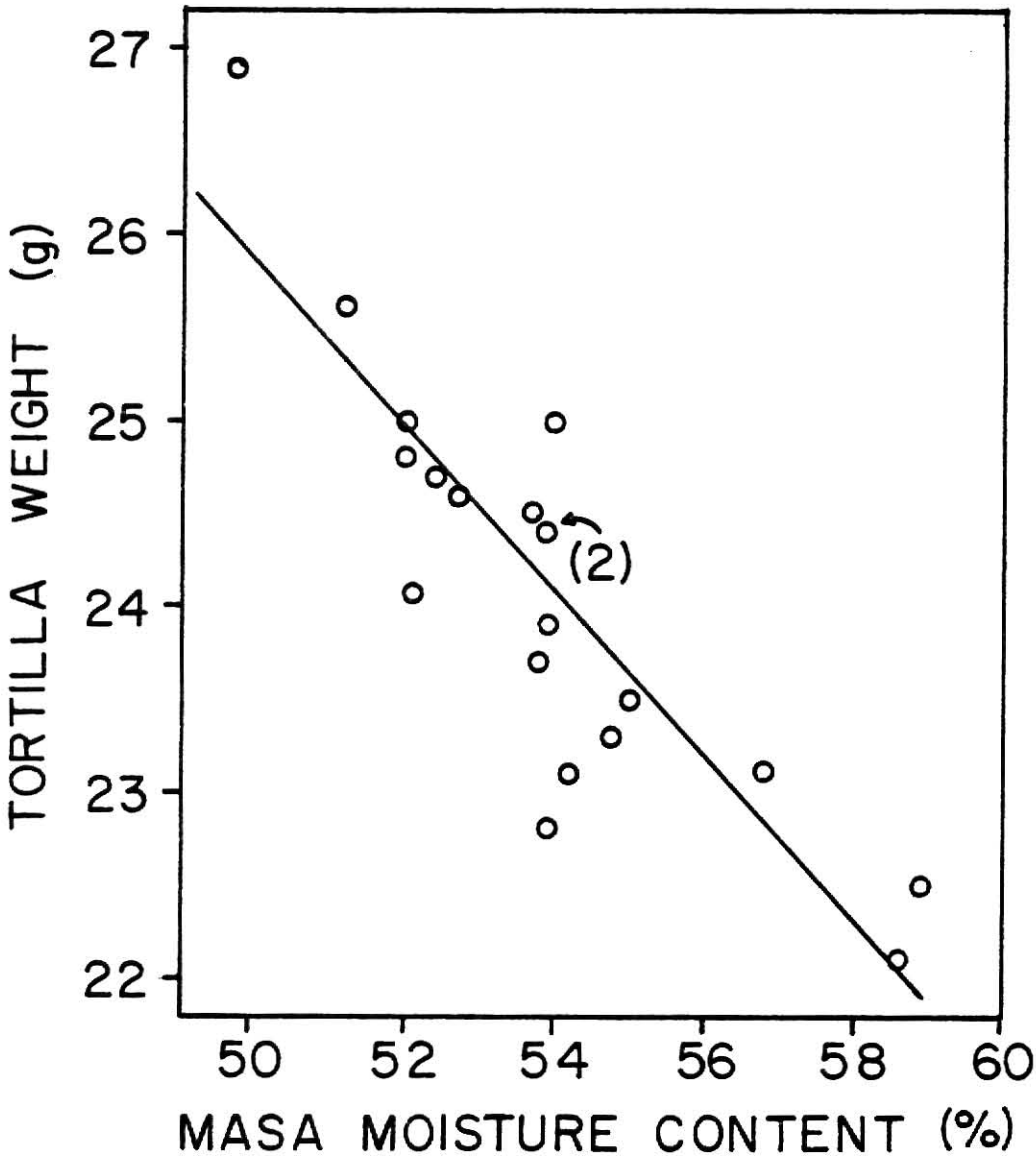

TORTILLA WEIGHT (g)
27
26
25
24
23
22
(2)
50
52
54
56
58
60
MASA MOISTURE CONTENT (%)

Fig. 55 Contour plot of tortilla axis ratio versus temperature and hold time at 9 hr. steep time. Axis ratio code values are:

B = 0.92 (units)
C = 0.93
D = 0.94
E = 0.95
F = 0.96
G = 0.97
H = 0.98

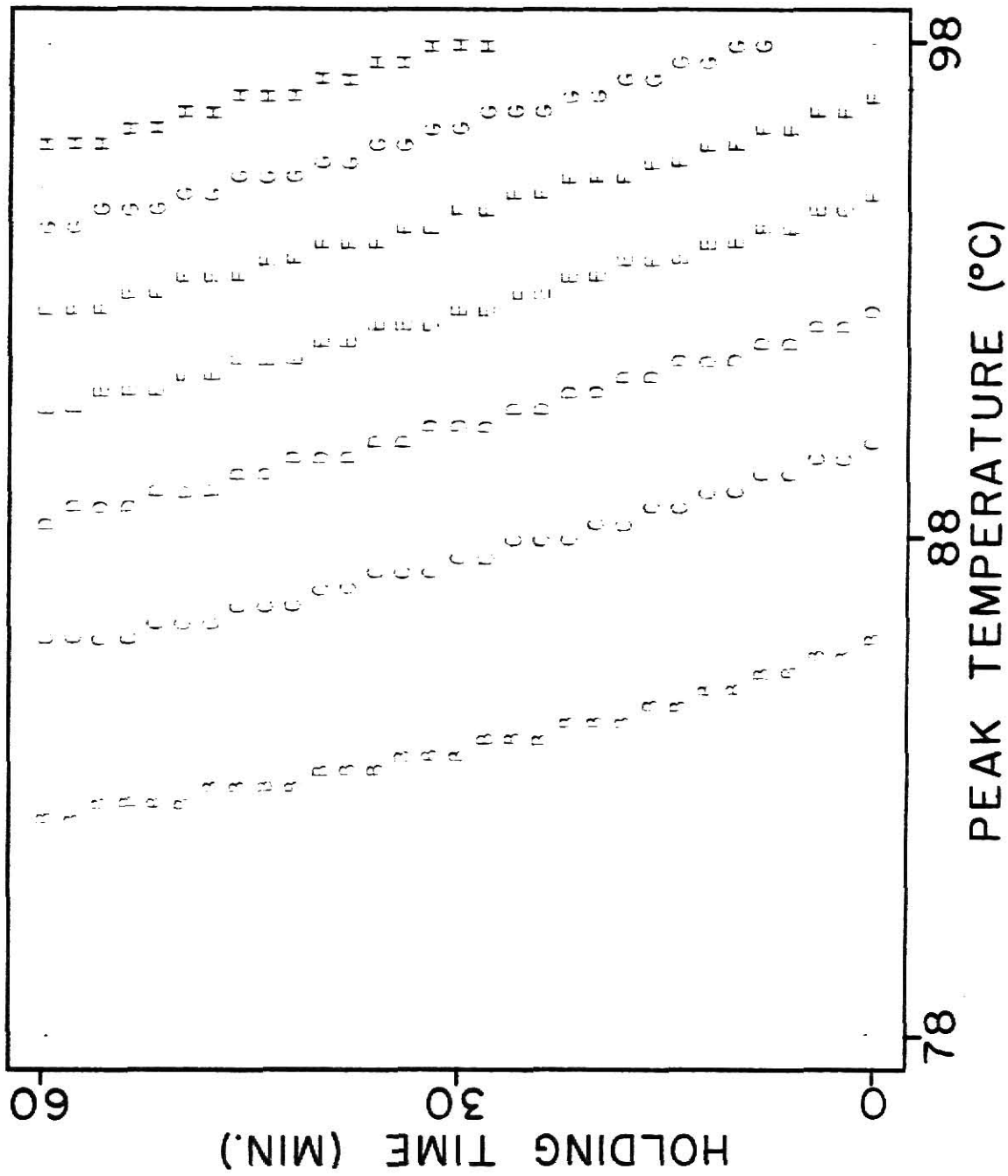

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 56 Masa moisture content versus tortilla axis ratio.

$$Y = 0.00778X + 0.516$$
$$X = 0.91$$

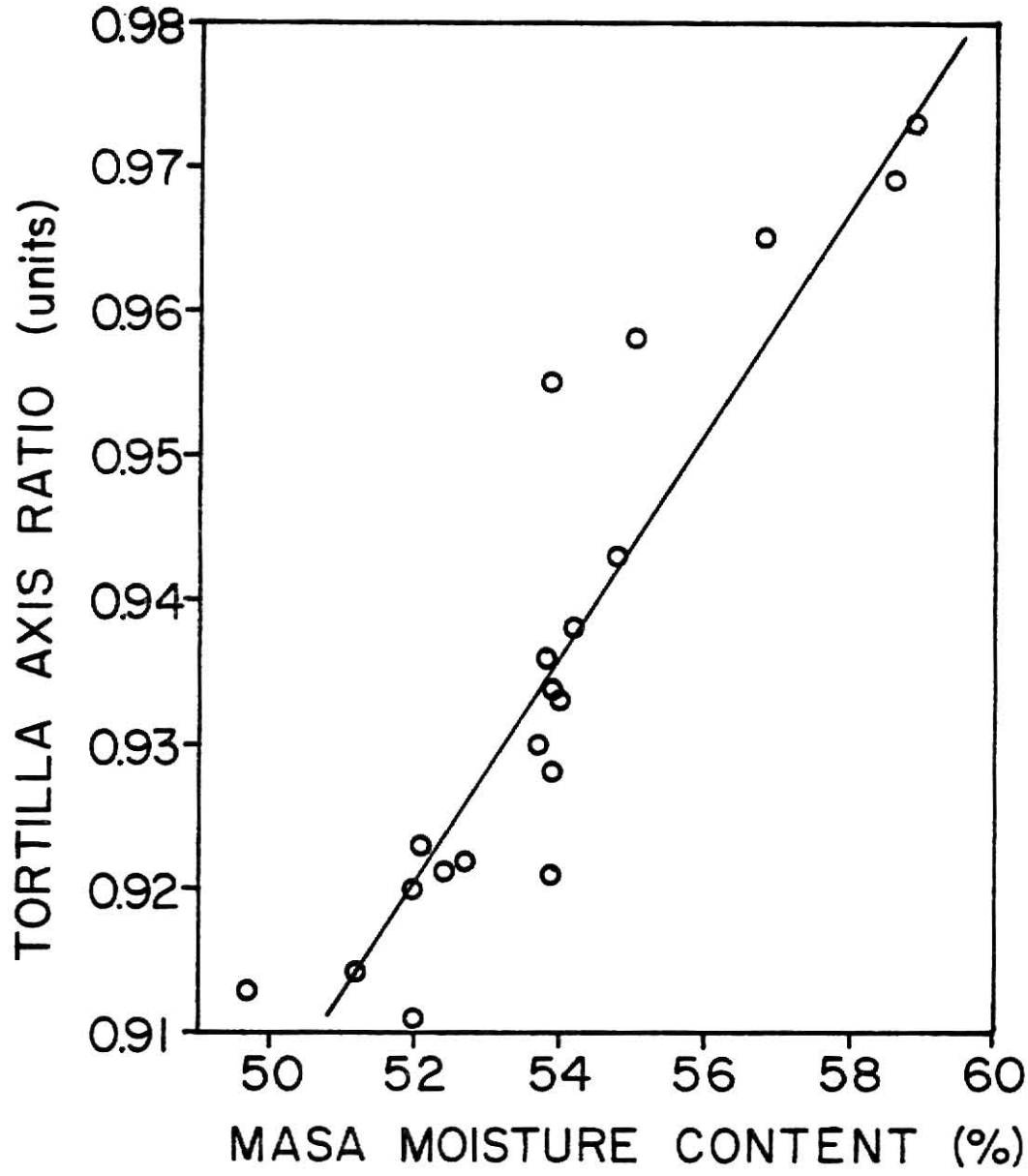
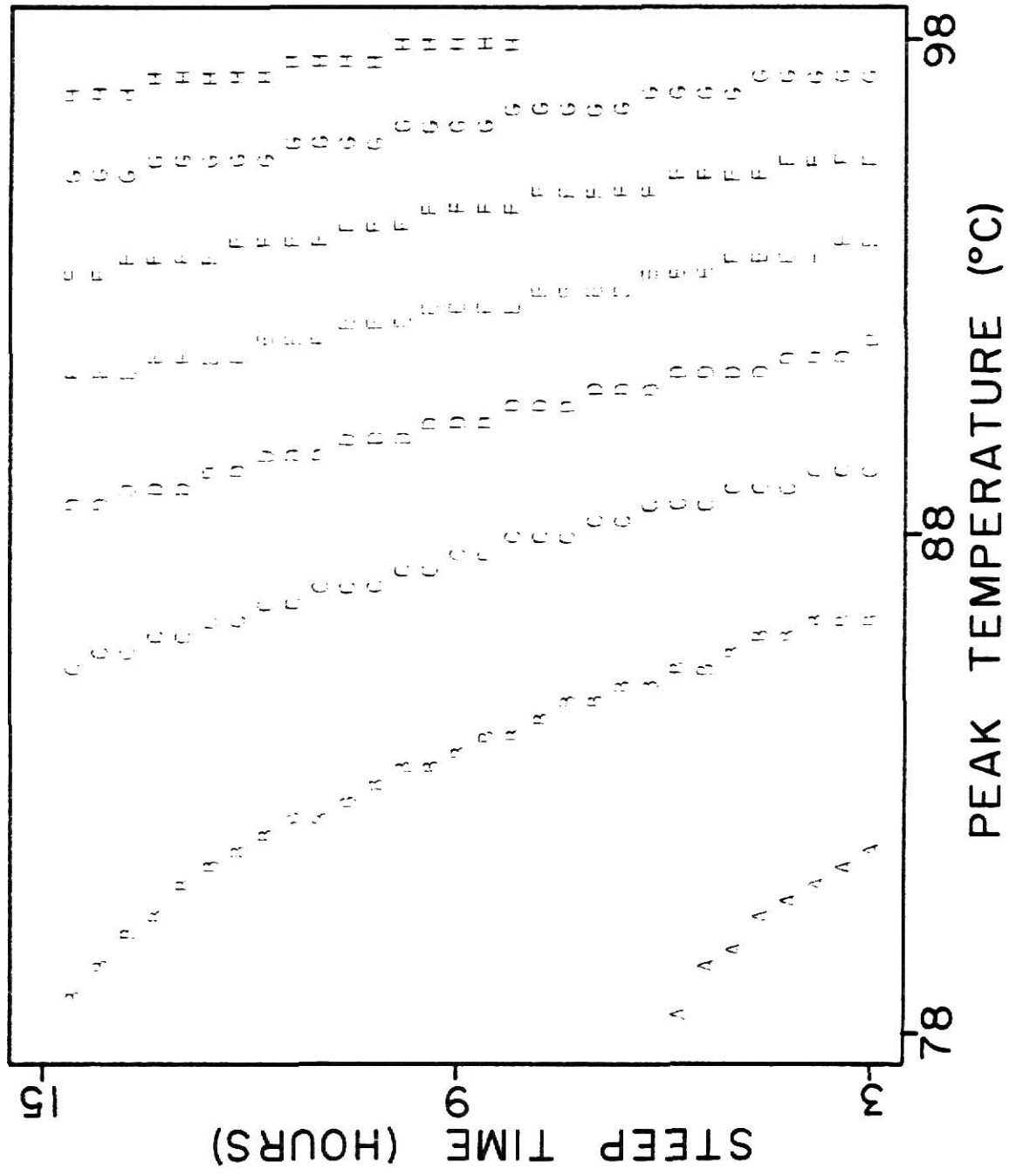

0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
TORTILLA AXIS RATIO (units)
50
52
54
56
58
60
MASA MOISTURE CONTENT (%)

Fig. 57 Contour plot of tortilla axis ratio versus temperature and steep time at 30 min. hold time. Axis ratio code values are:

A = 0.91 (units)
B = 0.92
C = 0.93
D = 0.94
E = 0.95
F = 0.96
G = 0.97
H = 0.98


STEEP TIME (HOURS)
3
9
15
78
88
98
PEAK TEMPERATURE (°C)

Tortilla Thickness. The determination coefficient was low (R^2 = 0.82) for thickness, and temperature only showed a linear correlation of -0.58, with hold time and steep time being higher than in other responses. Figure 58 indicates a decrease in tortilla thickness as temperature is increased at a constant 9 hour steep time. Changes in hold time above 30 minutes have minimal effect on thickness. As steep time is increased at a constant hold time of 30 minutes (Figure 59), thickness decreases. At 60 minutes hold time, however, an increase in steep time results in a decrease in thickness (Figure 60). Temperature appears to have the overriding effect, resulting in decreased thickness at higher peak temperatures.

Shear Force Testing. The fresh and frozen tortilla shear force tests resulted in high, identical determination coefficients, and very similar correlation factors, with temperature having a high, significant, negative correlation. Generally, shear force in the fresh tortillas decreased with increasing temperature, hold time, and steep time (Figures 61 and 62). Hold times greater than 30 minutes and steep times beyond 9 hours resulted in negligible change. Shear force showed similar patterns for frozen tortillas, only the shear force required was normally 50 - 60% higher (Figures 63 and 64). In order to correct for differences in shear force due to tortilla thickness differences, shear force was divided by thickness to give a corrected shear force (Figure 65). A comparison of Figures 61 and 65 (at a constant steep time of 9 hours), indicate small differences between shear force and corrected shear force, except at higher shear force values (i.e., lower temperatures and times).

The shear force testing measured the amount of force required to counteract the internal forces holding the tortilla together. One important factor that effects these internal (cohesive) forces is moisture content. Masa

Fig. 58 Contour plot of tortilla thickness versus temperature and hold time at 9 hr. steep time. Thickness code values are:

B = 1.00 (mm)
C = 1.05
D = 1.10
E = 1.15
F = 1.20

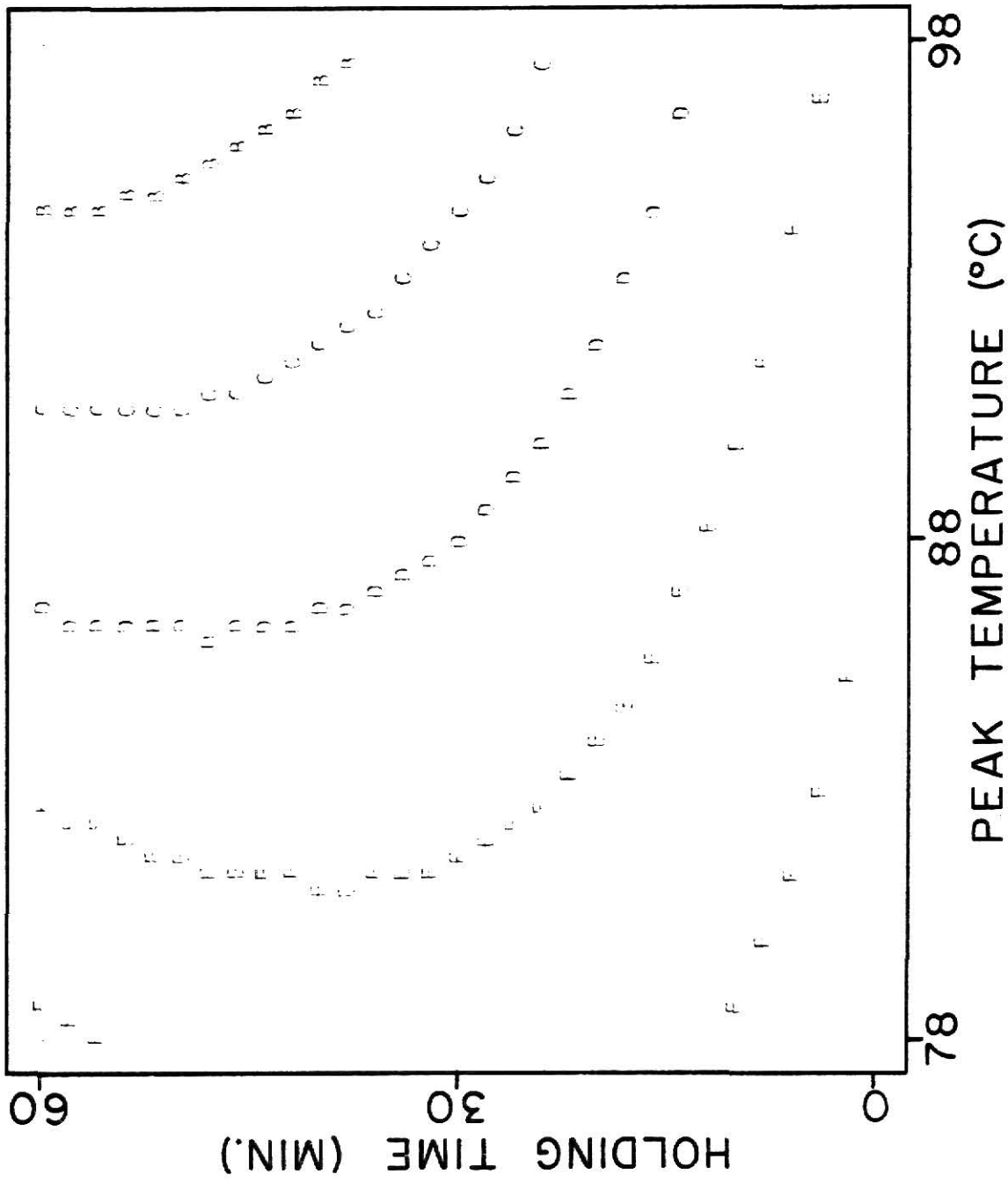

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 59 Contour plot of tortilla thickness versus temperature and steep time at 30 min. hold time. Thickness code values are:

B = 1.00 (mm)
C = 1.05
D = 1.10
E = 1.15
F = 1.20

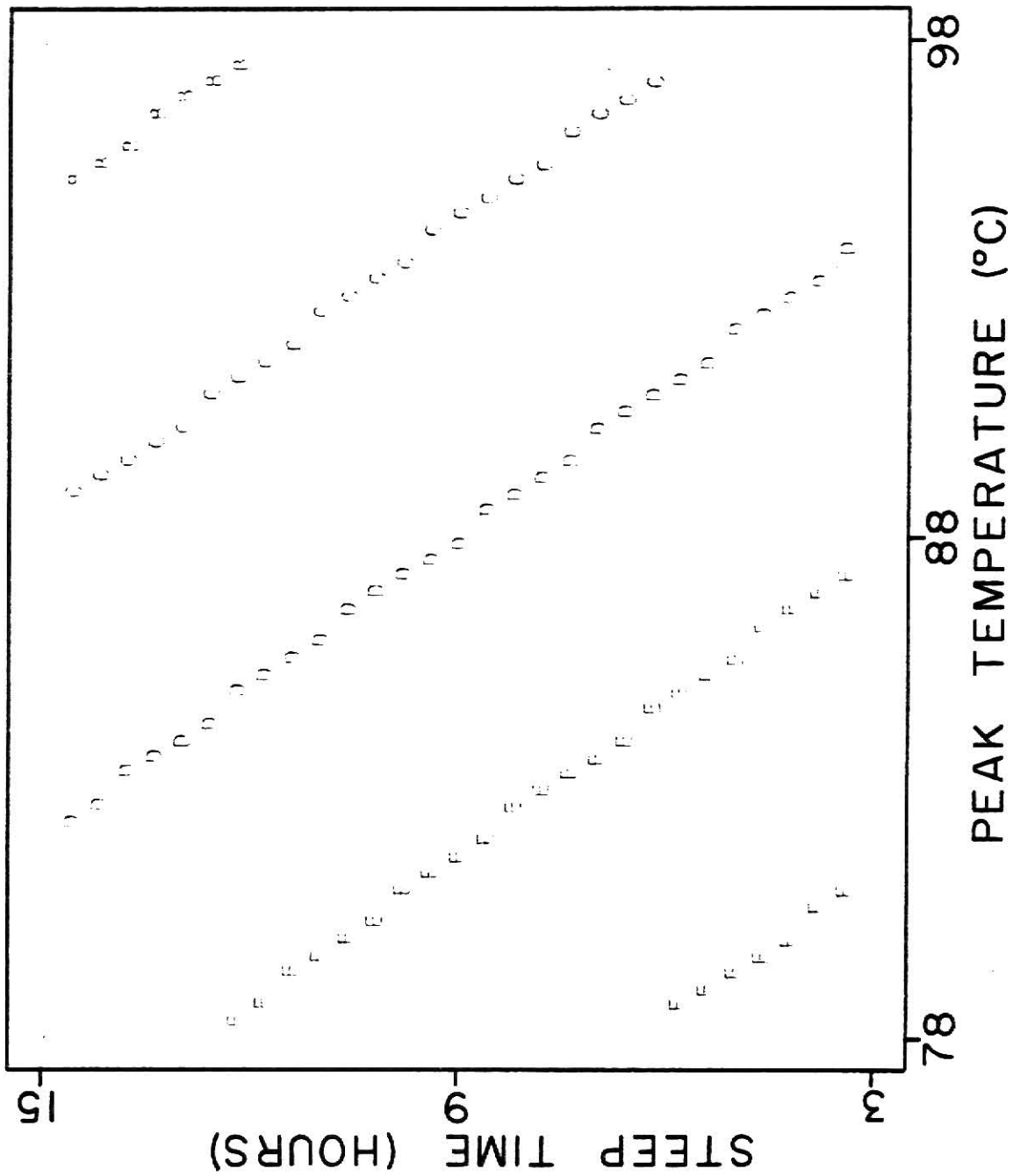

STEEP TIME (HOURS)
3
9
15
PEAK TEMPERATURE (°C)
78
88
98

Fig. 60 Contour plot of tortilla thickness versus temperature and steep time at 60 min. hold time. Thickness code values are:

A = 0.95 (mm)
B = 1.00
C = 1.05
D = 1.10
E = 1.15
F = 1.20

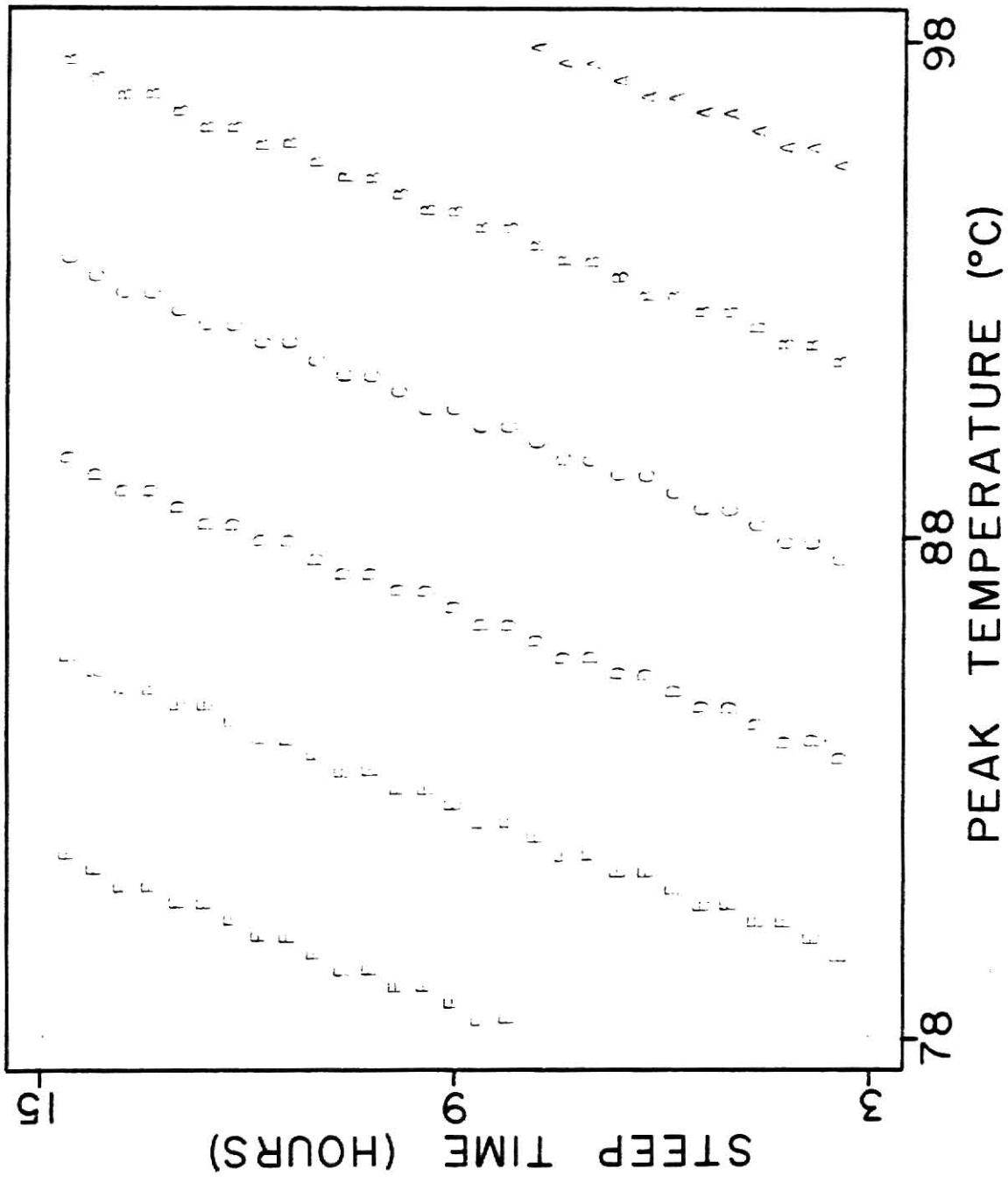

STEEP TIME (HOURS)
3
9
15
PEAK TEMPERATURE (°C)
78
88
98

Fig. 61 Contour plot of tortilla shear force (fresh) versus temperature and hold time at 9 hr. steep time. Shear force code values are:

A = 2.0 (Kg.)
B = 2.5
C = 3.0
D = 3.5
E = 4.0
F = 4.5
G = 5.0
H = 5.5
J = 6.0
K = 6.5

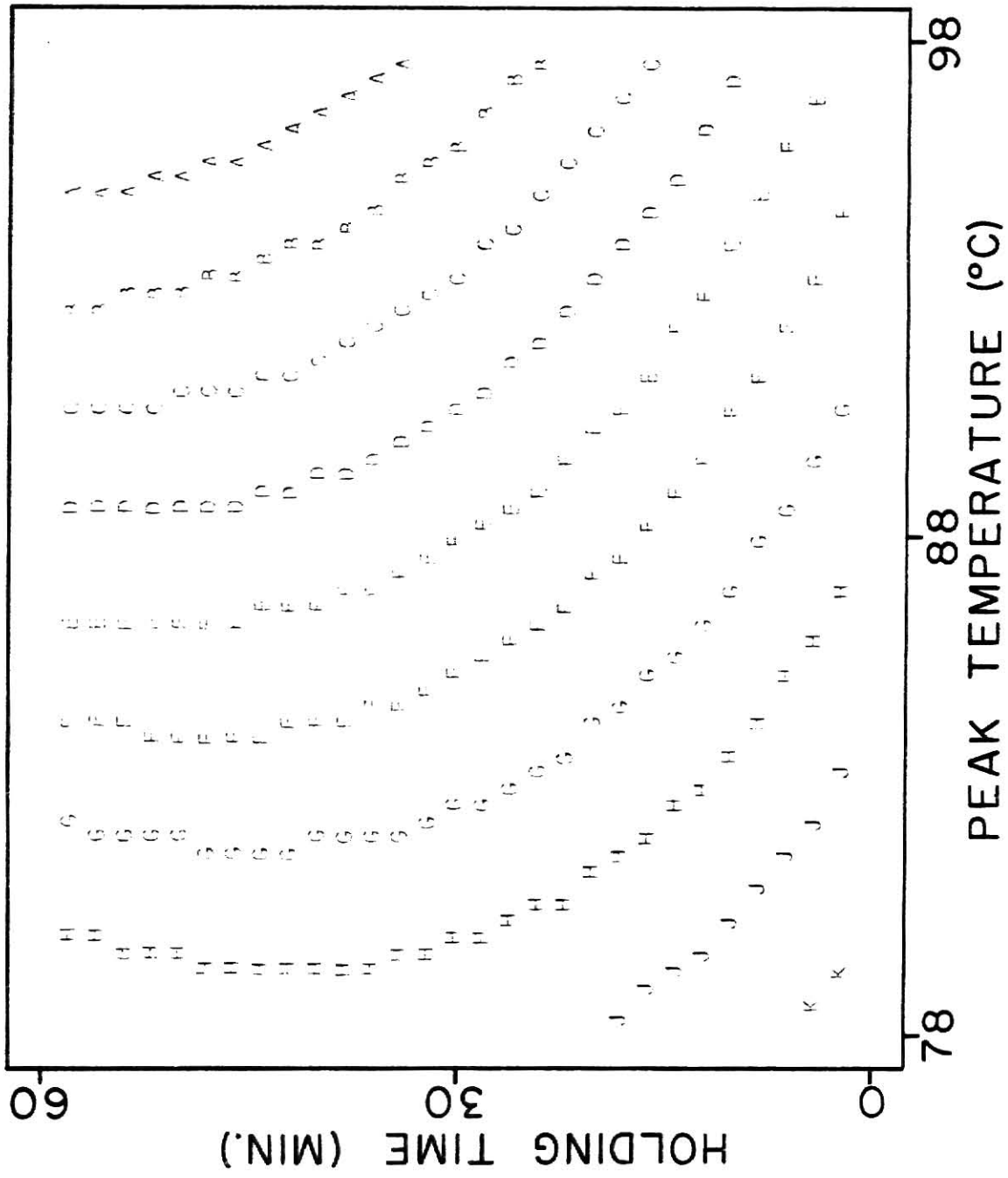

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 62 Contour plot of tortilla shear force (fresh) versus temperature and steep time at 30 min. hold time. Shear force code values are:

B = 2.5 (Kg)
C = 3.0
D = 3.5
E = 4.0
F = 4.5
G = 5.0
H = 5.5
J = 6.0
K = 6.5

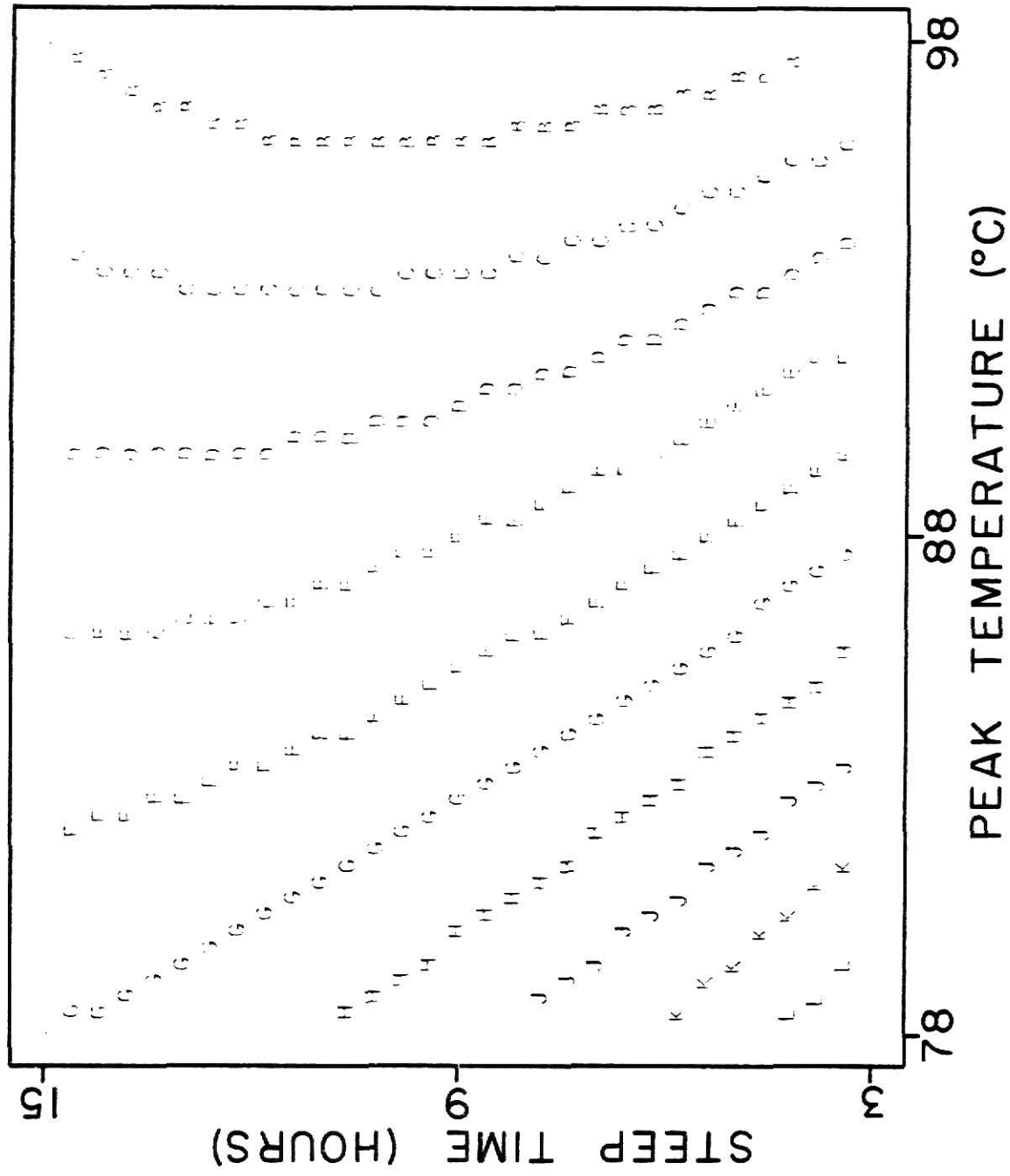

STEEP TIME (HOURS)
15
9
3
78
88
98
PEAK TEMPERATURE (°C)

Fig. 63 Contour plot of tortilla shear force (frozen-thawed) versus temperature and hold time at 9 hr. steep time. Shear force code values are:

A = 3.0 (Kg)
B = 4.0
C = 5.0
D = 6.0
E = 7.0
F = 8.0
G = 9.0
H = 10.0
J = 11.0

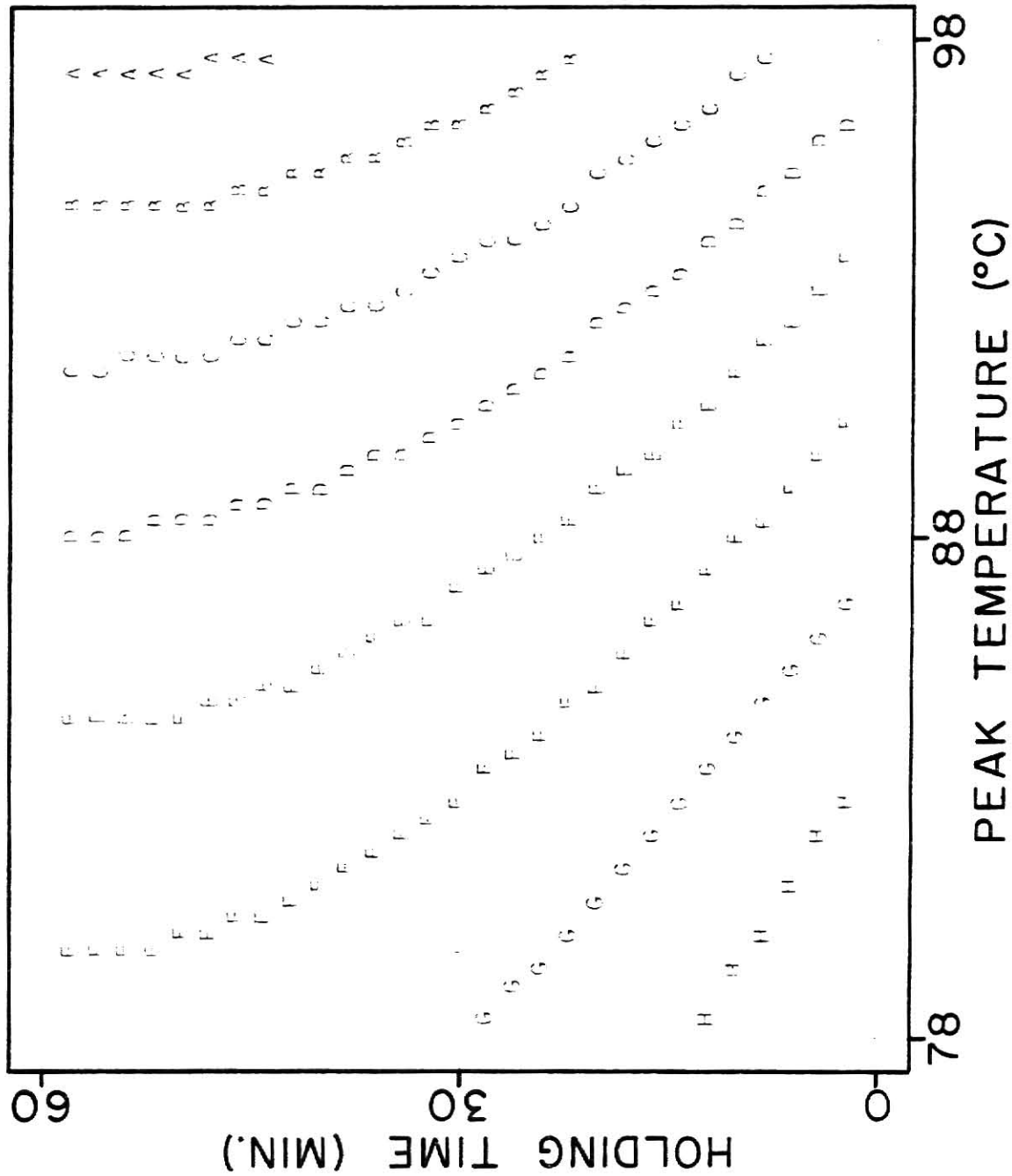

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 64 Contour plot of tortilla shear force (frozen-thawed) versus temperature and steep time at 30 min. hold time. Shear force code values are:

B = 4.0 (Kg)
C = 5.0
D = 6.0
E = 7.0
F = 8.0
G = 9.0
H = 10.0

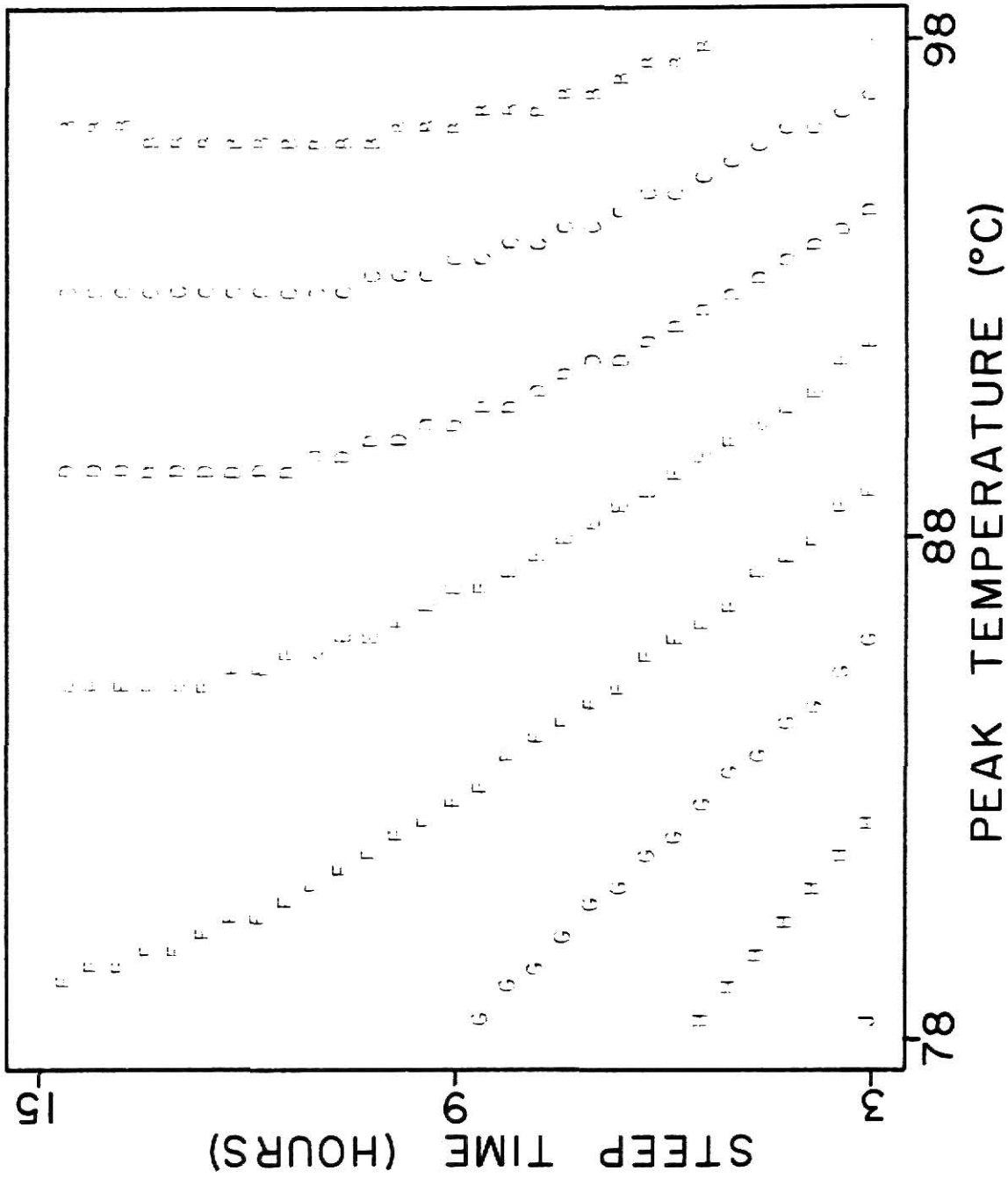
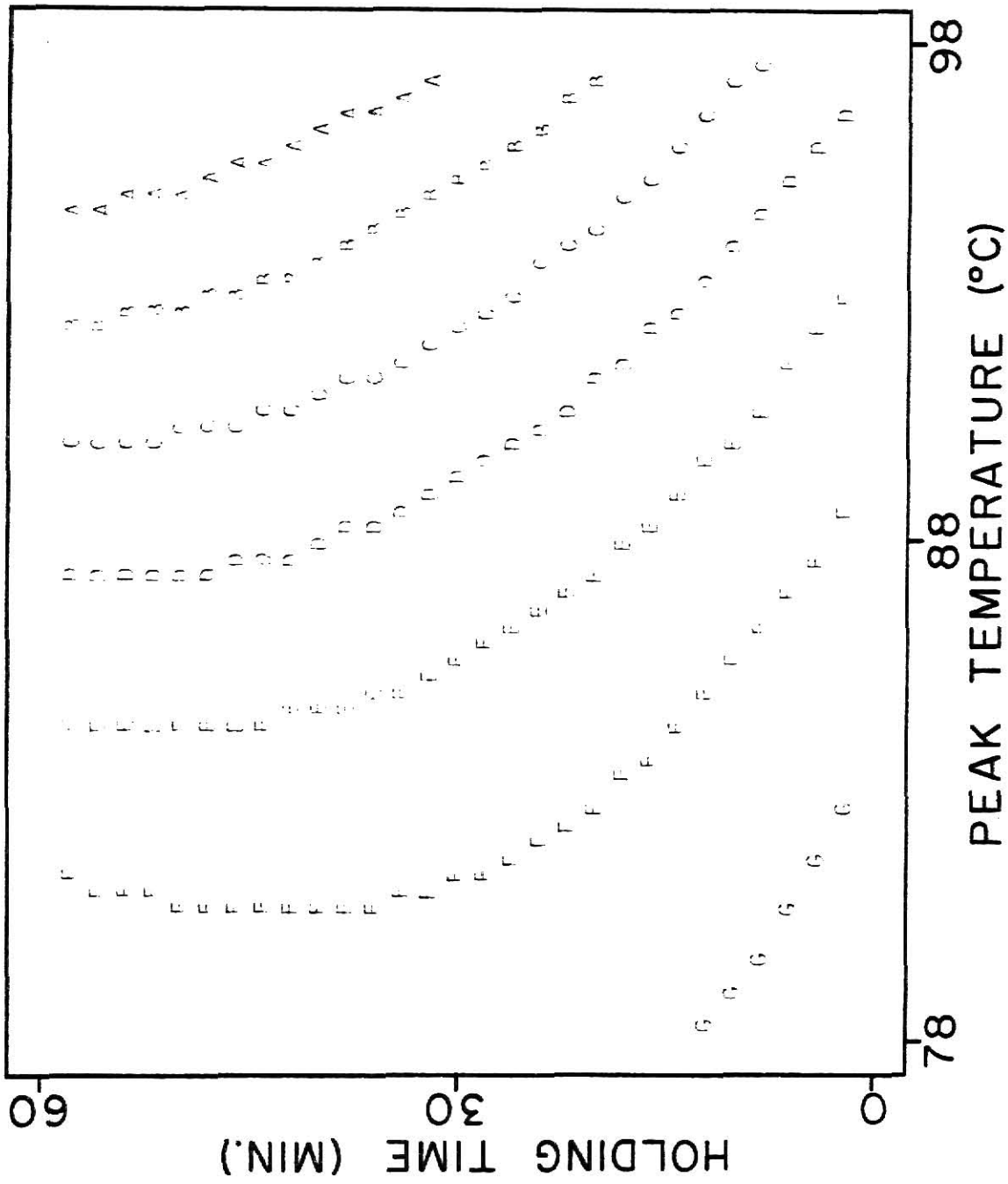

STEEP TIME (HOURS)
3
9
15
PEAK TEMPERATURE (°C)
78
88
98

Fig. 65 Contour plot of tortilla shear force/thickness (fresh) versus temperature and hold time at 9 hr. steep time. Shear force/thickness code values are:

A = 2.0 (Kg/mm)
B = 2.5
C = 3.0
D = 3.5
E = 4.0
F = 4.5
G = 5.0


HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

moisture content was plotted versus tortilla shear force in Figure 66. Shear force was highly and negatively correlated with masa moisture content ($r = -0.962$).

Tortilla Organoleptic Parameters. Of the four parameters evaluated (aroma, flexibility, mouthfeel, and taste), only flexibility is not discussed due to the very low determination coefficient ($R^2 = 0.50$) (Table 2). The other three factors resulted in coefficients greater than 0.75 and were considered reliable enough for taste panel evaluation. Aroma was most significant ($R^2 = 0.89$), with temperature having the highest linear correlation ($r = 0.53$) for aroma. Figures 67 to 69 reveal an optimum area for the most desirable aroma (i.e., highest value). At 3 hours steep time, short hold time (20 minutes or less) and high peak temperature (95°C or more) are most desirable. At 9 hours steep (Figure 68) holding time and temperature can vary widely (0 - 45 minutes hold time and 98 - 88°C temperature). At long steep times (15 hours, Figure 69), it is necessary to use longer hold times (20 minutes or more) and lower temperatures (90 - 81°C) for optimum aroma. It is easily seen that over a rather broad area, peak temperature, hold time, and steep time can be varied and not affect aroma greatly (i.e., not change the aroma ranking over 0.2 - 0.4 units). However once near the outside of this broad area (for example 93° peak temperature and 30 minute hold time in Figure 69, where the aroma value is +0.4) an increase in time, or especially temperature, can cause the aroma ranking to fall rapidly. Figure 70 is a plot at 30 minutes holding time and shows variations in aroma with changing temperature and steep time.

Examination of Table 2 reveals that the simple linear correlations of the mouthfeel response with temperature and with steep time are equal ($r = 0.55$ for both). The only other responses that had high correlations with steep

Fig. 66 Masa moisture content versus tortilla shear force.

$$Y = -0.494X + 30.9$$
$$r = -0.96$$

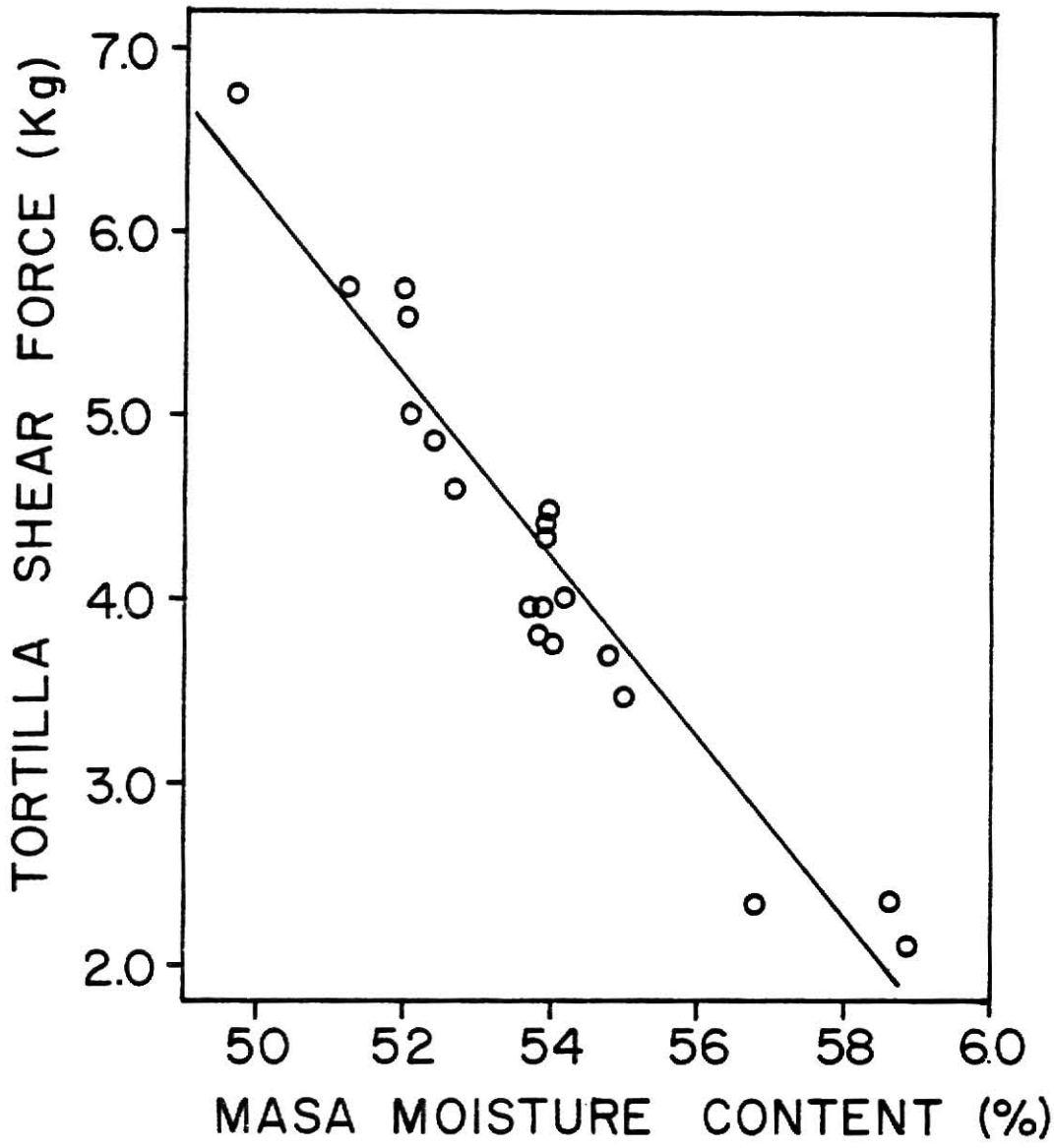

TORTILLA SHEAR FORCE (Kg)
7.0
6.0
5.0
4.0
3.0
2.0
50
52
54
56
58
6.0
MASA MOISTURE CONTENT (%)

Fig. 67 Contour plot of tortilla aroma (ranking compared to control) versus temperature and hold time at 3 hr. steep time. Aroma ranking code values are:

A = -1.0 (units)
B = -0.8
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4
J = +0.6

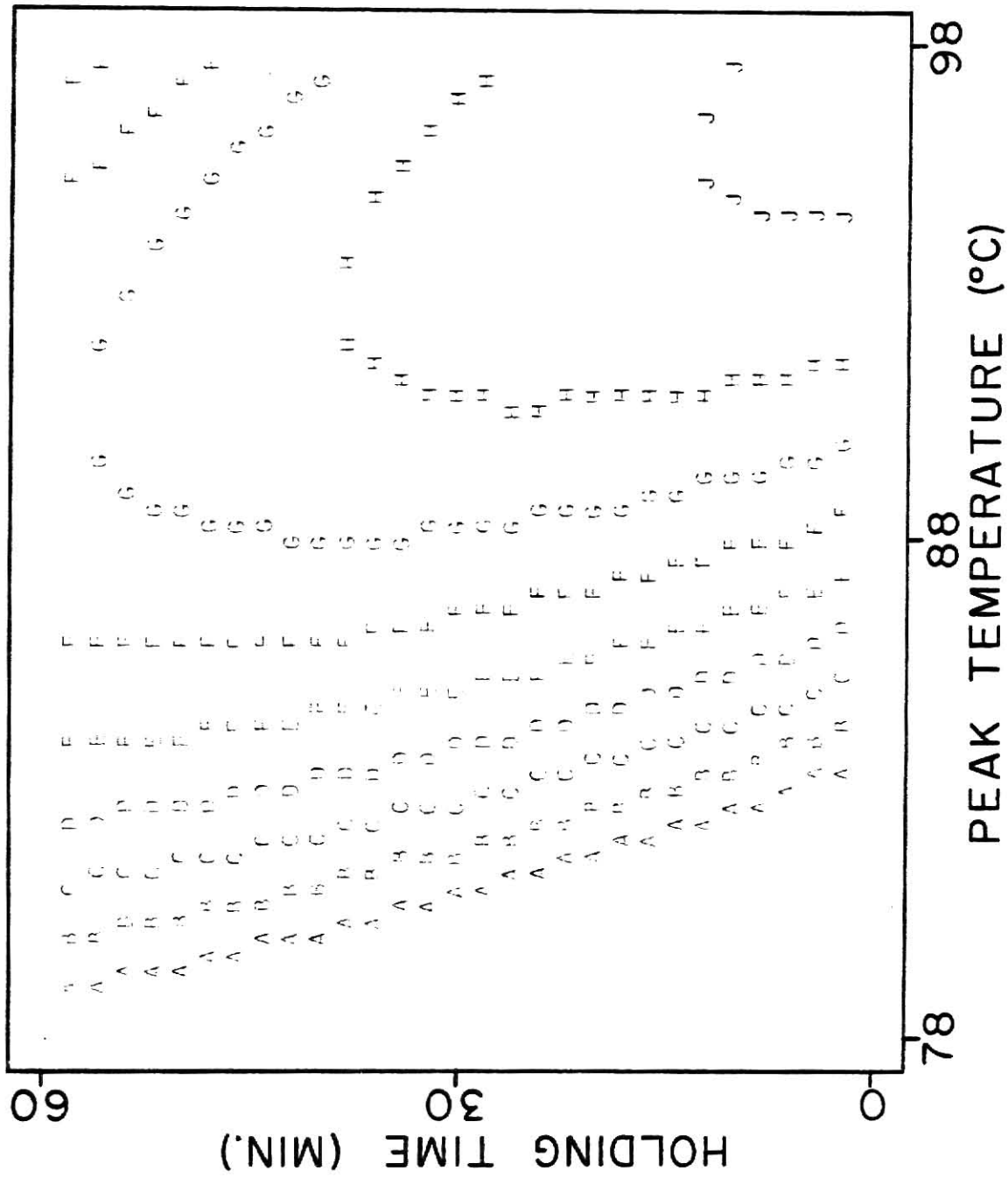

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 68 Contour plot of tortilla aroma (ranking compared to control) versus temperature and hold time at 9 hr. steep time. Aroma ranking code values are:

A = -1.0 (units)
B = -0.8
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4
J = +0.6

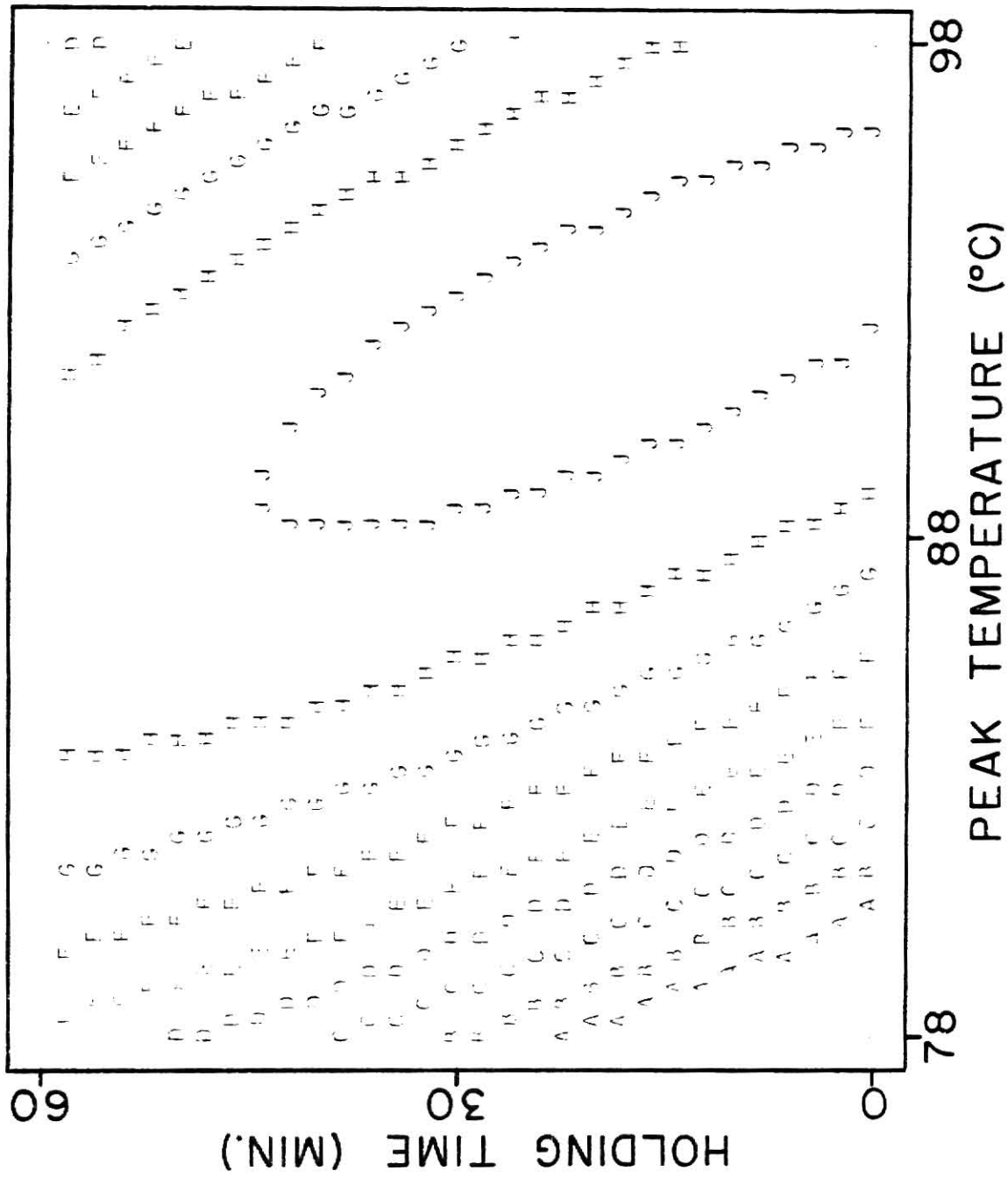

HOLDING TIME (MIN.)
60
30
0
78
88
98
PEAK TEMPERATURE (°C)

Fig. 69 Contour plot of tortilla aroma (ranking compared to control) versus temperature and hold time at 15 hr. steep time. Aroma ranking code values are:

A = -1.0 (units)
B = -0.8
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4
J = +0.6

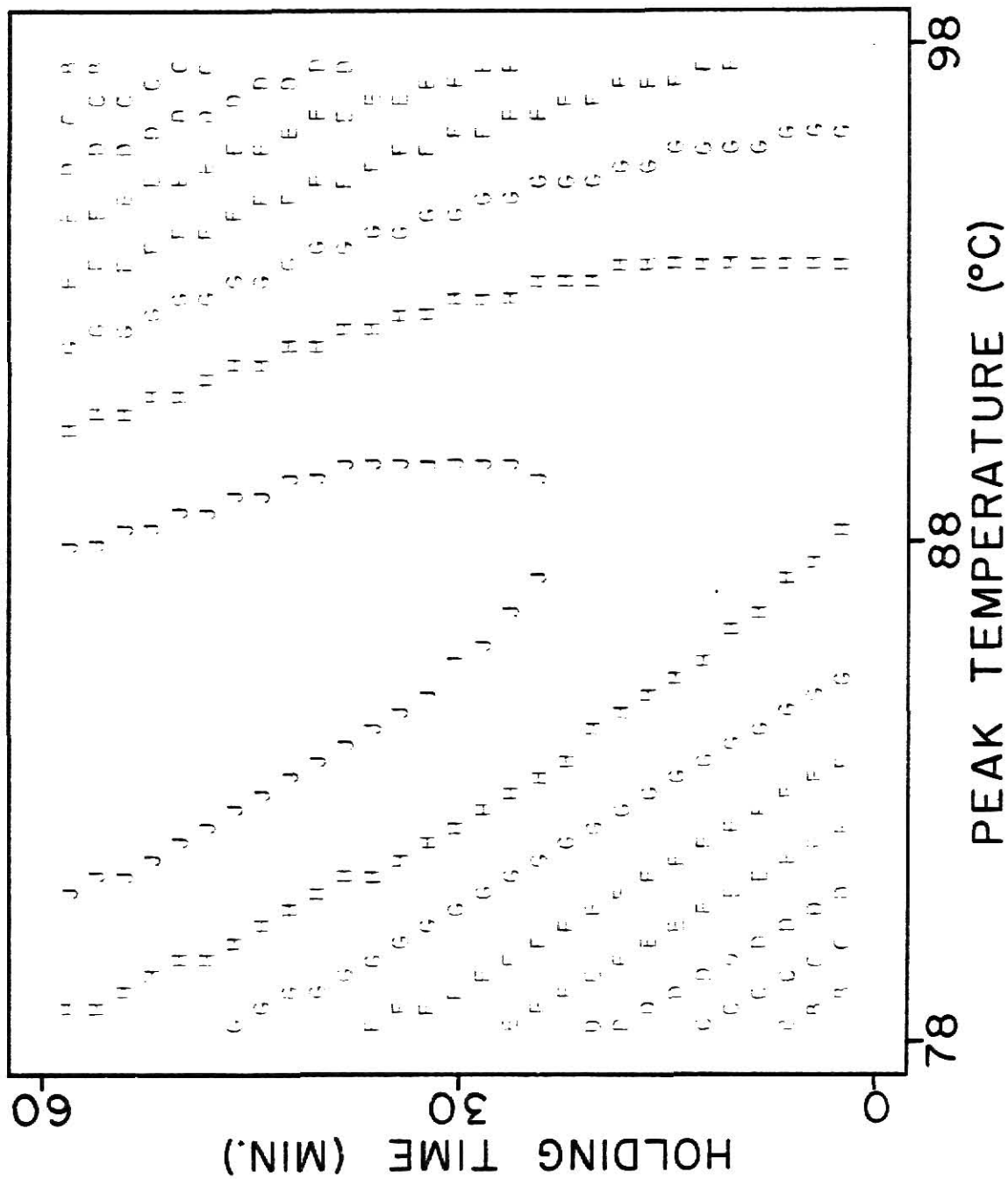
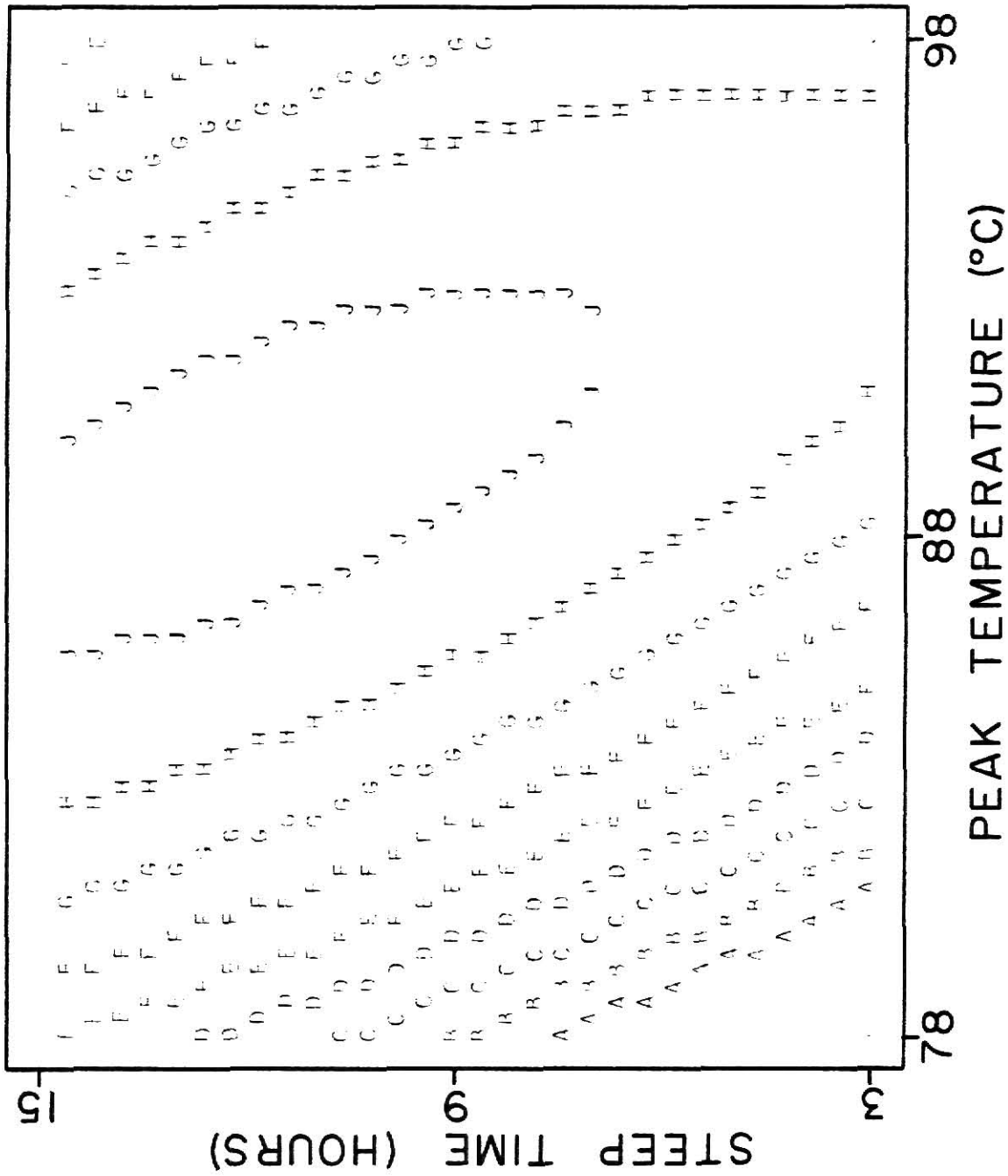

HOLDING TIME (MIN.)
60
30
0
78
88
98
PEAK TEMPERATURE (°C)

Fig. 70 Contour plot of tortilla aroma (ranking compared to control) versus temperature and steep time at 30 min. hold time. Aroma ranking code values are:

A = -1.0 (units)
B = -0.8
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4
J = +0.6


STEEP TIME (HOURS)
15
9
3
78
88
98
PEAK TEMPERATURE (°C)

time were the particle size responses ($r = -0.70$ and -0.73 respectively). This implies that particle size does have a significant determinable effect upon mouthfeel ranking. At the short holding time, peak temperature and steep time appeared to have an equal effect upon mouthfeel, but at the long holding time, steep time had a much greater effect than temperature (Figures 71 - 73). Both steep time and peak temperature changes appear to have a linear effect upon mouthfeel. Plots of hold time and peak temperature versus mouthfeel (Figures 74 and 75) indicate that holding time is at an optimum between 30 and 45 minutes (depending upon temperature).

Tortilla Taste. Inspection of Table 2 establishes that all three parameters have approximately the same linear correlation with taste (r approximately equal to 0.40). Figures 76 - 78 illustrate the relationships between the three variables. The highest taste value occured at the lowest temperature (Figure 76, 78°C) and at longest hold and steep times. As temperature increased (Figure 77), the ratings were spread out so that changes in hold and steep times effected smaller changes in ranking. At maximum temperature (Figure 78, 98°C) an optimum was located, yet the value of the area (+0.2) was considerably below the maximum ranking (+0.8) at 78°C. Increasing either or both hold and steep time further decreased desirable taste.

Series 3 - Moisture Content Variation. The third series consisted of varying the rate of water addition at the grinder, using three different levels and running duplicates of each, requiring size tests total. The three rates used were 0, 70, and 150 g/min. Cooking conditions chosen were 90°C peak, 40 minutes hold time, and 11 hours of steep time.

Masa Production Rate. Figure 79, Line A, illustrates the increase in masa output as water input is increased from 0 - 150 g/min. Line B was corrected for the amount of water added, to find out whether nixtamal input

Fig. 71 Contour plot of tortilla mouthfeel (ranking compared to control) versus temperature and steep time at 0 min. hold time. Mouthfeel ranking code values are:

A = -1.0 (units)
B = -0.8
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4
J = +0.6

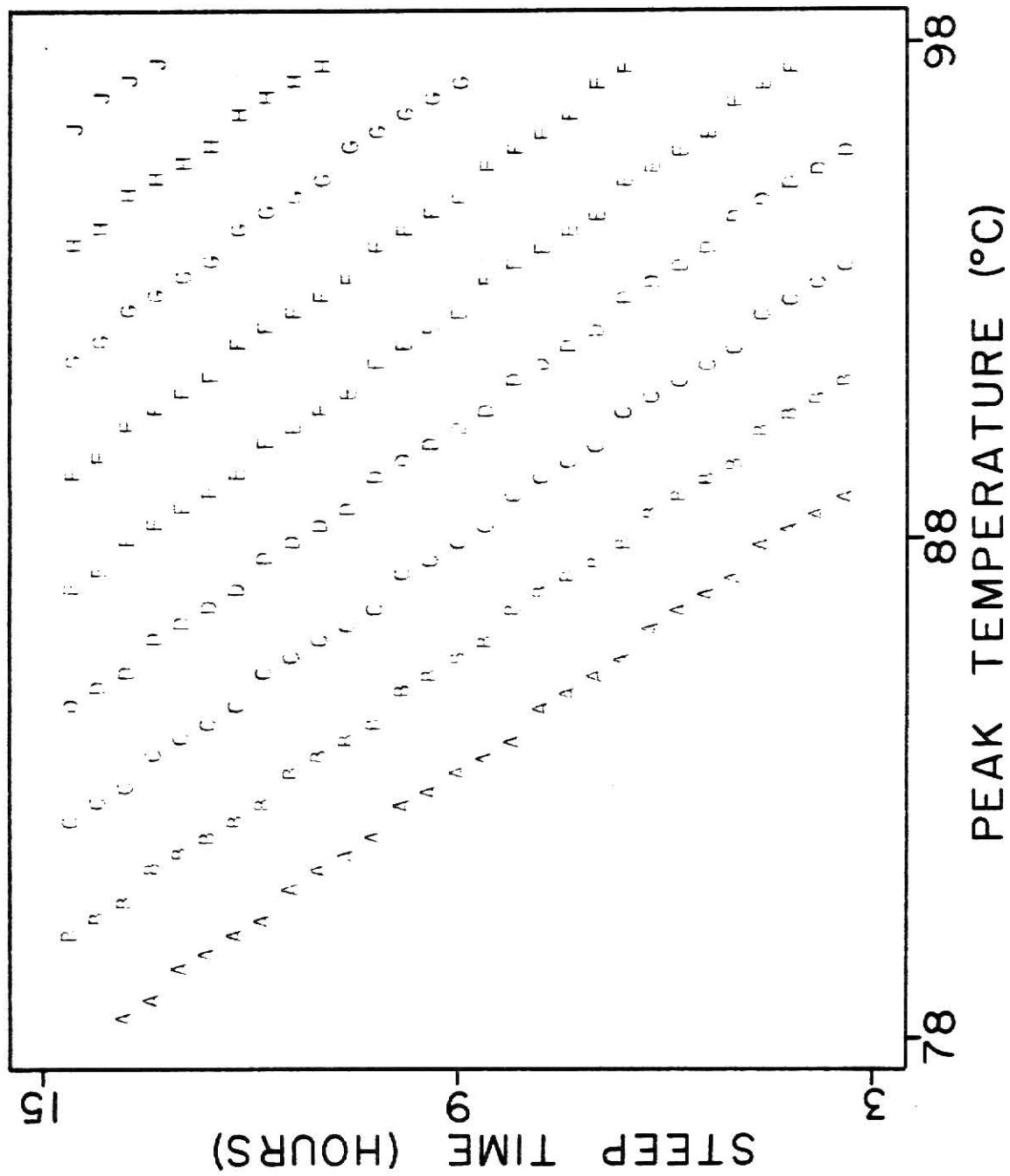

STEEP TIME (HOURS)
15
9
3
78
88
98
PEAK TEMPERATURE (°C)

Fig. 72 Contour plot of tortilla mouthfeel (ranking compared to control) versus temperature and steep time at 30 min. hold time. Mouthfeel ranking code values are:

A = -1.0 (units)
B = -0.8
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4
J = +0.6

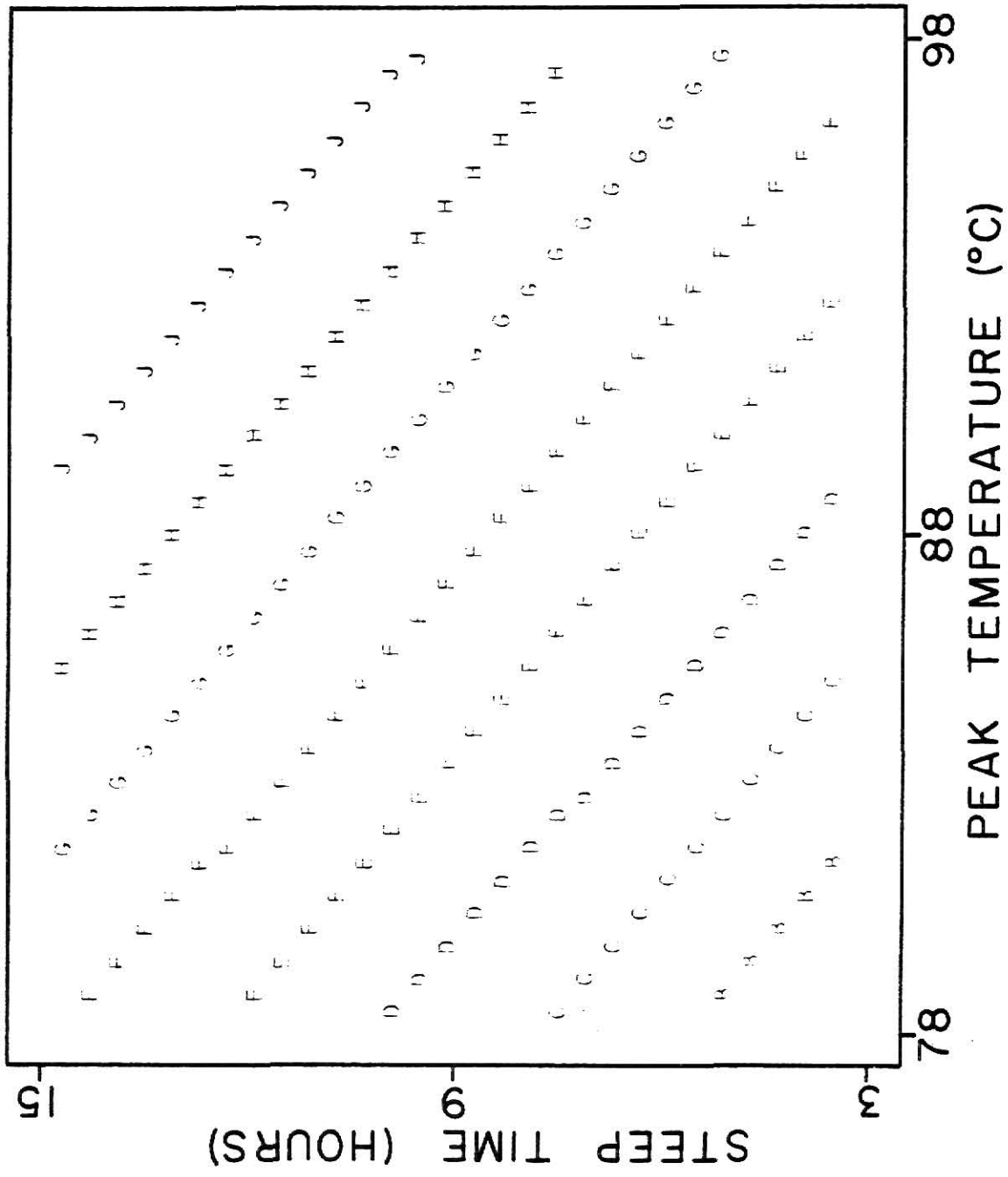

STEEP TIME (HOURS)
3
9
15
78
88
98
PEAK TEMPERATURE (°C)

Fig. 73 Contour plot of tortilla mouthfeel (ranking compared to control) versus temperature and steep time at 60 min. hold time. Mouthfeel ranking code values are:

B = -0.8 (units)
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4

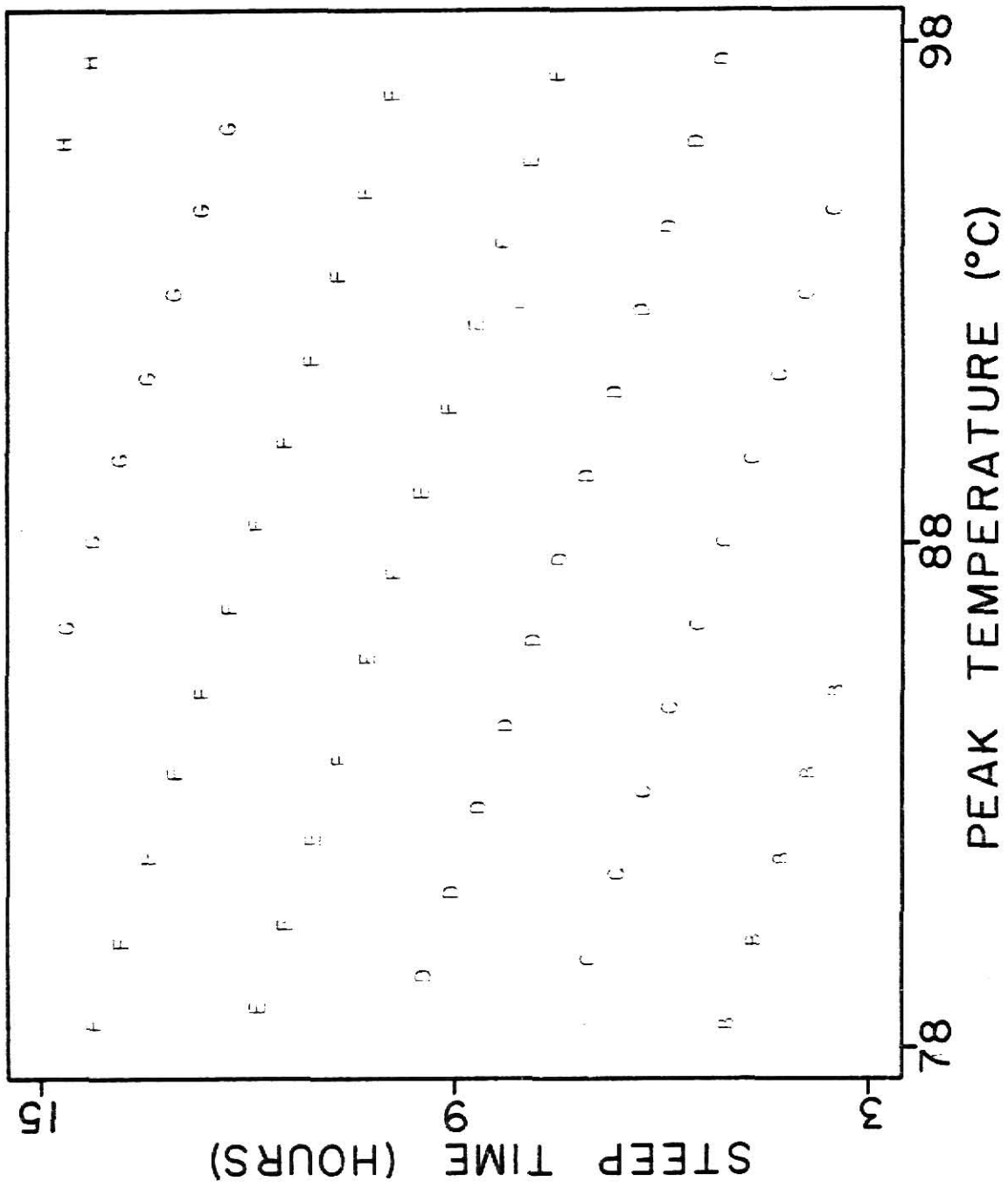

STEEP TIME (HOURS)
15
9
3
78
88
98
PEAK TEMPERATURE (°C)

Fig. 74 Contour plot of tortilla mouthfeel (ranking compared to control) versus temperature and hold time at 9 hr. steep time. Mouthfeel ranking code values are:

A = -1.0 (units)
B = -0.8
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4

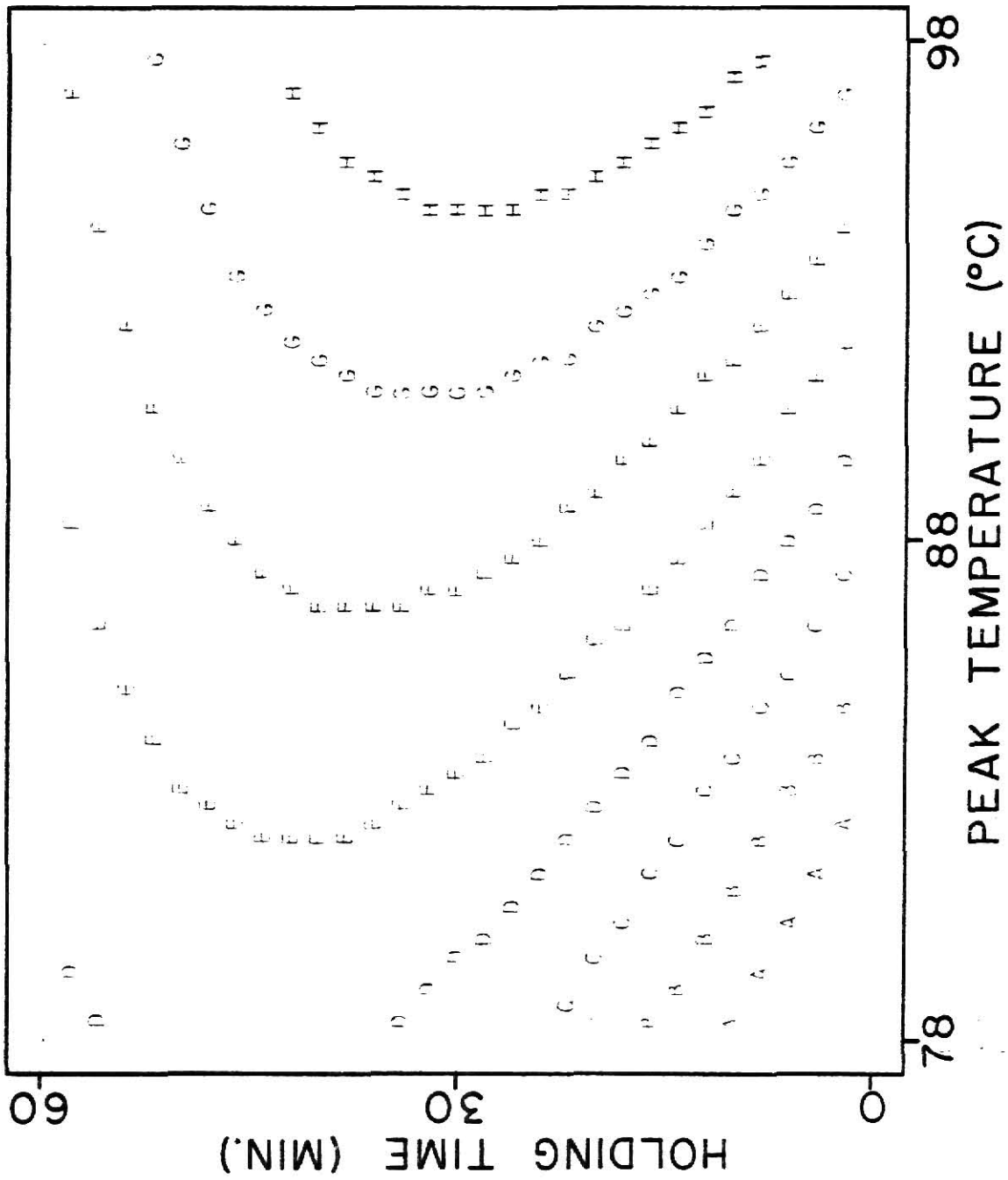

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 75 Contour plot of tortilla mouthfeel (ranking compared to control) versus temperature and hold time at 15 hr. steep time. Mouthfeel ranking code values are:

B = -0.8 (units)
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4
H = +0.6

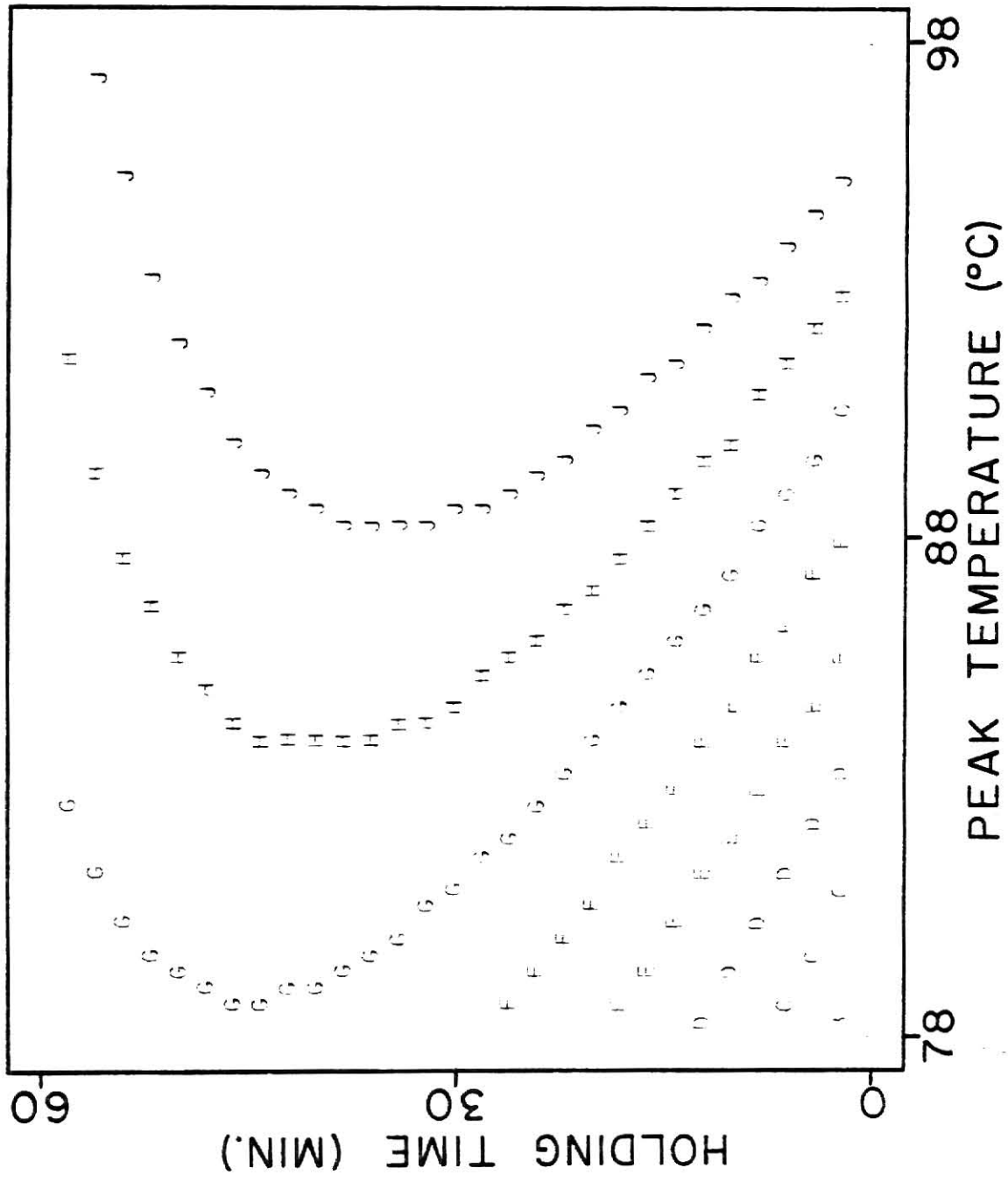

HOLDING TIME (MIN.)
0
30
60
78
88
98
PEAK TEMPERATURE (°C)

Fig. 76 Contour plot of tortilla taste (ranking compared to control) versus hold time and steep time at 78°C temperature. Taste ranking code values are:

A = -1.0 (units)
B = -0.8
C = -0.6
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4
J = +0.6
K = +0.8

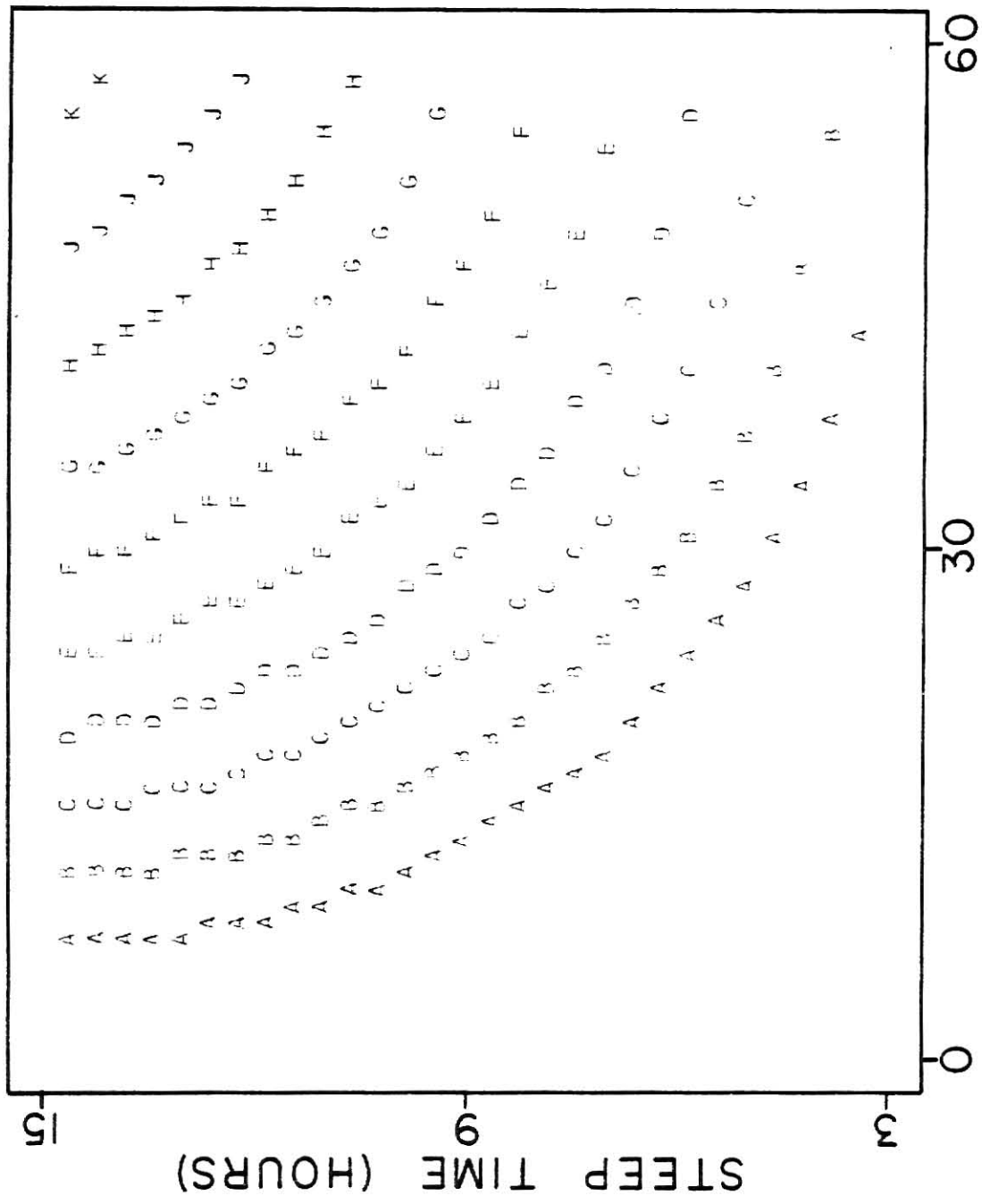

STEEP TIME (HOURS)
3
9
15
0
30
60
HOLDING TIME (MIN.)

Fig. 77 Contour plot of tortilla taste (ranking compared to control) versus hold time and steep time at 88°C temperature. Taste ranking code values are:

C = -0.6 (units)
D = -0.4
E = -0.2
F = 0.0
G = +0.2
H = +0.4
J = +0.6

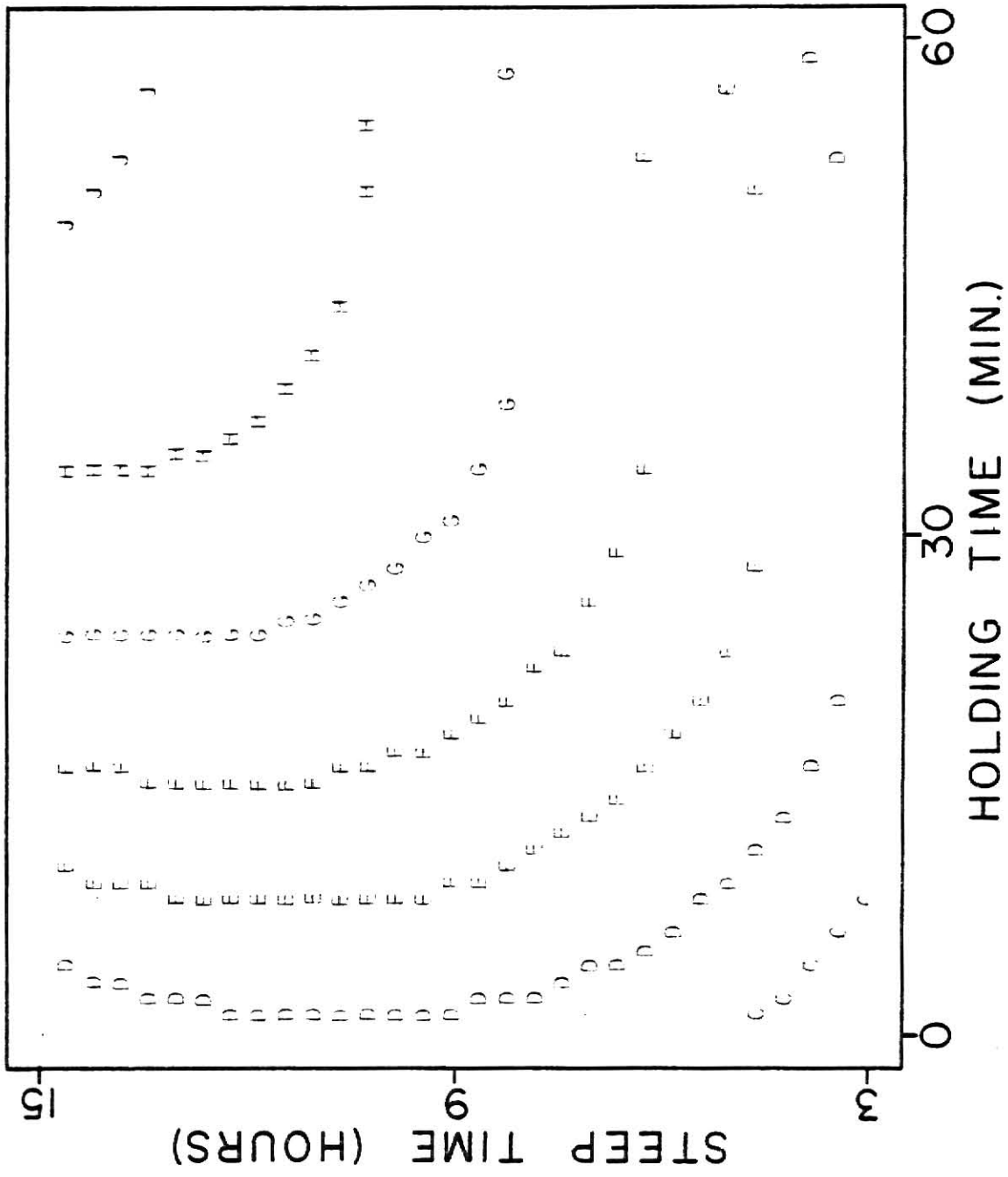

STEEP TIME (HOURS)
15
9
3
0
30
60
HOLDING TIME (MIN.)

Fig. 78 Contour plot of tortilla taste (ranking compared to control) versus hold time and steep time at 98°C temperature. Taste ranking code values are:

C = -0.6 (units)
D = -0.4
E = -0.2
F = 0.0
G = +0.2

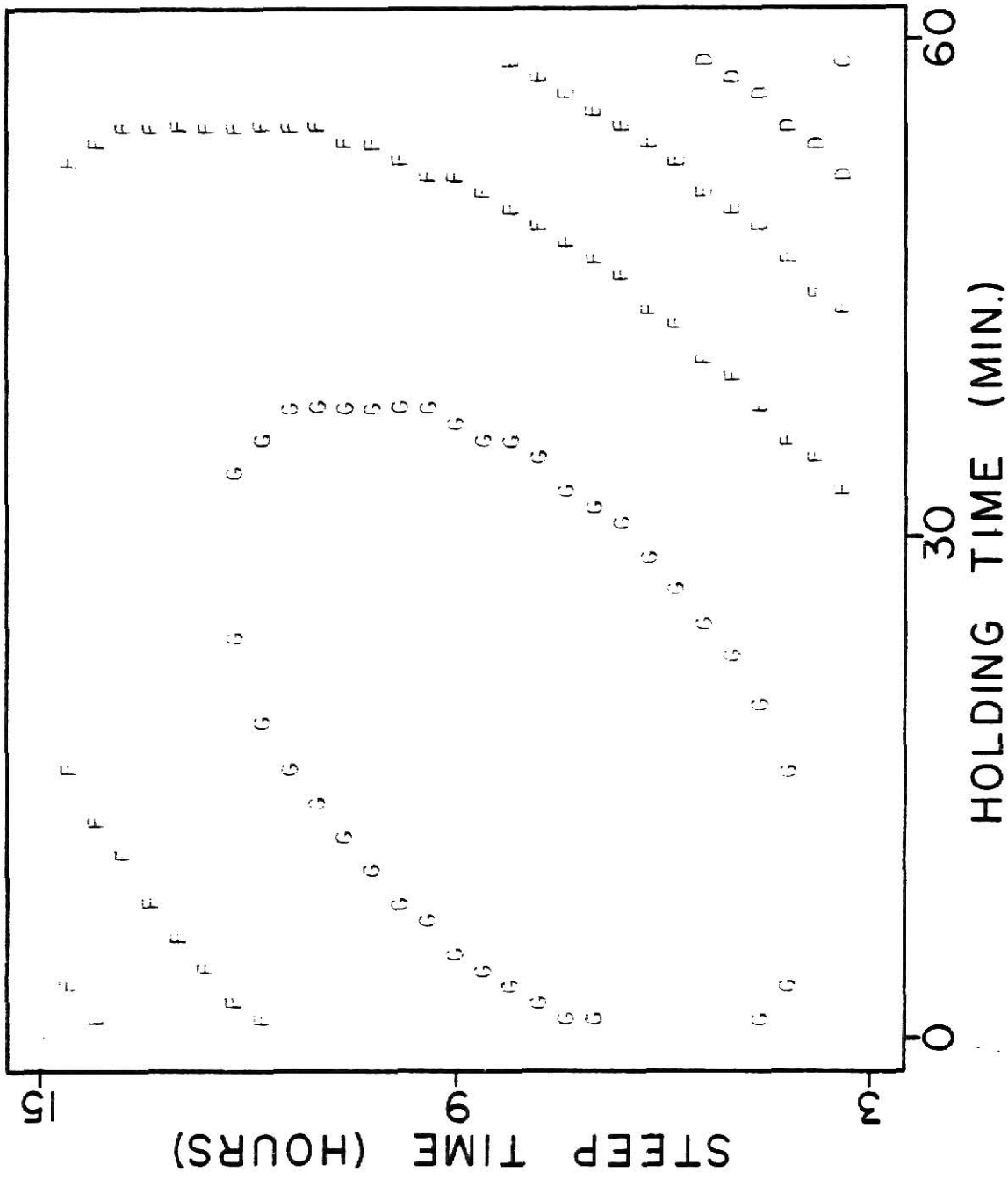
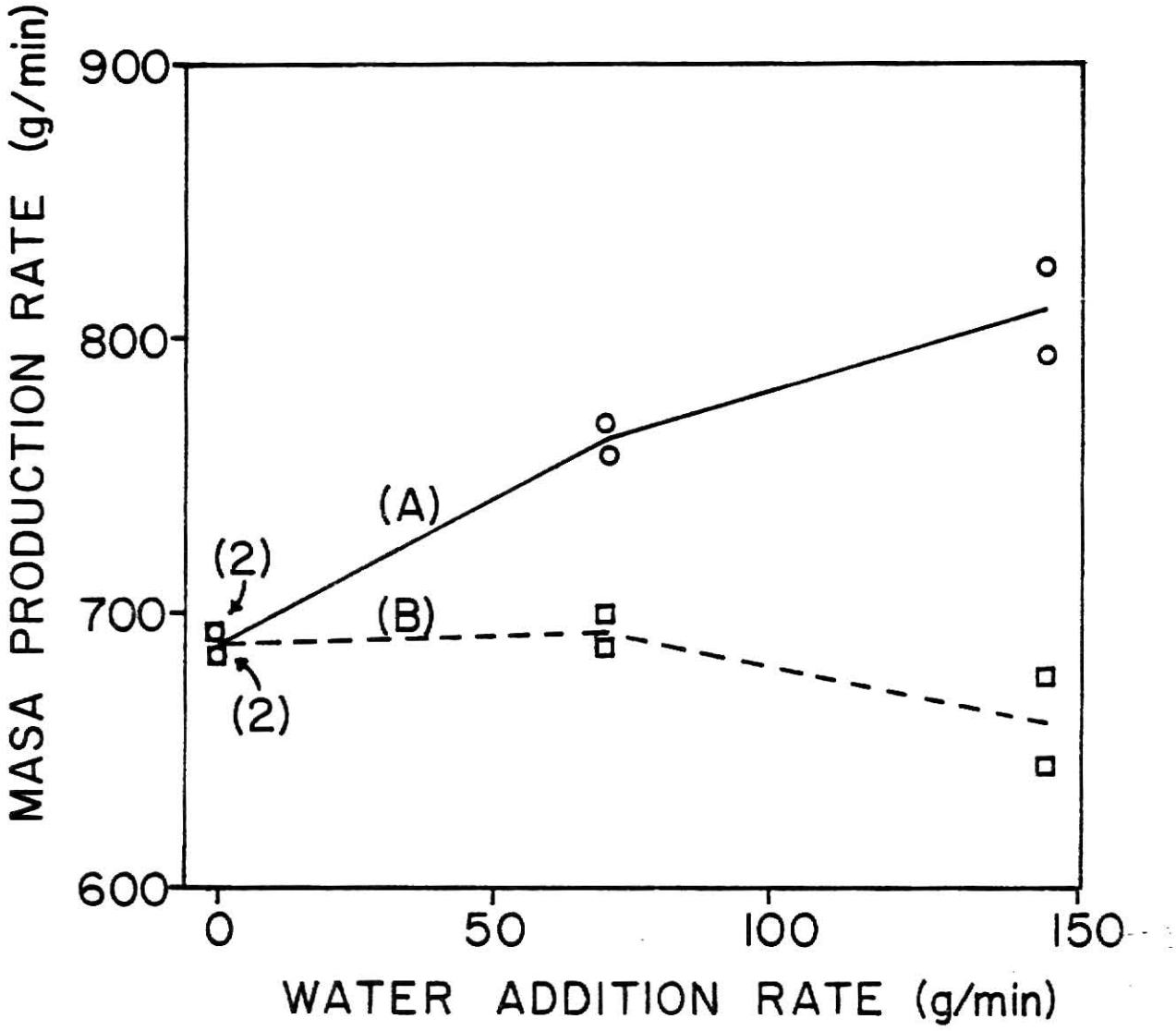

STEEP TIME (HOURS)
15
9
3
0
30
60
HOLDING TIME (MIN.)

Fig. 79 Water addition rate versus masa production rate

A - Grams of masa produced (O)
B - Grams of masa produced minus grams of water added (□)


MASA PRODUCTION RATE (g/min)
900
800
700
600
0
50
100
150
WATER ADDITION RATE (g/min)
(A)
(B)
(2)
(2)

into the grinder is effected. During water addition of 0 and 70 g/min, masa ground from nixtamal is the same. As water addition is increased to 150 g/min, less nixtamal appears to be ground. It should be noted that the grinding stones were spaced so as to provide a constant pressure between the stones for each test. As the water addition rate was increased, friction decreased, and the stones were adjusted slightly closer so as to provide constant pressure. The drop in Line B could be explained if you assume that the gap between the stones was decreased to the point that restriction of passage of the material overcame the effect of increasing throughput due to increasing moisture content.

Nixtamal and Masa Moisture Content. Nixtamal moisture content ideally should have been equal for all six tests. Figure 80, Line B shows that this was almost so. Line A shows resultant masa moisture contents of 49.7, 54.2 and 58.1% for averages of the three rates at 0, 70, and 150 g/min respectively.

Masa Color and pH. In the RSM-S2 testing pH and color appeared inversely related. However Figure 81 reveals almost no change in pH as the water rate was increased, whereas the Agtron relfectance increased significantly. The more yellow the sample, the more absorption of the blue wavelength there is, and the smaller the Agtron color number, which indicates reflectance. Therefore, as water input was increased and grinding pressure maintained at a constant, the sample color evolved from a yellow to a whiter color.

Masa Particle Size. Masa samples were wet sieved, and the overs of each sieve dried and calculated as percents of the original dry matter in the masa (Figure 82). As the water addition rate was increased, the percent of material remaining over the sieve was reduced indicating reduced particle size in the sample. The overs of the 104 micron screen dropped from 36% to

Fig. 80 Water addition rate versus nixtamal and masa moisture content.

A - Masa moisture content (%) (O)
B - Nixtamal moisture content (%) (□)

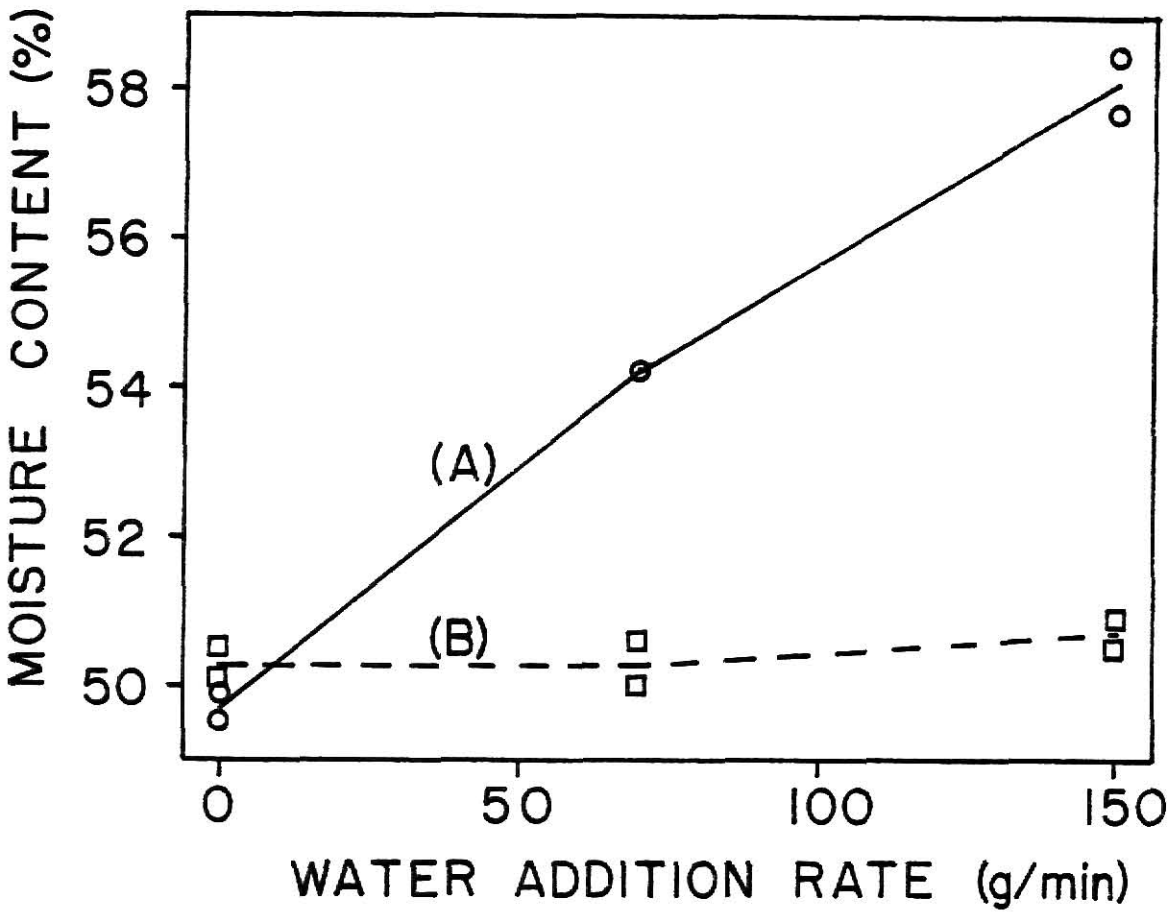

MOISTURE CONTENT (%)
58
56
54
52
50
(A)
(B)
0
50
100
150
WATER ADDITION RATE (g/min)

Fig. 81 Water addition rate versus masa color (Agtron) and masa pH.

A - Masa color - Agtron (O)
B - Masa pH (□)

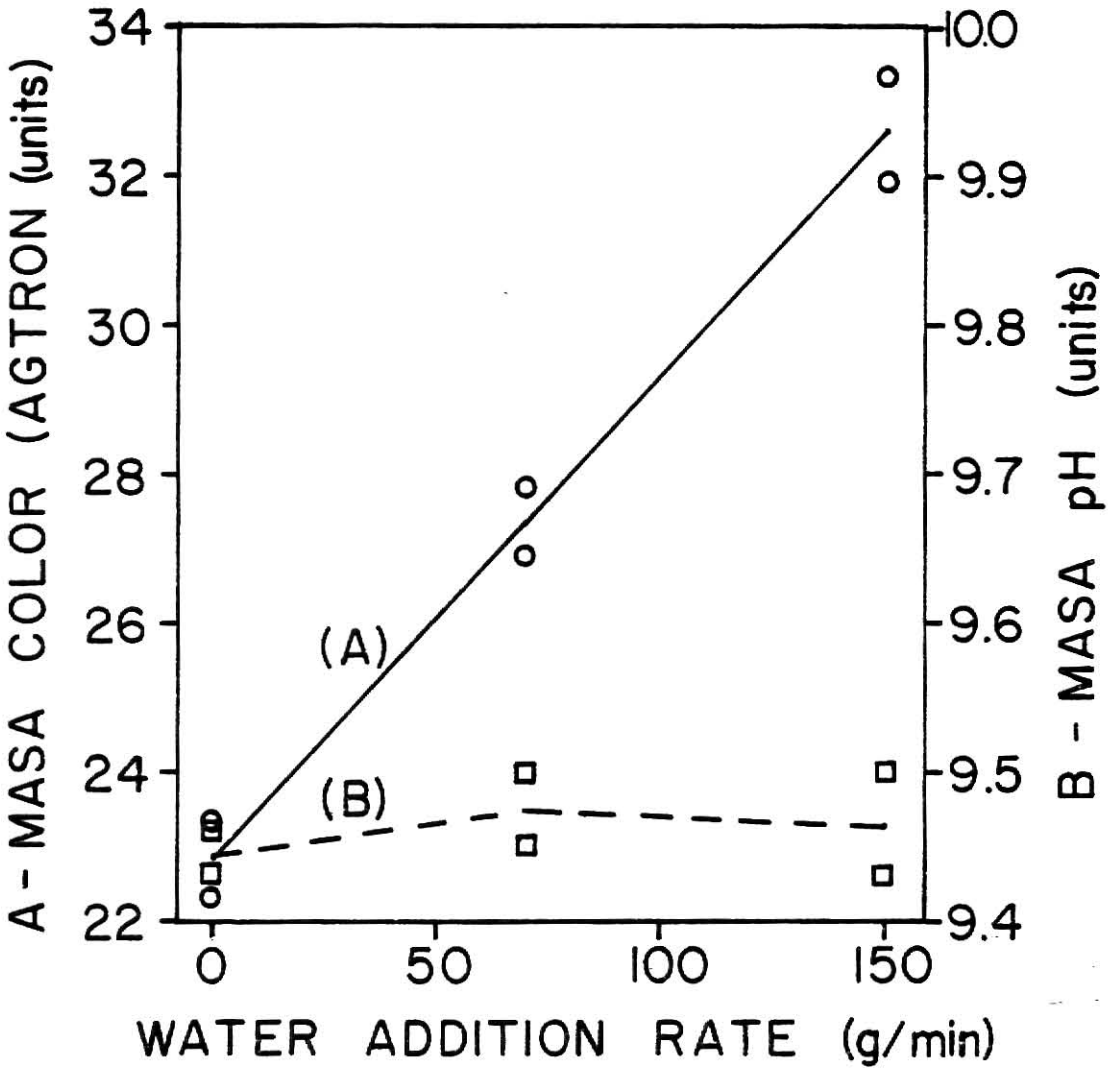
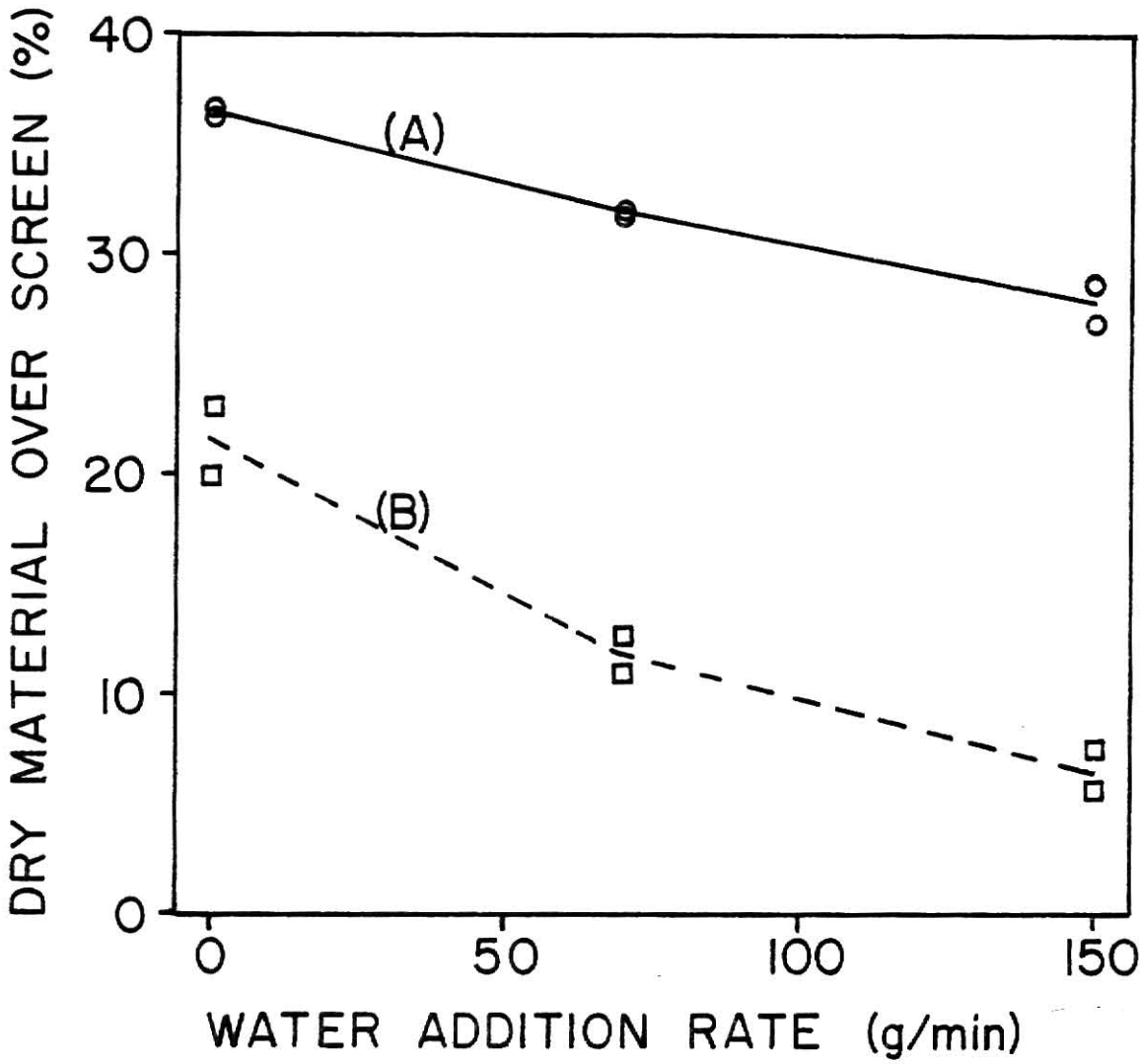

A - MASA COLOR (AGTRON (units)
B - MASA pH (units)
WATER ADDITION RATE (g/min)
(A)
(B)
34
32
30
28
26
24
22
10.0
9.9
9.8
9.7
9.6
9.5
9.4
0
50
100
150

Fig. 82 Water addition rate versus masa particle size (% overs of 104 micron and 417 micron screens)

A - % overs of 150 mesh (104 micron) screen (O)
B - % overs of 35 mesh (417 micron) screen (□)


DRY MATERIAL OVER SCREEN (%)
40
30
20
10
0
(A)
(B)
0
50
100
150
WATER ADDITION RATE (g/min)

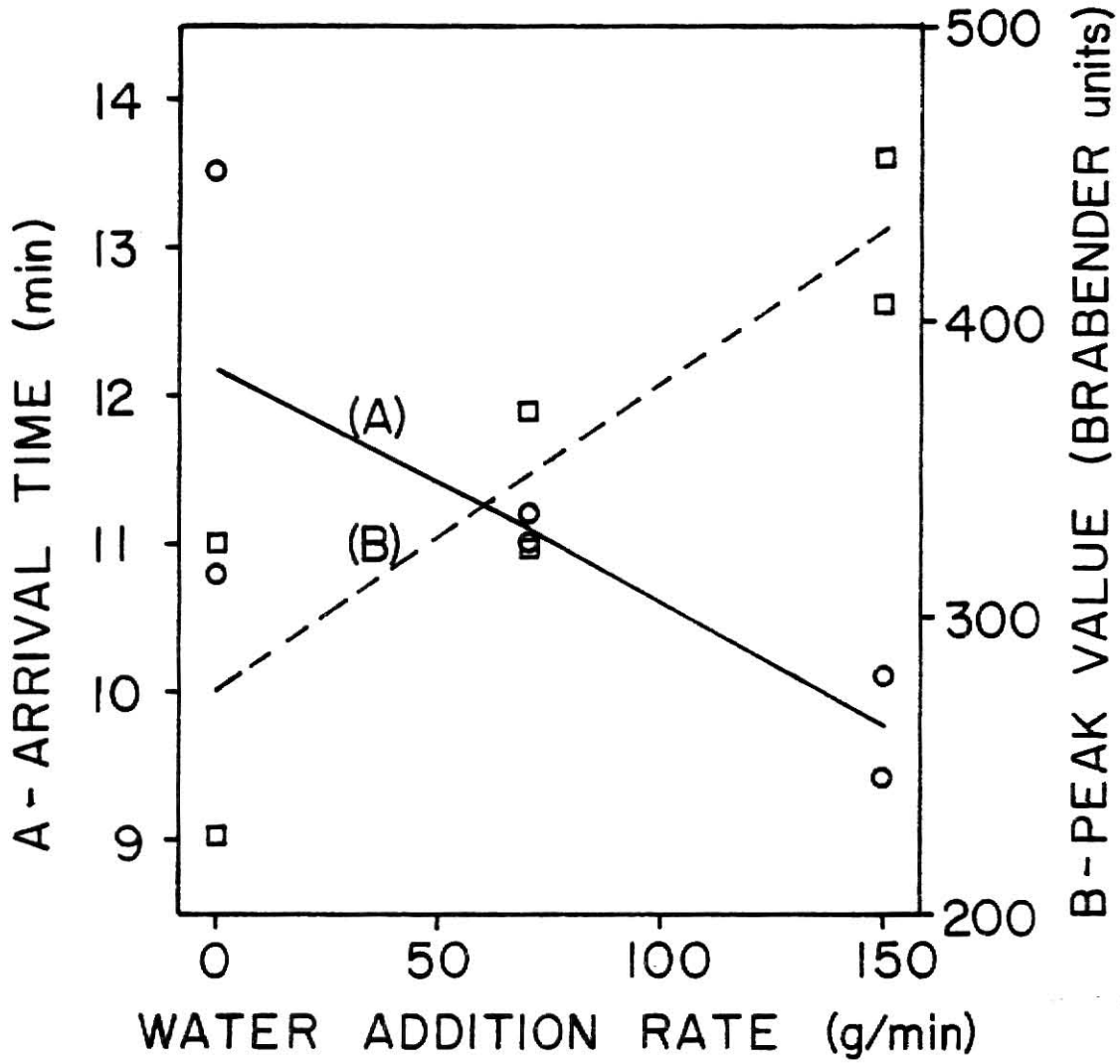
28% as water rates increased from 0 - 150 g/min. Overs of the 417 micron screen experienced a greater drop, from 23% - 8%. The particles remaining over the 417 micron screen were larger and fewer in number, making separation easier when compared to separations over the 104 micron screen. If more accurate methods of particle size determination had been used, possibly the overs of the 104 micron screen would have experienced more of a drop in going from 0 to 150 g/min water addition.

Considering the rise in Agtron color (Figure 81) with no coincident pH change, and a parallel decrease in particle size, it appears logical that the particle size change could have effected the color change as the water rate increased from 0 to 150 g/min. There was a coincident increase in masa moisture content from 50 - 58% as the water rate was increased. Most likely the Agtron color change is a function both of water content and particle size, but these tests do not elucidate the more important factor.

Amylograph Parameters. Although the arrival time of the curve varied greatly for the two tests run at 0 g/min water addition, the overall curve (Line B, Figure 83) showed a downward trend. It should be remembered that the masa samples were corrected for moisture content variations, so that the amylograph differences would reflect dry component changes and not differences in water content. Line B in Figure 83 shows an increase in amylograph peak value. One particular test, at 0 g/min water addition, gave a peak value of 225 BU, whereas the other five tests demonstrated values of 325 - 450. During monitoring of the steep temperature when the one sample was processed, it was noticed that the overall temperatures were significantly lower than the other five samples. It is believed that the temperature difference in steeping the corn might have contributed to the low peak value. A plot of the slope index shows an increase very similar to that of the peak value as the water rate is increased.

Fig. 83 Water addition rate versus amylograph arrival time and peak value.

A - Arrival time in minutes (O)
B - Peak value in Brabender Units (□)


A - ARRIVAL TIME (min)
B - PEAK VALUE (BRABENDER units)
WATER ADDITION RATE (g/min)
(A)
(B)
14
13
12
11
10
9
500
400
300
200
0
50
100
150

Tortilla Physical Parameters: Moisture Content, Weight, Axis Ratio and Thickness. Figure 84 is a plot of tortilla moisture content and tortilla weight. Due to higher masa moisture contents (Figure 80, Line A) as water rate is increased, it is obvious that tortilla moisture content would also increase (Figure 84, Line A). In contrast to moisture content, tortilla weight (Figure 84, Line B) decreased. Tortilla axis ratio (Figure 85, Line A) increased, and tortilla thickness (Figure 85, Line B) decreased. In RSM-S2 it was postulated that increased moisture content caused less spreading in the longitudinal axis of the tortilla, thereby resulting in higher axis ratio (rounder) tortillas. Figures 84 and 85 appear to support this. Whereas axis ratio increases, thickness and tortilla weight decrease. It might be theorized that the increased plasticity in the masa (due to increased moisture content), which causes less longitudinal spread (higher axis ratios), also conforms more to the pressure of sheeting, thereby yielding a slightly flatter tortilla. A loss in tortilla thickness (Figure 85, Line B), considering that length and width remained somewhat similar, would logically result in a weight loss (Figure 84, Line B). Also, the higher moisture masa (formed at the higher water addition rates) would be more susceptible to water loss during baking. This would contribute to weight loss at the higher water addition rates.

Shear Force Tests. Figure 86 illustrates results of the shear force tests. Variation in shear force of the fresh tortillas as water addition was varied is given by Line A, showing a decrease as water rates were increased. Line C is a plot of shear force corrected by tortilla thickness. A large difference occurred between 0 and 70 g/min, and less between 70 and 150 g/min. When tortillas were frozen, rethawed, and tested, the shear forces, illustrated by Line B, were very similar to fresh tortillas. These tortillas

Fig. 84 Water addition rate versus tortilla moisture content and weight.

A - Tortilla moisture content in % (O)
B - Tortilla weight in grams (□)

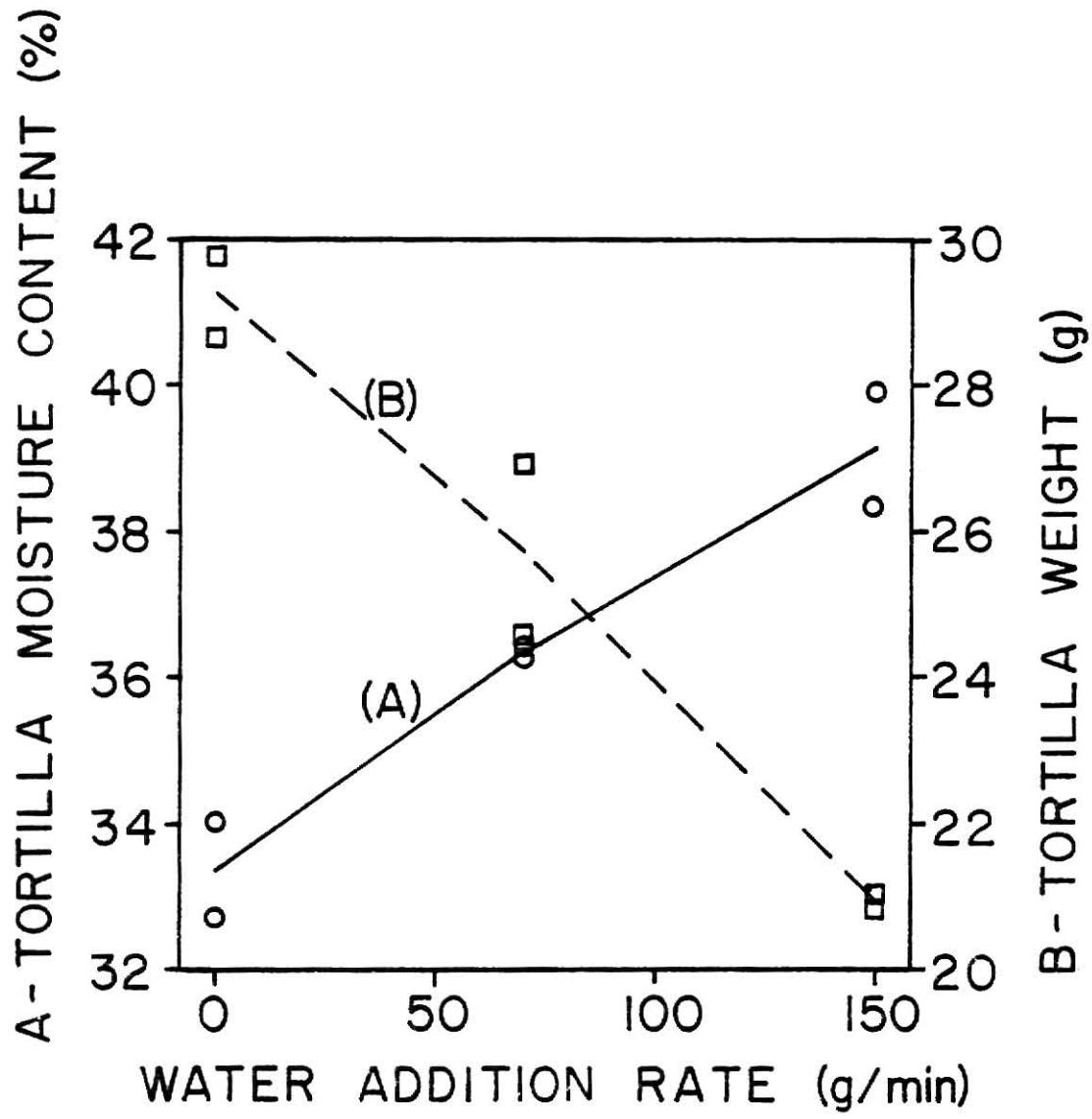

A-TORTILLA MOISTURE CONTENT (%)
B-TORTILLA WEIGHT (g)
WATER ADDITION RATE (g/min)
42
40
38
36
34
32
30
28
26
24
22
20
0
50
100
150
(A)
(B)

Fig. 85 Water addition rate versus tortilla axis ratio and thickness.

A - Tortilla axis ratio in units (O)
B - Tortilla thickness in mm. (□)

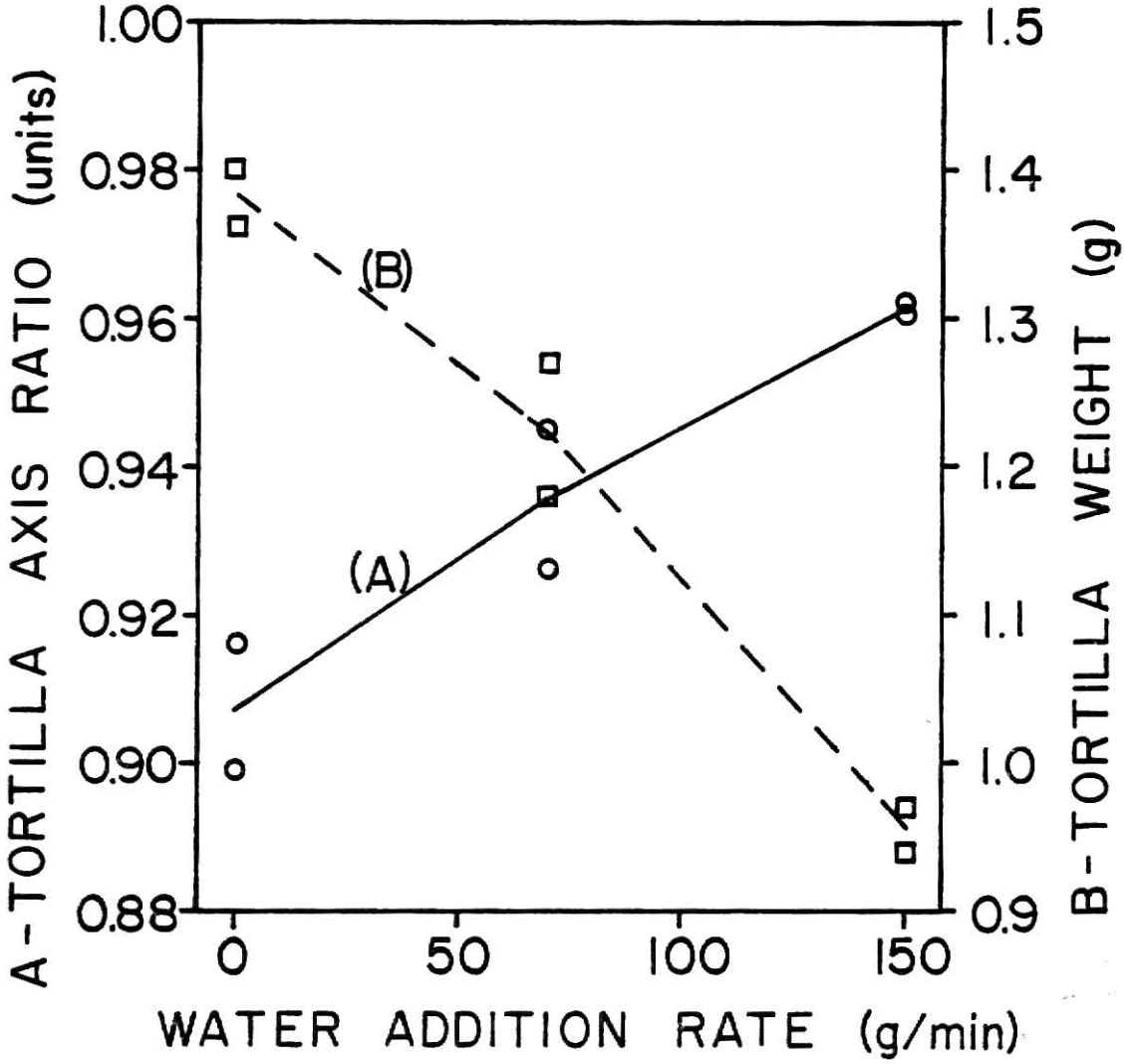
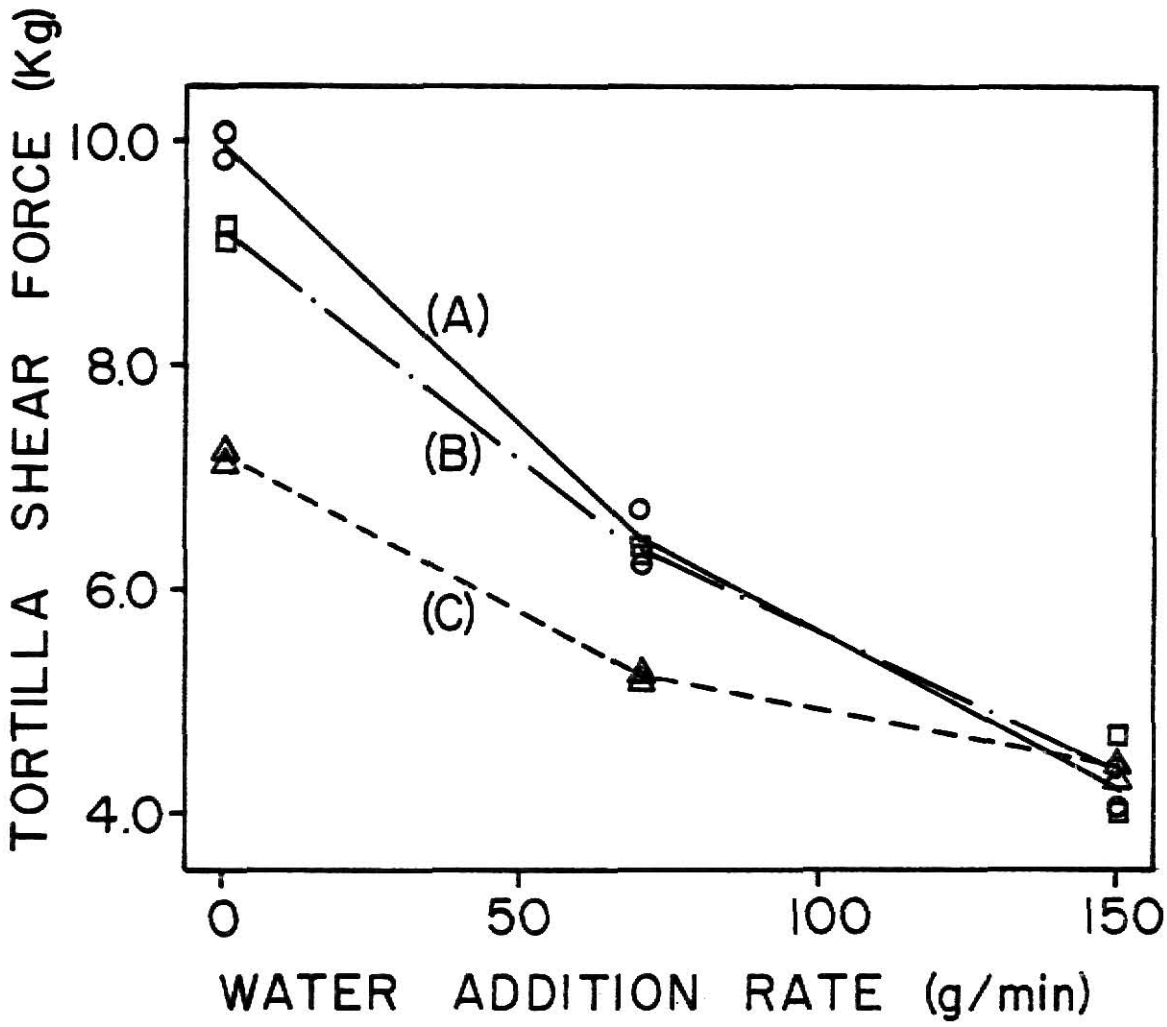

1.00
0.98
0.96
0.94
0.92
0.90
0.88
A-TORTILLA AXIS RATIO (units)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
B-TORTILLA WEIGHT (g)
(A)
(B)
0
50
100
150
WATER ADDITION RATE (g/min)

Fig. 86 Water addition rate versus tortilla shear force.

A - Shear force for fresh tortillas, in Kg (O)
B - Shear force for frozen, thawed tortillas, in Kg (□)
C - Shear force for fresh tortillas corrected for thickness, in Kg/mm. (△)


TORTILLA SHEAR FORCE (Kg)
10.0
8.0
6.0
4.0
(A)
(B)
(C)
0
50
100
150
WATER ADDITION RATE (g/min)

were held in a frozen state for approximately one week prior to testing. It is easily noticed that at higher water addition rates (which produced tortillas with smaller particle size and higher moisture contents) the shear values were in the same range of 4 - 5 Kg force for all tests.

Tortilla Organoleptic Parameters. Three of the organoleptic tests (aroma, mouthfeel, and taste) exhibited reasonably good duplication (normally less than 0.5 unit difference between duplicates) (Figures 87 and 88). However flexibility showed wide variation (Figure 87 Line B) between duplicates. Flexibility appeared to decrease in tortillas produced with the highest rate of water addition. In contrast, the other three responses were rated higher when increased water rates were used at the grinder. Desirable aroma (Line A) increased slightly as water rates were increased. A second testing would be desirable to support this conclusion. Both mouthfeel and taste increase significantly in going from 0 - 70 g/min of water addition. The changes in the two responses between 70 and 150 g/min are not sufficient to assume that one value has an advantage over the second.

Fig. 87 Water addition rate versus tortilla aroma and flexibility.

A - Tortilla aroma; relative ranking when compared to control, in units (O)
B - Tortilla flexibility; relative ranking when compared to control, in units (□)

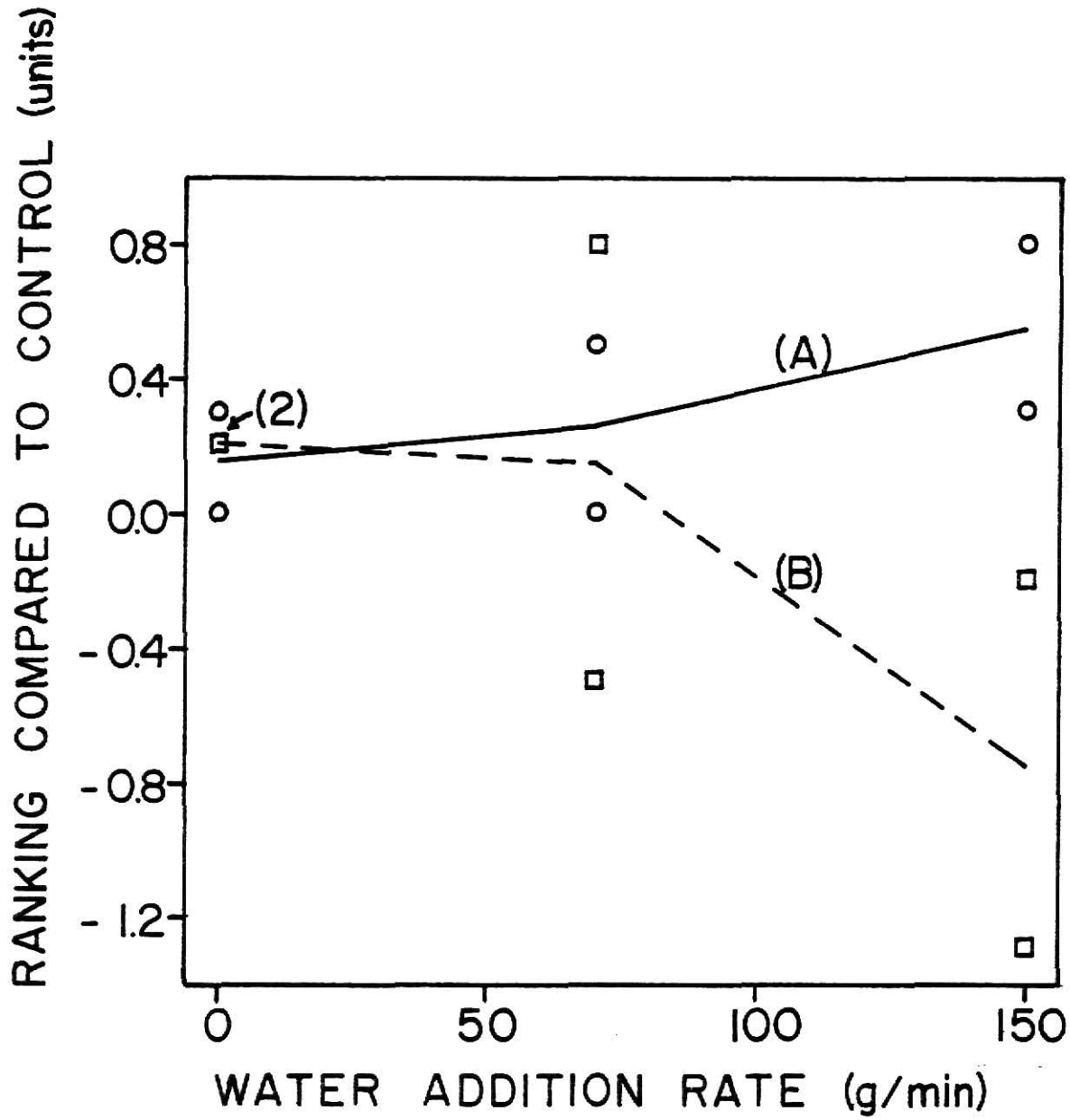
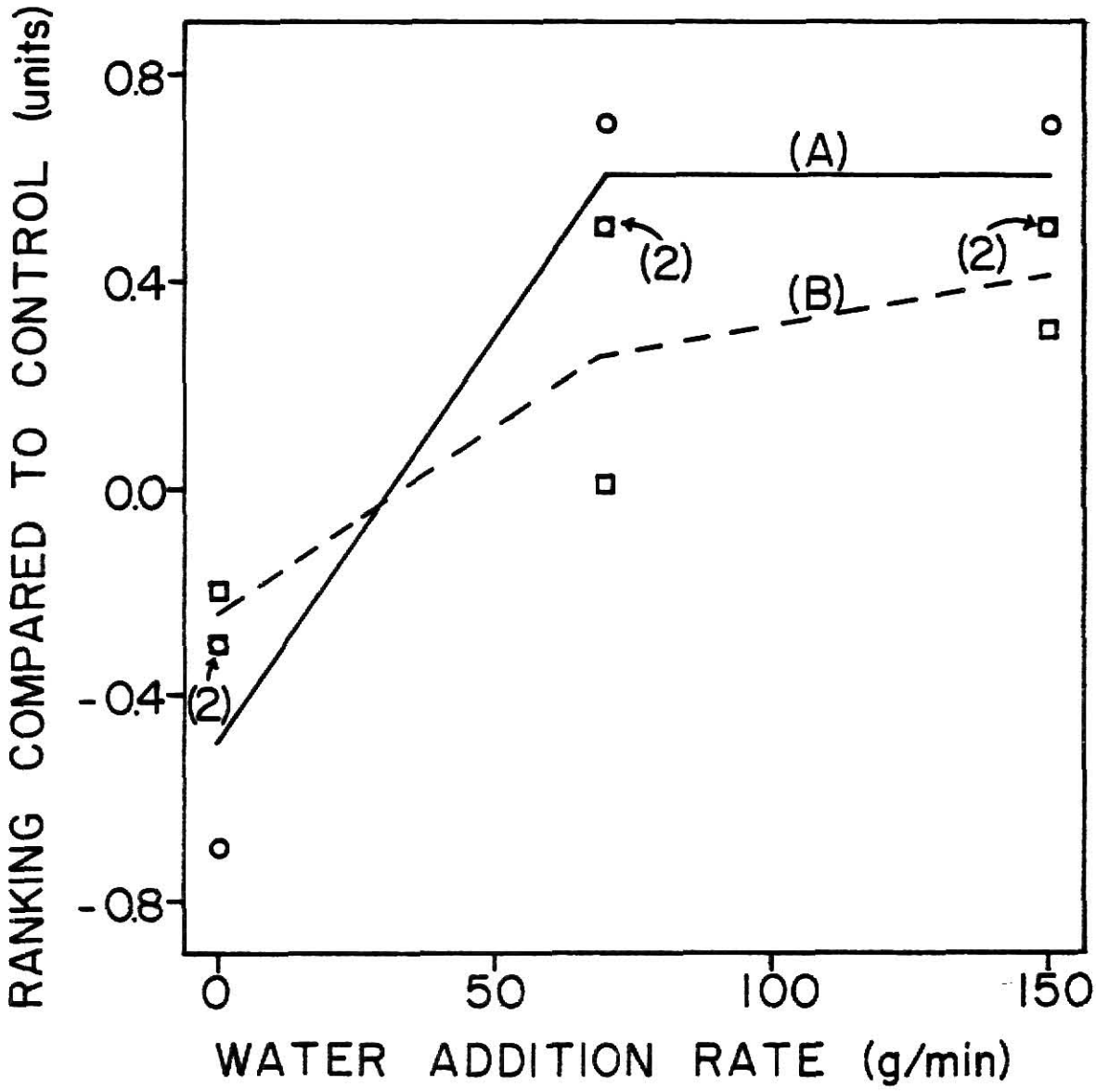

RANKING COMPARED TO CONTROL (units)
0.8
0.4
0.0
-0.4
-0.8
-1.2
(A)
(B)
(2)
0
50
100
150
WATER ADDITION RATE (g/min)

Fig. 88 Water addition rate versus tortilla mouthfeel and taste.

A - Tortilla mouthfeel; relative ranking when compared to control, in units (O)
B - Tortilla taste; relative ranking when compared to control, in units (□)


RANKING COMPARED TO CONTROL (units)
0.8
0.4
0.0
-0.4
-0.8
(A)
(B)
(2)
(2)
(2)
0
50
100
150
WATER ADDITION RATE (g/min)

CONCLUSIONS

Series 1 - RSM. Temperature appeared to be the dominant variable in most of the thirteen responses evaluated in the first series, except for pH responses. pH of the steep liquor, nixtamal, and both masas was almost solely dependent upon lime concentration. A lime concentration of 0.7 or 0.8% resulted in peaks for nixtamal and masa moisture content data, and mixograph data; concentrations above that level resulted in either little change or a decrease in the parameter measured. Lime concentration was also an important variable in masa production rate, specific volume of nixtamal, and nixtamal and masa moisture content. Holding time was a more important variable in masa 1 production rate and the mixograph moisture peak, but of minimal importance concerning the remaining responses.

The moisture content and pH tests yielded reliable, understandable data. The specific volume test performed on nixtamal appears promising, but could be refined. Although one of the mixograph parameters (moisture content at the mixograph peak) was quite significant, its implications are not understood. The Research Water Absorption Meter was found unsuitable for masa evaluation. Several tests could not be evaluated through RSM due to insufficient lime content in some of the samples which yielded a masa too coarse to be made into tortillas.

Series 2 - RSM. Of the three variables evaluated (peak temperature, hold time, and steep time), temperature was again the most highly correlated with most of the responses. Most correlations were positive. However, Agtron color, Amylograph peak, Amylograph slope, tortilla weight, tortilla thickness, tortilla shear force and tortilla flexibility were negatively correlated with temperature. Steep time was highly and negatively correlated with particle

size (i.e., size became smaller at longer steep times), but positively correlated with tortilla mouthfeel, masa production rate, and masa pH. Hold time normally possessed correlations much below those of temperature, but above those of steep time. The importance of hold time was especially noticeable in nixtamal and masa moisture content, the amylograph responses, tortilla shear force, thickness, and moisture content.

In general, as the three variables increased from minimum to maximum values, tortilla weight, thickness, shear force, and flexibility decreased. Tortilla moisture content, axis ratio, aroma, taste, and mouthfeel increased with increasing variables. Desirable tortilla aroma occurs through a wide range dependent upon all three variables. At short steep times, high peak temperatures and short hold times produce the best aroma. At long steep times, a lower temperature and longer hold is required to reach the same degree of desirability. Temperature resulted in the greatest change in aroma ranking. Mouthfeel ranked highest at an intermediate (30 - 40 minute) hold time. Increasing temperature or steep time favorably affected mouthfeel. Taste, however, was equally correlated with all three variables. The highest taste ranking occurred at the lowest temperature and maximum hold and steep times. As temperature was increased, preference ranking decreased in value.

Series 3. Increasing water addition at the grinding stage resulted in first increasing, and later decreasing throughput rates of dry material. Masa moisture content increased significantly, pH experienced no change, color changed to a more whitish tint, and particle size decreased. The amylograph arrival time decreased, whereas the peak and slope index increased. Tortilla moisture content and axis ratio increased, while thickness and weight were reduced. Shear force decreased with water addition. Fresh and frozen-thawed tortillas had the same trend. Considering the four organoleptic parameters,

flexibility ranking dropped at the highest water addition rate. Aroma ranking appreciated slightly as the rate was increased from 0 - 150 g/min. Mouthfeel and taste rankings increased noticeably from 0 - 70 g/min, but experienced little change from 70 - 150 g/min.

Total Series Summary. The first testing series indicated a lime concentration of 0.7 - 0.8% as sufficient in effecting desirable tortilla production; peak temperature and hold time were not optimized in the first series. A lime control of 1.0% was then selected for the second series. Selection of an "optimum" tortilla in the second series depends upon which parameter responses are considered most important by the consumer; i.e., taste, mouthfeel, aroma, softness, flexibility, axis ratio, or color, etc. The highest taste ranking occurred at 78°C, 60 minutes hold time, and 15 hours steep time. Highest mouthfeel ranking occurred at 98°C, 35 minute hold time, and 15 hours steep time. Maximum aroma ranking was variable; 92°C, 30 minute hold time, and 9 hours steep time was one set of conditions yielding optimum rating. Axis ratio increased with increasing variable levels. Masa color (yellowness) was a maximum at 98°C, 30 minute steep time, and 9 hours steep time. Considering all responses evaluated, this author selected 90°C peak temperature, 40 minutes hold time, and 11 hours steep time as a suitable compromise. Series three was performed unter these conditions. A water addition rate ot 70 g/min. appeared to result in a tortilla with optimum organoleptic quality. Therefore, under the conditions imposed for these tests, optimum tortilla production occurs in the proximity of the following conditions: 1.0% lime concentration, 90°C peak temperature, 40 minutes holding time, 11 hours steep time, and with a water addition level of 70 g/min at the grinder.

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TORTILLA PRODUCTION: STUDY OF VARIABLES EFFECTING THE PROCESSING OF RAW CORN INTO TORTILLAS

by

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Initial studies of tortilla production led to the question of which parameters are important in quality of corn (Zea mays) for tortillas, and how these quality parameters are affected by processing variables. Using a standardized and well-defined processing flow, the effect of specific processing variables upon certain tortilla quality parameters was studied. Response surface methodology (RSM) was used to design and analyze the first two of the three testing series performed.

Peak heating-cooking temperature (80 - 98°C) of the raw corn, holding time at peak temperature (0 - 60 minute), and calcium hydroxide concentration (0.1 - 1.0%, by dry corn weight) in the steep liquor were varied in the first series. Temperature was most highly correlated with most of the 13 quality responses evaluated by RSM. Calcium hdroxide concentration was very highly correlated with the pH response. Holding time was least highly correlated with most responses. A calcium hydroxide concentration of 1.0% was selected as near optimum for tortilla production. Preferred peak temperatures and holding times were not established.

For the second series, peak heating-cooking temperature (78 - 98°C) of the raw corn, holding time (0 - 60 minute), and steep time 3 - 15 hours) were the variables evaluated. Again temperature was most highly correlated with most response parameters (21 of 24 responses evaluated by RSM). Tortilla aroma, flexibility, mouthfeel, and taste were selected as main tortilla quality parameters, and evaluated by a trained 7-member panel. From these test results, 90°C peak temperature, 40 minutes holding time, and 11 hours steep time were selected by the author as processing variable levels resulting in the best compromise in quality among the varied responses.

A third series was performed to observe the effect of variations in water addition at the grinding step on tortilla quality parameters. Three different

water rates (0, 70, and 150 g/min) were added to the test samples and duplicates run. The 70 g/min rate appeared to result in the best overall tortilla quality.